A Cross-Country Analysis of

Energy Efficient Development

By

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ABSTRACT

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Maximizing energy efficiency, producing as much as possible with as little energy as possible, is something every country should be working toward. This study measures the efficiency of specific countries by examining the interrelationships that exist among each country's energy consumption and such measures of development as health, education, income, access to essentials and CO_2 emissions. It then analyses why certain countries are more efficient than others and how these inefficient countries can improve.

Data Envelopment Analysis (DEA) is used to generate a cross country comparison of energy efficiency scores over multiple dimensions of development. Pairs of inefficient countries and their efficient role models are examined in detail to understand which factors contribute to their relative efficiencies. The paper hypothesizes that countries which have made significant commitments to renewable energy sources will have higher levels of sustainable development than those that have not. Furthermore those countries which have invested in health, education, jobs and access to essential services such as water and sanitation will have higher efficiency scores than those that have not. This study's ultimate goal is to provide policy recommendations for improving energy efficiency.

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Chapter 1: Introduction

1.1 Alternatives to GDP Growth

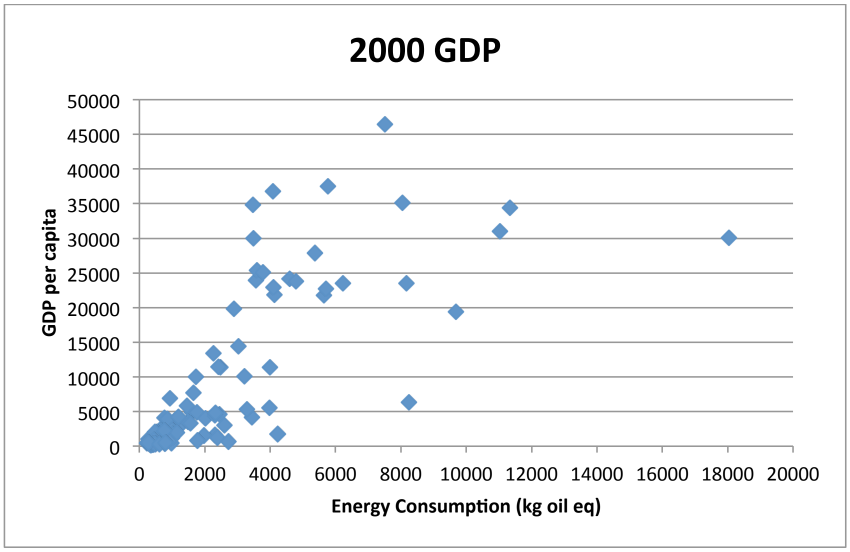
Research on energy efficiency has so far focused on the relationship between energy consumption and the traditional measure of development, economic output. However, there is much more to a country's development than simple gross domestic product (GDP) growth. Other measures such as social welfare and sustainable development are also extremely important and must be considered as well. Since GDP is in many ways a poor measure of a country's social well-being, countries should strive to do more than just increase their GDP; they should work to provide better living standards through improving health, education, income and access to essentials like drinking water and sanitation in addition to reducing pollution for their citizens. This kind of development outside of traditional economic growth is important because increasing GDP is somewhat meaningless for a country if the living standards of its citizens do not improve or if the country destroys its natural resources in the process.

It is worthwhile for a country to maximize its energy efficiency simply because it will lower costs over time and ensure that its citizens receive the full benefits of its energy consumption. There is some debate surrounding how countries can become more efficient though, with a large amount of the discussion specifically concerning the effects of different energy policies. Therefore there is an opportunity for research on the role energy consumption plays in determining living standards and environmental quality in addition to economic growth, and how countries can optimize their energy policies toward these goals. This paper addresses that need by answering the research question: how efficient are specific countries around the world in their ability to use energy to produce health, education, income and access to essentials while minimizing pollution, and what can specific countries do to improve? This study begins by introducing the key concepts involved in this study's analysis, then surveys the relevant economic literature to provide context for its own research, next it delves into the methodologies and data used, followed by the results of the analysis itself, and ends with the study's conclusions.

1.2 Economics of Energy Efficiency

Countries must decide how to use their scarce resources, and these decisions are precisely what the field of economics seeks to enlighten. Energy policy is a particularly interesting segment of economics because it deals with the proper allocation of a country's energy resources. The first part of this paper's analysis compares how much energy different countries consume in order to generate particular levels of health, education, income, access to essentials and pollution. While this paper chooses to examine other measures of development than GDP, the relationship between energy consumption and GDP is still worth investigating. Most economists agree that as an economy expands it tends to require more energy to support its needs, though the growth in required energy use may diminish as GDP per capita increases (Hannesson, 2009). Figure 1 plots GDP per capita in relation to energy consumption during 2000 for the 104 countries examined in this study, and there does seem to be a significant positive relationship.

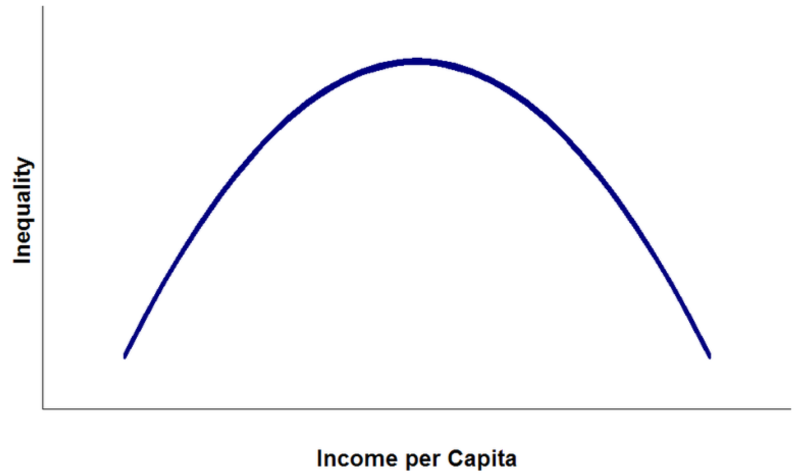
Figure 1. GDP vs. Energy in 2000



The evidence is less clear when it comes to the existence of convergence of more developed economies toward higher energy efficiencies, meaning that as countries become more developed they require less energy to increase their GDP further. This debate over whether or not development exhibits increasing returns to scale is quite contested, largely because there is a lot of country to country variation in energy efficiency because each country has its own unique circumstances that contribute to its level of economic output and energy consumption. This makes the conclusions that these studies come to rely heavily on which countries they include in their investigations, which has made it difficult for the research community to come to a consensus regarding the relationship between the growth rates for GDP and energy consumption.

There has been a somewhat similar debate around the so-called environmental Kuznets curve (EKC), based on Simon Kuznets' findings, illustrated in Figure 2, that as a country develops at first it experiences rising inequality, but at some point in its development its average income reaches a certain level which creates a turning point for its inequality, and after leveling off around that point it begins to decrease. Although Kuznets' original hypothesis related to inequality some economists have argued that an EKC exists as well, which operates in the same way except pollution is the output instead of inequality. The idea is that smaller and less developed economies do not pollute very much, but as they grow they use more fuel and their pollution increases. However just like in the original Kuznets curve the EKC has a turning point where pollution levels off and decreases for economies of a certain size, implying that they become more efficient. While the jury still seems to be out on the relationship between the growth rates of energy use and GDP, recent findings have generally discredited the EKC hypothesis, largely because low income countries are actually more efficient than one might expect (Stern, 2004). Even though an EKC has not been found, the assumption that pollution is a necessary byproduct of economic development has largely been refuted (Levinson).

Figure 2. Kuznets Curve



The relationship between energy consumption and development is understandably complex even when development is simply understood as a country's level of GDP, but if development also includes living standards and environmental quality then the relationship between energy consumption and development becomes even more complex. Some countries are much better at energy efficient development than others, particularly at expanding living standards while keeping energy consumption and pollution relatively low. Some countries do choose to pursue growth with little care to the amount of energy required, however many seek to increase their output while simultaneously reducing their energy consumption. Therefore energy is not always assumed to be a traditional input in which more output necessarily requires more input.

1.3 Measuring Energy Efficiency

When economists discuss energy efficiency they usually mean one of two things, either productive efficiency or allocative efficiency. Productive efficiency refers to the ability to make the most of energy inputs while allocative efficiency is the extent to which market prices reflect energy's true costs. This study chooses to focus on productive efficiency. Economists often compare differences in productive energy efficiencies between countries by calculating how much GDP or gross national product (GNP) each country is able to produce with a given amount of energy units. Researchers also compare countries based on an opposite measure called energy intensity, calculated by dividing a country's energy consumption by its GDP or GNP, which instead shows how much energy each country requires to produce one standard unit of GDP or GNP. Economists sometimes also look at energy elasticity, defined as the percentage change in energy consumption necessary to cause a 1% change in the country's GDP. There is in fact some disagreement among professional economists and researchers regarding the best way to measure energy efficiency. Rather than using one of these somewhat standard measures of energy efficiency this paper identifies health, education, income, access to essentials and pollution as alternative metrics of development to GDP, and uses them as outputs in its analysis of energy efficient development.

1.4 Current Energy Situation

Energy consumption is at an interesting place right now. Global demand is shifting as many developed countries try to replace old technologies with newer more efficient ones, while developing countries try to keep up with their economies' growing energy needs.

Developing countries such as China, India, and Brazil have been ramping up their consumption of energy to fuel their recent rapid economic expansion. While the economies of many developed countries have slumped as a result of the 2007 financial crisis, these developing countries have emerged fairly unscathed, continuing on their path of high growth. Figure 3 illustrates these trends by displaying data on energy consumption for various years from 1985 to 2009 for three developing countries contrasted with three developed countries. To supply the energy necessary for their rapid growth these developing countries have turned largely to cheap, though fairly inefficient and environmentally unfriendly, sources of power generation like coal power plants. Their expansion has also had mixed results on the living standards of their citizens since much of the growth has been due to low wage factory labor, but more recently it has started to produce a more affluent middle class. Understanding the underlying dynamics of global energy demand is key to grasping how energy efficiency works in today's world.

Figure 3. Global Trends in Commercial Energy Consumption (kg oil equivalent per capita)

	1985	1990	1995	2000	2007	2008	2009
Brazil	949	937	996	1085	1240	1298	1243
China	658	760	869	867	1490	1599	1695
India	333	373	412	450	530	543	585
Switzerland	3413	3623	3417	3481	3412	3501	3481
United Kingdom	3551	3597	3728	3786	3448	3390	3184
United States of America	7457	7672	7763	8057	7749	7481	7045

1.5 Overview of Methods

This paper utilizes a method of nonparametric frontier analysis designed to measure productive efficiency known as data envelopment analysis (DEA) to conduct the first part of its evaluation. The DEA generates technical efficiency (TE) scores for each of the countries in the study, as well as information on which countries each specific country was compared to in order to calculate their TE score. A Malmquist Index analysis is also run on panel data for a number of countries in an effort to see how they have performed over time. While the first part of the paper's analysis does inform on which countries are inefficient and by how much, unfortunately it does not do a very good job of revealing how countries can hope to increase their level of energy efficiency. This is where the paper's second series of analyses comes in; by comparing inefficient countries to their efficient peers it is possible to gain insights into how the inefficient countries can improve.

Chapter 2: Previous Research

There have been numerous papers published on the relationship between energy and development. Much of the previous research on energy efficiency has examined energy consumption in relation to GDP. However GDP is not a perfect measure of development and while some studies have incorporated measures of environmental quality there is a significant lack of research on energy efficiency and alternative measures of development. That is precisely where this study comes in; it goes beyond GDP and measures standards of living and sustainable development by incorporating health, education, income, access to essentials and pollution as outputs. The following section surveys relevant literature to provide some background and perspective for this study.

2.1 DEA Studies on Energy Efficiency

Studies like Bampatsou and Hadjiconstantinou (2009) and Hu and Kao (2007) are particularly relevant to this paper because they both used DEA approaches to examine the issue of energy efficiency. Both Bampatsou and Hadjiconstantinou (2009) and Hu and Kao (2007) chose to use CRS models of DEA for their analyses, however they differed in their selection and treatment of variables. Bampatsou and Hadjiconstantinou (2009) examined the 31 countries of Europe during 2004, using both a “dirty” energy consumption index (DEI) and a “clean” energy consumption index (CEI) as inputs, and GDP and CO2 emissions for outputs. Hu and Kao (2007) on the other hand estimated and analyzed the energy savings targets(EST) of 17 Asia-Pacific Economic Cooperation (APEC) countries from 1991-2000 using energy, labor, and capital as inputs, the data for which came from Penn Worlds Tables, and real GDP transformed by purchasing power parties as the output, data for which came from IEA Statistics. In Bampatsou and Hadjiconstantinou (2009) the DEI is the sum of the consumption of oil, coal, and natural gas, while the CEI is the sum of the consumption of nuclear, geothermal, and hydro-electric energy, and a nonlinear monotone decreasing transformation 1/b was used to treat the undesirable factor of CO2 emissions in the model so that increases in the variable were "good".

A nonlinear monotone decreasing transformation is not the only method available to deal with undesirable outputs though, Zhang et al. (2008) and Ramanathan (2002) demonstrated the common practice in research involving environmental or ecological efficiency of treating undesirable outputs instead as inputs to be minimized, and likewise desirable inputs instead as outputs to be maximized. Bampatsou and Hadjiconstantinou(2009) did a good job of noting the various options available for dealing with an undesirable output, but Zhou et al.(2008) went a step further and proposed two specific DEA models for analyzing environmental performance efficiency to address this problem. The paper described how various forms of an undesirable output orientation model can be used to create a pure environmental performance index (EPI) depending on whether the situation calls for constant returns to scale (CRS), variable returns to scale (VRS), or non-increasing returns to scale (NIRS) DEA approach. Zhou et al. (2008) also described models that can be used to run DEA on a mixed EPI, one that incorporates both desirable and undesirable outputs, under different VRS conditions as well. This study sheds more light on the issue of how to study environmental performance. It provides some useful conceptual information on how to evaluate returns to scale and undesirable output variables in environmental performance measurement. It also notes that although most studies assume CRS, real situations are far more likely to exhibit VRS because at some point an input is likely to display a change in returns to scale, and it emphasizes the importance of choosing between an undesirable and a mixed EPI.

Despite the fact that Zhang et al. (2008) and Ramanathan (2002) used similar techniques to deal with their variables, their analyses of energy efficiency varied based on their selection of data and variables. Zhang et al. (2008) used the standard model of DEA first developed by Charnes et al. (1978) with CRS and data from the various versions of China Statistical Yearbook in 2005 to compare the eco–efficiency of 30 of China's provinces. Ramanathan (2002) also assumed CRS and used data from ENERDATA to compare 64 countries based on their energy consumption, CO_2 emissions, and economic output during the years 1990 and 1996. Zhang et al. (2008) chose to run three different analyses, all of which use the value of products or services added as the output being maximized. However the first analysis used resource impacts added as its input, which included water, raw mining, and energy inputs, the second used environmental impacts added as its input, which included various undesirable pollution emissions, and the third used both resource and environmental impacts added as inputs. Ramanathan (2002) considered CO_2 emissions and fossil fuel consumption as its inputs to be minimized, while non-fossil fuel energy consumption and GDP were considered as its outputs to be maximized.

Aldea et al. (2012) is another related study that used DEA to obtain efficiency estimates of renewable energy development by country in the EU, with an interest in how energy policy has affected the countries' efficiencies. While it has much in common with the literature discussed so far, it differs significantly in that it chose to run a regression analysis on the TE scores generated by its two DEA models. Aldea et al. (2012) used the bootstrap algorithm developed by Simar and Wilson (1998, 2007, 2008) to eliminate bias from its efficiency estimations in an effort to validate its regression analysis, along with data collected by the European Commission and obtained from EurObserv'ER and the EUROSTAT database, to investigate the energy efficiencies of 27 countries for the year 2009. The study used the effectiveness indicator for energy from RES, estimated with data from EurObserv'ER as the ratio of the share of renewable energy in gross final energy consumption in 2009 to the target level of this indicator for 2020, as the output variable in both of its DEA models. The first model considers energy intensity of the economy, energy dependency, and the greenhouse gas intensity of energy consumption as its three inputs, while the second model utilized an aggregated input variable based on energy intensity of the economy and the greenhouse gas intensity of energy consumption.

Bampatsou and Hadjiconstantinou (2009) found that Switzerland was the most efficient country, followed by Sweden, Norway, France, Denmark, while Romania, Bosnia & Herzegovina, Bulgaria, and Serbia & Montenegro are the fourth, third, second and least efficient countries in the study. Hu and Kao (2007) most notably found that China had the largest EST, that Hong-Kong, the Philippines and the US were the most energy efficient, and that energy efficiency was generally increasing over the time period for all APEC countries except Canada and New Zealand. Hu and Kao (2007) also found that Chile, Mexico, and Taiwan stood out in the last 5 years as they significantly increased their energy efficiency, that the relationship between per capita EST and per capita GDP resembled an inverted U, and that ESTs increased the value added as a percent of GDP in the energy sector but decreased it in the service sector. Ramanathan (2002) found the most efficient countries to be: Luxembourg, Norway, Sweden, Switzerland and Tanzania, while central European countries like Poland, Romania, Chez Republic and South Africa were the worst. The final analysis in Aldea et al. (2012) found Estonia to be the most efficient country followed by Austria, Romania, Sweden, Latvia, Hungary, and the Netherlands, while Luxembourg, Malta, and the UK were the third, second and least efficient countries in the analysis. One curious thing about this paper was that it claims to reveal the impacts of each country's energy policy on its development of renewable energy markets, supposedly through its regression analysis, however the study's authors did not offer any specific examinations of the energy policies of the countries in the study.

Although Hu and Kao (2007) did not use a Malmquist Index to analyze data over time, it did look at panel data to compare energy efficiencies over time. Although it does not incorporate time series data, Bampatsou and Hadjiconstantinou (2009) went on to estimate that the possibilities for long term sustainable economic activity, mostly based on each country's exhaustible energy resources, are very good in Switzerland, good in the United Kingdom, fair in Luxembourg and poor in Greece using a case analysis model similar to this study's. Furthermore, it found that countries which invest in renewable energy resources, as Switzerland has done with hydro-power and nuclear power, and the UK has done with nuclear power, and less polluting fossil fuels, as Luxembourg has done with natural gas, ensure better prospects for sustainable economic activity. Ramanathan (2002) noted just how far away each country is from being considered efficient in each of the indicators in the study and recommends that the inefficient countries try to emulate their efficient peers. It is also worth noting that Aldea et al. (2012) found that reducing the dimension space used to generate the efficiency estimates from the first model to the second gave the study more reliable results. In addition Zang et al.(2008) actually mentioned that research on eco-efficiency has been heavily criticized for not including measures of social welfare in its attempts to study sustainable development.

Many of the studies that utilized a DEA approach to compare energy efficiencies across countries seem to share somewhat similar findings with one another. This is particularly notable with countries like Switzerland and Sweden which both appeared in the top tier of more than one of the studies examined here. Interestingly, some countries have exhibited vastly different efficiency scores depending on the study in question, particularly Luxembourg and Romania, which each placed in the top tier of one study and the bottom tier of another. Since each study used different methods and combinations of variables this is not too surprising, but such temperamental results also suggest somewhat unique situations in these countries, which makes it prudent to keep an eye on them.

2.2 Non-DEA Studies on Energy Efficiency

Most non-DEA research conducted on energy efficiency tends to have a broader focus than DEA research on the subject, but it is still very relevant to this paper as background information on the topics involved. One example is Mohammadi and Ram (2012), which conducted an assessment of trends in cross-country energy and electricity consumption per capita from 1971-2007. The study looked for both conditional and unconditional convergence, which is defined as a reduction in the variable’s dispersion, which in turn is mostly measured in terms of the coefficient of variation (CV). The authors also used quantile regressions to look for differences in convergence in the top and bottom segments of the distributions of changes in the variables. Chuku (2010) offers a good description of the synergies and trade-offs involved in implementing a policy approach in Africa focused on stimulating economic development while ensuring climate change mitigation. Graus et al. (2007) conducted a much more focused analysis than Mohammadi and Ram (2012) or Chuku (2010), in which it calculated and compared the energy efficiencies of seven countries and two small groups of counties based on the "Handbook of International Comparisons of Energy Efficiency in the Manufacturing Industry", which divides power and heat production by energy input, using data from the year 2003.

When it comes to conclusions, Mohammadi and Ram (2012) made ten separate observations. Most importantly that global convergence in energy consumption is weak but convergence in electricity consumption by itself is actually strong, likely due to electricity's much higher rate of global increase. The study also noted trends are similar throughout the entire period, energy conservation in the top and bottom deciles is generally week, and convergence in electricity is observed in the top but not the bottom deciles. Mohammadi and Ram (2012) provided an excellent and informative backdrop of the historical trends in this study's input variable of energy consumption. Meanwhile Chuku (2010) argued that an integrated development path would produce economic, social, health, and ecological synergies including employment opportunities, accelerated technological transfusion, a reduction of demographic impacts such as traffic noise, traffic accidents and urban congestion, as well as a reduction of air pollution and disaster probabilities. However it acknowledged that development activities typically have a negative impact on environment, and the need for the use of a common metric, such as monetary loss avoided, human lives saved, or environmental and natural capital saved, to assess the adverse effects of specific energy policies on development.

Chuku (2010) went on to describe how environmental concerns can naturally be brought into the mainstream of African policy making by focusing development planning and implementation on four key criteria, namely environmental effectiveness, equity considerations, cost effectiveness and institutional compatibility. This analysis provided a fairly simple and sensible explanation of the important factors driving the relationship between economic development and environmental quality, and how this relationship can actually be mutually beneficial. In contrast to Mohammadi and Ram (2012) and Chuku (2010), the findings of Graus et al. (2007) fairly closely resembled those of DEA studies on energy efficiency. Specifically Graus et al. (2007) found that Nordic countries, Japan, and the United Kingdom and Ireland performed best in terms of fossil power generating efficiency, with Nordic countries and Japan operating at 8% and Ireland at 7% above average efficiency. South Korea was 6% and Germany was 4% above average, while the United States was 2% and France was 4% below average. The lowest performers in the study were Australia at 7%, China at 9% and India at 13% below average efficiency. This study represents a good example of an alternative method to the DEA approach for comparing energy efficiencies between countries.

2.3 Research on Energy Efficiency Policy

Economic literature on policies relating to energy efficiency can do much to inform this paper's country comparisons, especially since there are numerous methods of analyzing the issues surrounding energy related policies. Geller et al. (2006) provides relevant background and perspective by reviewing the energy intensity trends of major OECD countries starting from 1973, focusing on energy policies in Japan, Western Europe, the US, and specifically California. Geller et al. (2006) highlighted the importance of energy efficiency for economies everywhere with the finding that OECD counties would have used 49% more energy than they have since 1998 if it weren't for energy efficiency improvements. Schipper et al. (2001) on the other hand examined cross-country trends in energy efficiency in more detail by applying factor decomposition methods to various indicators of energy efficiency and even extended its energy indicators to incorporate carbon emissions.

Schipper et al.(2001) obtained its indicators by examining the structure of economic and human activities, energy intensities, and index-number decomposition, which builds an understanding of the important economic factors relating to energy efficiency, such as the three main sectors of energy use: Travel(fuel economy), Household consumption, and manufacturing. Factoral decomposition has become a popular technique for separating the effects of structural and intensity changes on energy use, and Schipper et al. (2001) indeed used time-series data for a sample of 14 countries to conduct factor decomposition analysis to distinguish between energy services and intensities. The paper went on however to expand the services component to become energy/carbon services and the intensity component to include two new terms, one for fuel mix and one for utility carbon intensity(the ratio of carbon released to electricity(or heat) supplied to final energy users). By further breaking these down by sector, it was possible to see precisely where the energy or emissions growth is strongest. Schipper et al. (2001) found that energy intensity had improved across the board, though most dramatically in Denmark, Germany, and the USA, while energy services had become significantly less efficient, especially in Australia, the final fuel mix, a ratio of pollution released to energy produced, had improved modestly for all the studied countries except France whose fuel mix had dropped significantly, and utility carbon intensity had improved somewhat for all of the countries but most in France.

Gillingham et al. (2009) took a different approach, it instead examined the range of barriers and failures that may be preventing countries from reaching an economically efficient level of energy efficiency, the particular policies available to governments to address each of these issues, and the effectiveness of these policies. Gillingham et al. (2009)'s analysis differentiated between potential behavioral failures and potential market failures, which the paper separates into the four categories of energy market failures, capital market failures, innovation market failures, and information problems. In a similar fashion Parry et al. (2010) used a theoretical framework to analyze issues of energy efficiency and noted that energy efficiency increases do not always reduce pollution emissions per unit of energy, and that market failures, specifically caused by consumer reluctance to adopt seemingly cost-effective and efficient technologies, are common due to misperceptions held by consumers. Parry et al. (2010) argued that if policies to educate consumers are implemented correctly, thereby eliminating the misperceptions failures, then the optimal policy for CO2 mitigation would to combine a fuel tax increase with a CO2 tax, because all other policies (efficiency standards, electricity taxes, emissions standards) would be less cost effective.

Some studies examined specific policy options in great detail, such as Oikonomou and Gaast (2008) which chose to evaluate the prospect of implementing a combination of the fairly new White Certificates (WhC) policy with the already well-established policy of Joint Implementation (JI) in the Netherlands. WhCs are somewhat similar to domestic cap and trade policies in that WhCs also sets specific energy saving targets for suppliers, which must be completed within a certain time frame and through the use of energy efficiency measures that benefit their clients. JI is a system in which developed countries can reach their emissions reduction targets partly by funding emissions reducing projects is less developed countries. Oikonomou and Gaast (2008) argued that there are complementary benefits to integrating the two policies into one, and admited that the success of the WhC/JI scheme depends almost entirely on the fulfillment of two parameters, methods for defining baselines in energy savings and ways of converting different tradable commodities. Oikonomou and Gaast (2008) evaluated the proposed hybrid of the two policies based on five criteria: effectiveness, efficiency, innovation process, impacts on society, and market effects. The study found that the scheme can indeed be effective, efficient, minimally negative to society, and promising in terms of market effects, however its effects on innovation are difficult to estimate. Geller et al. (2006) also included analyses of the success of specific US energy policies and programs, particularly the fact that they combined to reduce primary energy use by around 11% in 2002. Geller et al. (2006) stated that the CAFE vehicle efficiency standards generated the most savings, followed by appliance efficiency standards, Energy Star labeling and promotion, PURPA and other CHP initiatives, utility and state end-use efficiency programs, building energy codes, DOE industrial efficiency programs, the weatherization assistance program, and lastly the Federal energy management program. Geller et al. (2006) concluded that well designed policies can indeed generate significant energy savings.

“Well designed” is the key word there though because as Parry et al. (2010) explained, without effective educational policies misperceptions failures will persist, meaning the optimal policy would combine a CO2 tax with efficiency standards for the power sector (though not an electricity tax) and a gasoline tax (though not an efficiency standard for autos). Parry et al. (2010) concluded more generally that energy efficiency improvements face a higher hurdle in the transport sector than in the power sector. Parry et al. (2010) found that fuel taxes have a much lower net cost than the other policy measures examined, and that if fuel taxes are fixed, efficiency standards can significantly improve welfare, however only if CO2 damages are very high. Parry et al. (2010) also found that the potential welfare gains from efficiency standards can easily exceed those from electricity taxes. Geller et al. (2006) added to our understanding of effective energy policies by explaining that government-funded research and development (R&D) has been beneficial in the past, but that R&D portfolios should contain a mix of high risk, potentially high reward projects in as well as lower risk ones. Also, since the benefits from R&D can take years to materialize, governments must promote commercialization and market development as well as technological progress. Geller et al. (2006) also found that minimum efficiency standards, voluntary agreements between governments and the private sector, carefully designed financial incentives like those for newly commercialized technology, the elimination of subsidies for fossil fuels, and improvements in labeling, information distribution, and training, all continue to be key methods of improving energy efficiency.

The impressively comprehensive research done by Gillingham et al. (2009) clarified even more issues surrounding energy efficiency policies. Gillingham et al. (2009) began by identifying three problems within the category of energy market failures, the first is environmental externalities, which can be addressed through emissions pricing (tax, cap-and-trade), the next is average-cost electricity pricing, which can be addressed by real-time pricing as well as market pricing, and the last is energy security, which can be addressed through energy taxation and strategic reserves. The paper goes on to explain that liquidity constraints, the only problem listed under the capital market failures category, can be addressed by financing and loan programs. Then that the innovation market failures category contains two problems, research and development (R&D) spillovers, which can be addressed by R&D tax credits and public funding, and learning-by-doing spillovers, which can be addressed by incentives for early market adoption. The last of the market failures are the three information problems of lack of information and asymmetric information, principal–agent problems, and learning-by-using, which can all be addressed through the use of information programs. The paper includes three distinct behavioral failures relevant to energy efficiency as well, namely prospect theory, bounded rationality, and heuristic decision making, all of which can be addressed by improving education, information, and product standards.

After outlining which policies should be used to address which failures, Gillingham et al.(2009) went on to analyze three of the policy options in more detail. The study found that information programs, which seek to increase energy efficient investment decisions by ensuring that customers are aware of potential energy savings, vary widely as far as their method and implementation, and their effectiveness is mixed. The paper found that incentive programs, which provide direct subsidies, tax credits, tax deductions, rebates, or loan subsides to stimulate energy efficiency investments, may be effective, however results for these policies are mixed as well which means more research must be done to determine their cost-effectiveness. Product standards, which force products in a given market to operate above a certain energy efficiency level, seem to produce net benefits however verifiably definitive research is lacking here as well.

Another interesting aspect of energy policy is the idea first put forth by Kazzoom (1980) and Brookes (1980) that increased energy efficiency somewhat paradoxically leads to increased energy consumption. Later Saunders (1992) validated this hypothesis and termed it the Khazzoom-Brookes postulate, stating that energy efficiency improvements can increase consumption by making energy appear effectively cheaper than other inputs and by increasing economic growth, which raises energy use. Twenty years later the Kazzoom-Brookes postulate is mostly the same except that now it is known as the rebound effect. Despite being widely accepted, many economists are still conducting research on this intriguing phenomenon to estimate its precise effect on economies around the world. For instance, Lin and Liu (2012) not only validated the existence of the rebound effect, but also calculated that China’s energy rebound effect averaged 53.2% from 1981–2009. Similarly, Nässén and Holmberg (2009) estimated the total rebound effects of energy efficiency improvements in Sweden appear to be in the range 5–15% in most cases. In addition, Barla et al. (2009) estimated Canada’s rebound effect to be around 8% in the short-term and 20% in the long-term., and found both that the rebound effect will reduce the effectiveness of new fuel efficiency standards and that gasoline demand is only slightly affected by fuel price increases. Interactions like the rebound effect are clearly important to understanding energy efficiency policies and their outcomes.

Chapter 3: Methodology and Data Sources

3.1 How DEA Works

This paper utilizes Data Envelopment Analysis (DEA) to calculate each individual country's level of energy efficiency in terms of how well they utilize their energy consumption to produce health, education, income, and access to essentials for its citizens while minimizing pollution. DEA is a nonparametric approach to analyzing productive efficiency, often chosen because it is able to incorporate multiple input and output variables and because it does not require a specific production function. The DEA method simply uses data to establish a frontier made up of the most efficient countries and then evaluates each country in relation to its most efficient peers. Instead of using an equation for a production function, DEA generates a production frontier that relates inputs to outputs. The researcher chooses between input or output oriented results and between constant (CRS), non-increasing (NIRS) or variable (VRS) returns to scale, each illustrated in Figures 4, 5 and 6.

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Figure 4. Example of CRS Frontier

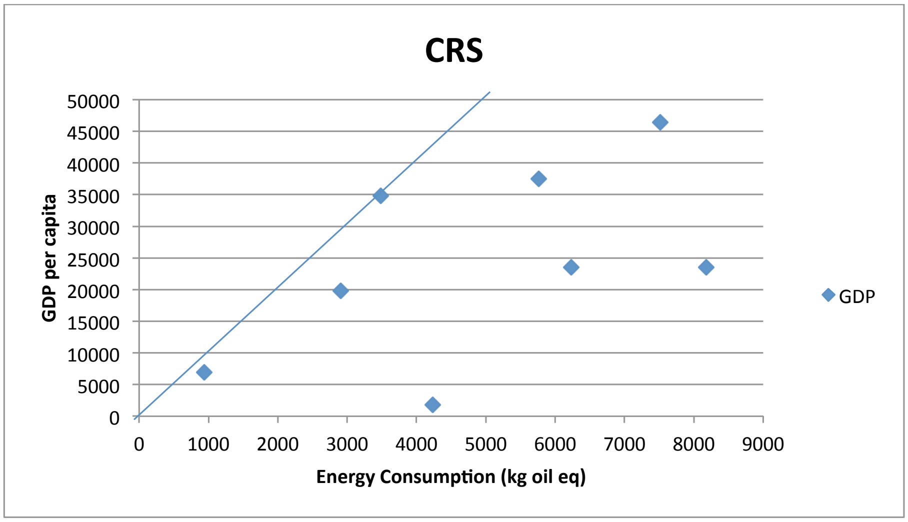


Figure 5. Example of NIRS Frontier

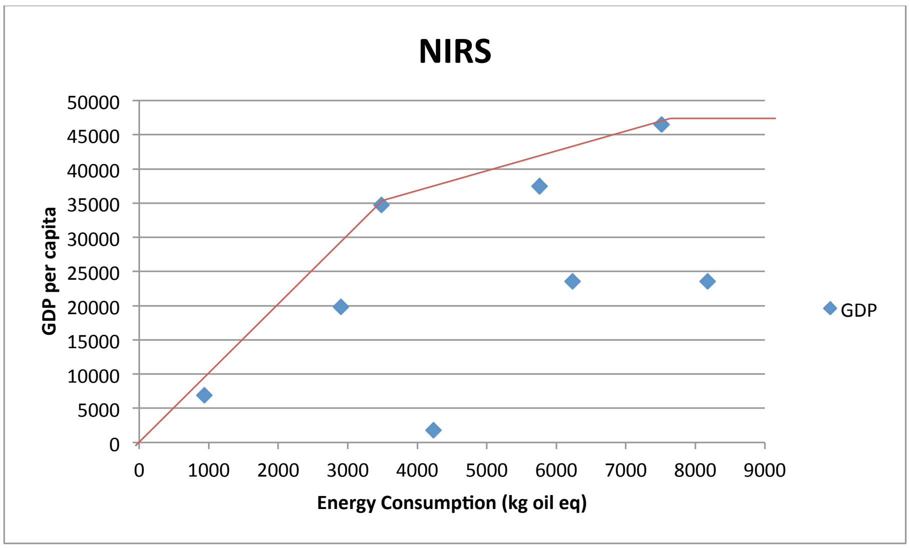
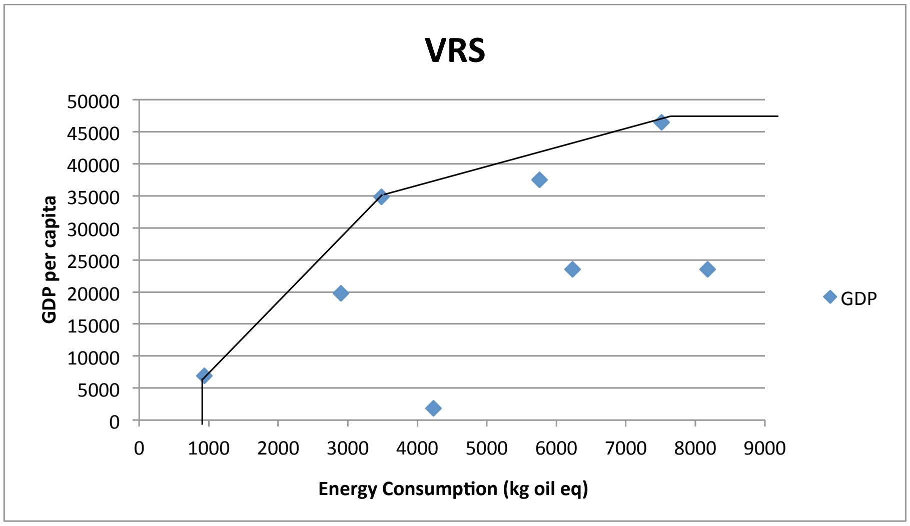


Figure 6. Example of VRS Frontier



Input orientation would mean that a country is more efficient than another if it produces the same amount of outputs with less inputs, while output orientation would mean that a country is more efficient than another if it produces more outputs using the same amount of inputs. With CRS the model's frontier starts at the origin and travels in a straight line through the most efficient point and onward, with NIRS the frontier starts at the origin and moves in a straight line from one efficient point to another before going horizontal, while with VRS the frontier starts directly below the point with the least inputs, goes straight to that point and then continues through the most efficient points before going horizontal.

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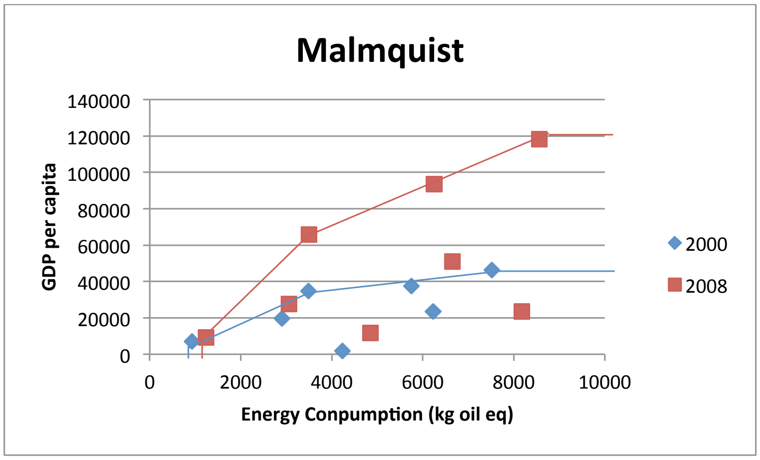
Once the orientation and returns to scale have been set a program essentially plots the data points, called decision making units (DMUs), on a graph using whatever combination of input and output variables desired. Then it draws a frontier line connecting the most efficient DMUs and assigns those DMUs on the frontier a technical efficiency (TE) score of 1, meaning they are operating at 100% efficiency, and those DMUs below the frontier a value between 1 and 0 depending on how close the DMU is to the frontier. For example, using output orientation if a DMU is halfway between the x axis and the point on the frontier directly above it, this means that it is operating at 50% of its potential so DEA would assign it a value of 0.5.

3.2 DEA Model

This study evaluates its data using an input oriented DEA analysis with VRS because it seeks to compare countries with similar levels of development and because VRS offers the most inclusive analysis. Energy consumption is selected as the sole input with strong disposability, while indices for health, education and access to essentials, as well as raw GNI per capita are chosen as outputs. While it is a common practice to treat undesirable outputs instead as inputs, DEAP, the software program used for this analysis, does not allow multiple inputs so instead a nonlinear monotone decreasing transformation of 1/(CO2 emissions per capita) is used to treat the undesirable output of pollution. A time series analysis is also conducted using a Malmquist Index to see how countries change over time, illustrated in Figure 7. It is also worth noting that this study dropped a small number of countries from its analysis because they had zero values for at least one of the indices used.

Figure 7. Malmquist Index Frontiers



3.3 Variable Selection

Appendix 1 illustrates basic information on all the variables used in this study. Consumption of commercial energy in kg of oil equivalent per capita is chosen as the input variable in this analysis because it is a good measure of relative energy use which is crucial for the evaluation of energy efficiency. Data on each country's energy use comes from Europa World Data (europaworld.com/comparative-statistics). Development in terms of standard of living is broken into 4 separate measures similar to how the Human Development Index is constructed. The first is an index for health computed by taking the geometric mean of two sub-indexes, one for life expectancy at birth in years and one for the rate of child mortality, which was converted into the rate of child survival by subtracting each number from 1 (HDI Technical Notes, p168). The second is an index for education also computed by taking the geometric mean of two sub-indexes, one for expected years of schooling of children and one for mean years of schooling of adults.

The third is an index for access to essentials computed by taking the geometric mean of sub-indices for the percent of the population with access to drinking water and access to sanitation. The last is the raw data for gross national income (GNI) per capita in PPP terms (constant 2005 international $). Data for the indicators used to compute the health and education indices, as well as for GNI, comes from the United Nations Development Programme's "Human Development Index" (http://hdr.undp.org/en/statistics/hdi/), while data on access to essentials comes from Yale's "Environmental Performance Index" (http://epi.yale.edu/). Pollution is also taken into account to reflect each country's level of sustainable development by performing a nonlinear monotone decreasing transformation on data from Yale's "Environmental Performance Index" for each country's metric tons of CO_2 emissions per capita to deal with the undesirable output. Table 1 in the Appendix shows descriptive statistics for this study's variables and Figure 9 illustrates the correlations between them, notably there is a high correlation between energy consumption and income per capita.

Figure 8. Correlation Matrix

	Energy	*Health*	*Education*	*Income*	*Environment*	*Access to Ess.*
Energy	1.00					
Health	0.45	1.00				
Education	0.57	0.79	1.00			
Income	0.89	0.58	0.67	1.00		
Environment	-0.34	-0.70	-0.58	-0.40	1.00	
Access to Ess.	0.60	0.83	0.77	0.72	-0.68	1.00

3.4 Case Study Method

The evaluations generated in the DEA analysis are used to guide this study's secondary analysis, which is similar to a case study approach. In addition to TE scores DEA also provides peer weights for each country, which detail the specific countries used as reference points on the frontier to determine a country's TE score, as well as the proportion of the country's TE score determined by each of those other countries. By looking at which countries have the highest peer weights for each individual country in the analysis this study is able to determine which countries should be compared in depth to understand the causes of particular inefficiencies. Most of the time the most relevant peer will be the one with the highest peer weight, however sometimes this paper chooses a country with a slightly lower peer weight than another simply because one is much more geographically relevant than the other.

Once countries are matched with their most relevant peer the most useful comparisons are selected for consideration by filtering out those countries with extremely difference levels of economic development measured in GDP. From there this paper identifies a handful of interesting country pairs to analyze in depth while ensuring that the low, medium and high levels of the development spectrum are represented. These country pairs are then evaluated based on their output data for health, education, income, access to essentials and pollution in order to understand what measures of development the inefficient country is falling behind on and therefore which types of policies should be given particular attention in each country. With this done the study compares the countries in each pair in detail based on world development indicators provided by The

World Bank specific to their areas of inefficiency, and generates conclusions on how the inefficient country should improve.

Chapter 4: Results

4.1 DEA

The previous chapter proposed a DEA method to calculate TE scores for 104 countries using data from the year 2000, the results of which are shown in Figures 9 and 10. They illustrate that TE scores for countries ranged from 0.139 to 1, with an average score of 0.766. Of the 104 countries studied, 31were considered efficient and received TE scores of 1, a reasonable number given that there were 5 separate output variables. The unit efficient countries were Albania, Armenia, Australia, Bolivia, Bulgaria, Congo, Costa Rica, Cuba, Cyprus, Denmark. Haiti, Ireland, Israel, Japan, Kyrgyzstan, Latvia, Luxembourg, Malta, Morocco, Nepal, Norway, Peru, Qatar, Senegal, Sri Lanka, Sweden, Switzerland, Tajikistan, Tanzania, Uruguay and Yemen. The most inefficient countries were Trinidad and Tobago, Russia, South Africa, Iceland and Mongolia. Peru was used the most as a peer for inefficient countries, 24 times, followed by Uruguay with 22, Israel and Malta with 21, Albania and Switzerland with 15, Haiti and Sri Lanka with 14, and Costa Rica and Morocco with 12.

Figure 9. DEA 2000 Results

Country	TE Sore	TE Rank	Energy	Energy Rank	Health	Health Rank	Education	Education Rank	Income	Income Rank	Access	Access Rank	Pollution	Pollution Rank
Albania	1	1	575	79	0.87	45	0.601	49	4914	66	0.924	46	1036	74
Algeria	0.699	70	885	63	0.79	68	0.442	76	5802	58	0.880	55	2046	60
Argentina	0.88	40	1651	47	0.89	37	0.698	29	10006	41	0.923	47	3768	48
Armenia	1	1	651	75	0.82	60	0.630	42	2370	82	0.892	52	1104	73
Australia	1	1	5645	12	0.97	6	0.953	1	28950	18	1.000	1	17582	6
Austria	0.803	49	3566	24	0.96	16	0.737	23	31163	11	1.000	1	7685	26
Belgium	0.728	62	5707	11	0.96	15	0.867	6	31064	12	1.000	1	11571	10
Benin	0.782	55	304	100	0.29	103	0.171	100	1253	95	0.076	104	212	96
Bolivia	1	1	455	87	0.64	84	0.606	47	3328	74	0.340	97	917	80
Botswana	0.761	57	1045	57	0.56	90	0.556	58	9122	46	0.647	76	2422	57
Brazil	0.667	73	1085	56	0.80	66	0.537	62	7698	50	0.811	64	1732	63
Bulgaria	1	1	2314	40	0.86	48	0.670	34	7017	54	1.000	1	5215	41
Cambodia	0.797	52	320	99	0.50	95	0.301	93	975	98	0.156	101	189	98
Cameroon	0.826	45	402	94	0.29	102	0.275	94	1731	89	0.460	89	176	100
Canada	0.498	88	8172	6	0.97	5	0.844	8	31602	10	1.000	1	17360	7
Chile	0.764	56	1602	48	0.93	28	0.639	41	10078	40	0.915	48	3534	50
China	0.54	87	867	64	0.84	53	0.432	77	2642	79	0.567	82	2406	58
Colombia	0.917	35	674	72	0.81	62	0.495	67	6457	56	0.780	69	1475	69
Congo	1	1	271	101	0.41	97	0.330	89	2273	83	0.373	94	194	97
Costa Rica	1	1	769	68	0.95	20	0.521	64	7467	52	0.938	43	1142	71
Croatia	0.827	43	1760	45	0.91	32	0.627	43	12108	35	0.988	31	3986	46

Cuba	1	1	1215	52	0.93	26	0.643	39	3197	75	0.854	58	2224	59
Cyprus	1	1	2265	41	0.96	14	0.654	37	21255	24	1.000	1	9087	20
Czech Republic	0.645	76	3989	21	0.91	33	0.797	15	16499	31	0.989	30	11868	9
Denmark	1	1	3491	25	0.94	25	0.833	10	31000	13	1.000	1	9457	18
Dominican Republic	0.603	83	908	62	0.83	57	0.493	68	5396	60	0.795	67	1995	61
Ecuador	0.849	42	651	76	0.85	51	0.557	57	5005	65	0.810	65	1506	68
Egypt	0.821	46	668	73	0.76	76	0.402	82	4051	68	0.895	49	1571	67
El Salvador	0.796	53	667	74	0.83	58	0.449	74	5069	63	0.782	68	881	83
Estonia	0.874	41	3443	27	0.83	56	0.834	9	10553	39	0.959	37	10650	13
Finland	0.447	92	6231	9	0.95	19	0.768	18	27117	22	1.000	1	10461	15
France	0.754	58	4145	17	0.97	7	0.756	20	28791	20	1.000	1	6206	34
Gabon	0.827	43	1184	54	0.58	88	0.484	69	11223	38	0.491	87	1122	72
Germany	0.819	48	4103	18	0.96	16	0.819	13	30262	14	1.000	1	10064	17
Ghana	0.656	74	404	93	0.50	94	0.328	90	1009	97	0.081	103	262	94
Greece	0.95	33	2481	34	0.97	11	0.674	33	20561	27	0.982	33	7984	25
Guatemala	0.742	60	631	77	0.73	79	0.261	95	3918	69	0.780	70	786	84
Haiti	1	1	233	104	0.54	92	0.242	98	1086	96	0.239	100	165	101
Honduras	0.799	50	481	84	0.78	72	0.387	84	2805	78	0.633	78	716	86
Hungary	0.91	36	2448	35	0.85	50	0.756	20	13017	32	0.993	27	5308	40
Iceland	0.337	101	11031	3	0.98	3	0.802	14	29065	16	1.000	1	7643	27
India	0.604	82	450	88	0.58	89	0.256	96	1747	88	0.369	95	966	79
Indonesia	0.489	90	730	70	0.72	81	0.398	83	2478	81	0.516	85	1300	70
Iran	0.377	99	1978	43	0.78	70	0.446	75	7678	51	0.858	57	4858	44
Ireland	1	1	3600	23	0.94	24	0.877	5	27836	21	0.995	26	10753	12
Israel	1	1	2902	31	0.97	10	0.826	11	21169	25	1.000	1	8706	23
Jamaica	0.432	95	1482	50	0.84	54	0.580	52	6275	57	0.852	59	3776	47

Japan	1	1	4090	19	1.00	1	0.780	17	28980	17	1.000	1	9328	19
Jordan	0.897	39	1013	58	0.86	49	0.561	55	3640	71	0.961	36	2977	53
Kazakhstan	0.433	94	2391	37	0.73	80	0.657	36	5030	64	0.956	38	8288	24
Kenya	0.608	80	447	89	0.46	96	0.344	88	1266	94	0.276	98	217	95
Korea (Republic of)	0.706	69	4001	20	0.91	31	0.820	12	18629	30	0.950	40	8957	21
Kuwait	0.418	96	9690	4	0.90	35	0.524	63	39519	6	0.993	27	22900	3
Kyrgyzstan	1	1	489	83	0.76	77	0.615	46	1406	93	0.832	61	904	81
Latvia	1	1	1566	49	0.82	61	0.711	27	8518	47	0.866	56	2878	54
Luxembourg	1	1	7520	8	0.95	21	0.698	29	53204	2	1.000	1	18227	5
Malaysia	0.453	91	2019	42	0.86	47	0.573	53	9461	43	0.935	44	4773	45
Malta	1	1	1732	46	0.94	23	0.684	31	20004	28	1.000	1	5410	39
Mexico	0.725	64	1452	51	0.88	42	0.551	59	11783	36	0.798	66	3519	51
Moldova	0.626	79	782	67	0.79	67	0.587	50	1662	90	0.828	62	1580	66
Mongolia	0.355	100	980	60	0.66	82	0.472	72	1997	85	0.485	88	3671	49
Morocco	1	1	356	96	0.78	73	0.247	97	2833	77	0.650	75	994	78
Namibia	0.799	50	537	80	0.62	85	0.503	66	4715	67	0.410	91	995	77
Nepal	1	1	332	98	0.55	91	0.200	99	915	101	0.353	96	125	103
Netherlands	0.925	34	4598	15	0.97	12	0.857	7	34415	9	1.000	1	10810	11
Nicaragua	0.708	68	536	81	0.79	69	0.353	86	2010	84	0.560	83	691	88
Norway	1	1	5760	10	0.97	9	0.919	2	43057	3	1.000	1	7470	29
Pakistan	0.688	71	440	92	0.61	86	0.138	102	1920	86	0.513	86	708	87
Panama	0.909	38	853	65	0.88	44	0.623	44	7721	49	0.730	74	1593	65
Paraguay	0.634	78	721	71	0.81	65	0.474	71	3820	70	0.589	81	607	89
Peru	1	1	473	86	0.77	75	0.603	48	5377	61	0.645	77	1017	76
Philippines	0.821	46	523	82	0.76	78	0.550	60	2574	80	0.743	73	900	82
Poland	0.793	54	2318	39	0.88	41	0.734	25	11694	37	0.944	42	7617	28

Portugal	0.746	59	2413	36	0.93	27	0.642	40	20662	26	0.982	33	5810	37
Qatar	1	1	18029	1	0.93	29	0.514	65	60912	1	1.000	1	39145	1
Russia	0.243	103	4233	16	0.78	71	0.658	35	8380	48	0.894	50	10269	16
Senegal	1	1	252	103	0.33	100	0.130	103	1441	92	0.455	90	363	92
Serbia	0.723	66	1771	44	0.88	43	0.681	32	6561	55	0.949	41	5200	43
Singapore	0.725	64	4778	14	0.97	12	0.581	51	37107	8	1.000	1	10591	14
Slovakia	0.682	72	3293	28	0.89	39	0.746	22	12496	34	1.000	1	6920	32
Slovenia	0.653	75	3224	29	0.92	30	0.729	26	19726	29	1.000	1	7080	30
South Africa	0.263	102	2600	33	0.60	87	0.621	45	7443	53	0.754	72	6784	33
Spain	0.99	32	3029	30	0.97	8	0.757	19	24911	23	1.000	1	7051	31
Sri Lanka	1	1	444	90	0.83	55	0.571	54	3028	76	0.762	71	568	91
Sweden	1	1	5362	13	0.98	2	0.914	3	28913	19	1.000	1	5948	35
Switzerland	1	1	3481	26	0.98	4	0.782	16	37268	7	1.000	1	5778	38
Syria	0.605	81	998	59	0.89	38	0.350	87	3545	73	0.849	60	2772	55
Tajikistan	1	1	348	97	0.64	83	0.548	61	951	99	0.629	79	352	93
Tanzania	1	1	393	95	0.29	101	0.150	101	839	102	0.251	99	75	104
Thailand	0.586	86	1146	55	0.88	40	0.431	78	5492	59	0.934	45	2557	56
Togo	0.599	84	440	91	0.39	99	0.313	92	786	103	0.128	102	183	99
Trinidad and Tobago	0.139	104	8248	5	0.81	63	0.561	56	12793	33	0.894	51	13800	8
Tunisia	0.732	61	764	69	0.85	52	0.457	73	5194	62	0.827	63	1885	62
Turkey	0.728	62	1200	53	0.77	74	0.406	81	9260	45	0.880	54	3121	52
Ukraine	0.591	85	2721	32	0.81	64	0.711	27	3595	72	0.952	39	5937	36
United Arab Emirates	0.437	93	11331	2	0.90	36	0.479	70	43052	4	0.984	32	26480	2
United Kingdom	0.712	67	3786	22	0.95	18	0.735	24	29529	15	1.000	1	8891	22

United States of America	0.636	77	8057	7	0.94	22	0.891	4	40259	5	0.993	27	20177	4
Uruguay	1	1	937	61	0.90	34	0.647	38	9589	42	0.964	35	1606	64
Venezuela	0.383	98	2321	38	0.86	46	0.431	79	9449	44	0.885	53	5213	42
Viet Nam	0.91	36	476	85	0.82	59	0.359	85	1583	91	0.614	80	573	90
Yemen	1	1	268	102	0.53	93	0.065	104	1905	87	0.402	92	727	85
Zambia	0.494	89	612	78	0.09	104	0.326	91	947	100	0.391	93	162	102
Zimbabwe	0.391	97	790	66	0.40	98	0.409	80	608	104	0.532	84	1020	75

Figure 10. 2000 Peer Results

Country	vrste	peer count:	Peer	Weight	Peer	Weight	Peer	Weight	Peer	Weight	Peer
Albania	1	15	Albania	1.00							
Algeria	0.699	0	Uruguay	0.17	Albania	0.64	Peru	0.19			
Argentina	0.88	0	Israel	0.32	Armenia	0.39	Uruguay	0.29			
Armenia	1	7	Armenia	1.00							
Australia	1	1	Australia	1.00							
Austria	0.803	0	Switzerland	0.65	Malta	0.35					
Belgium	0.728	0	Denmark	0.40	Australia	0.14	Israel	0.24	Norway	0.22	
Benin	0.782	0	Congo	0.14	Haiti	0.86					
Bolivia	1	0	Bolivia	1.00							
Botswana	0.761	0	Peru	0.74	Malta	0.26					
Brazil	0.667	0	Peru	0.48	Malta	0.01	Uruguay	0.51			
Bulgaria	1	0	Bulgaria	1.00							
Cambodia	0.797	0	Haiti	0.81	Tajikistan	0.19					

Cameroon	0.826	0	Sri Lanka	0.11	Congo	0.44	Tanzania	0.19	Tajikistan	0.27	
Canada	0.498	0	Norway	0.15	Switzerland	0.34	Sweden	0.22	Israel	0.29	
Chile	0.764	0	Cuba	0.33	Uruguay	0.26	Malta	0.28	Costa Rica	0.14	
China	0.54	0	Costa Rica	0.07	Sri Lanka	0.93					
Colombia	0.917	0	Albania	0.17	Peru	0.56	Uruguay	0.28			
Congo	1	8	Congo	1.00							
Costa Rica	1	12	Costa Rica	1.00							
Croatia	0.827	0	Malta	0.65	Uruguay	0.35					
Cuba	1	1	Cuba	1.00							
Cyprus	1	1	Cyprus	1.00							
Czech Republic	0.645	0	Armenia	0.07	Israel	0.84	Uruguay	0.08			
Denmark	1	4	Denmark	1.00							
Dominican Republic	0.603	0	Costa Rica	0.11	Albania	0.42	Morocco	0.01	Peru	0.46	
Ecuador	0.849	0	Costa Rica	0.23	Albania	0.24	Peru	0.22	Morocco	0.05	Sri Lanka
Egypt	0.821	0	Albania	0.74	Kyrgyzstan	0.23	Morocco	0.03			
El Salvador	0.796	0	Costa Rica	0.10	Albania	0.35	Peru	0.42	Nepal	0.01	Sri Lanka
Estonia	0.874	0	Ireland	0.15	Israel	0.85					
Finland	0.447	0	Malta	0.35	Switzerland	0.22	Denmark	0.28	Israel	0.14	
France	0.754	0	Israel	0.02	Malta	0.27	Switzerland	0.50	Japan	0.21	
Gabon	0.827	0	Malta	0.41	Peru	0.53	Congo	0.06			
Germany	0.819	0	Israel	0.25	Switzerland	0.25	Denmark	0.50	Norway	0.01	
Ghana	0.656	0	Tajikistan	0.28	Haiti	0.72					
Greece	0.95	0	Japan	0.16	Costa Rica	0.29	Cyprus	0.30	Israel	0.13	Switzerland
Guatemala	0.742	0	Albania	0.54	Morocco	0.39	Sri Lanka	0.01	Congo	0.07	
Haiti	1	14	Haiti	1.00							

Honduras	0.799	0	Sri Lanka	0.42	Haiti	0.08	Peru	0.01	Morocco	0.49	
Hungary	0.91	0	Israel	0.56	Malta	0.25	Uruguay	0.20			
Iceland	0.337	0	Japan	0.41	Sweden	0.07	Israel	0.26	Switzerland	0.26	
India	0.604	0	Haiti	0.58	Morocco	0.26	Peru	0.01	Yemen	0.01	Congo
Indonesia	0.489	0	Morocco	0.19	Sri Lanka	0.40	Peru	0.07	Haiti	0.35	
Iran	0.377	0	Albania	0.12	Uruguay	0.56	Peru	0.32			
Ireland	1	2	Ireland	1.00							
Israel	1	21	Israel	1.00							
Jamaica	0.432	0	Albania	0.44	Uruguay	0.26	Peru	0.30			
Japan	1	4	Japan	1.00							
Jordan	0.897	0	Albania	0.08	Uruguay	0.92					
Kazakhstan	0.433	0	Armenia	0.15	Uruguay	0.78	Israel	0.07			
Kenya	0.608	0	Haiti	0.54	Congo	0.18	Tajikistan	0.28			
Korea (Republic of)	0.706	0	Israel	0.94	Latvia	0.06					
Kuwait	0.418	0	Switzerland	0.86	Luxembourg	0.14					
Kyrgyzstan	1	3	Kyrgyzstan	1.00							
Latvia	1	2	Latvia	1.00							
Luxembourg	1	2	Luxembourg	1.00							
Malaysia	0.453	0	Peru	0.09	Uruguay	0.88	Malta	0.03			
Malta	1	21	Malta	1.00							
Mexico	0.725	0	Malta	0.40	Peru	0.36	Costa Rica	0.24			
Moldova	0.626	0	Sri Lanka	0.23	Albania	0.13	Kyrgyzstan	0.63			
Mongolia	0.355	0	Sri Lanka	0.12	Peru	0.17	Haiti	0.29	Tajikistan	0.42	

Morocco	1	12	Morocco	1.00							
Namibia	0.799	0	Peru	0.79	Congo	0.21					
Nepal	1	1	Nepal	1.00							
Netherlands	0.925	0	Switzerland	0.18	Israel	0.26	Norway	0.41	Denmark	0.15	
Nicaragua	0.708	0	Sri Lanka	0.33	Morocco	0.63	Haiti	0.04			
Norway	1	5	Norway	1.00							
Pakistan	0.688	0	Senegal	0.13	Morocco	0.42	Haiti	0.00	Yemen	0.45	
Panama	0.909	0	Peru	0.12	Uruguay	0.56	Albania	0.27	Costa Rica	0.05	
Paraguay	0.634	0	Sri Lanka	0.63	Costa Rica	0.04	Peru	0.30	Haiti	0.03	
Peru	1	24	Peru	1.00							
Philippines	0.821	0	Sri Lanka	0.70	Kyrgyzstan	0.10	Morocco	0.07	Tajikistan	0.14	
Poland	0.793	0	Latvia	0.07	Israel	0.50	Armenia	0.43			
Portugal	0.746	0	Switzerland	0.04	Malta	0.96					
Qatar	1	0	Qatar	1.00							
Russia	0.243	0	Armenia	0.32	Israel	0.09	Uruguay	0.59			
Senegal	1	3	Senegal	1.00							
Serbia	0.723	0	Israel	0.22	Uruguay	0.46	Armenia	0.32			
Singapore	0.725	0	Malta	0.01	Switzerland	0.99					
Slovakia	0.682	0	Malta	0.56	Israel	0.44					
Slovenia	0.653	0	Malta	0.68	Israel	0.32					
South Africa	0.263	0	Peru	0.63	Malta	0.05	Uruguay	0.33			
Spain	0.99	0	Malta	0.34	Japan	0.36	Israel	0.20	Switzerland	0.11	
Sri Lanka	1	14	Sri Lanka	1.00							
Sweden	1	2	Sweden	1.00							

Switzerland	1	15	Switzerland	1.00							
Syria	0.605	0	Albania	0.01	Sri Lanka	0.50	Costa Rica	0.49			
Tajikistan	1	9	Tajikistan	1.00							
Tanzania	1	3	Tanzania	1.00							
Thailand	0.586	0	Uruguay	0.21	Costa Rica	0.10	Albania	0.69			
Togo	0.599	0	Tajikistan	0.24	Tanzania	0.02	Haiti	0.74			
Trinidad and Tobago	0.139	0	Peru	0.27	Malta	0.42	Uruguay	0.32			
Tunisia	0.732	0	Costa Rica	0.22	Morocco	0.17	Albania	0.42	Peru	0.19	
Turkey	0.728	0	Uruguay	0.65	Malta	0.08	Peru	0.27			
Ukraine	0.591	0	Uruguay	0.24	Israel	0.39	Armenia	0.36			
United Arab Emirates	0.437	0	Switzerland	0.64	Luxembourg	0.36					
United Kingdom	0.712	0	Switzerland	0.55	Malta	0.45					
United States of America	0.636	0	Norway	0.71	Switzerland	0.17	Ireland	0.12			
Uruguay	1	22	Uruguay	1.00							
Venezuela	0.383	0	Malta	0.09	Uruguay	0.65	Peru	0.26			
Viet Nam	0.91	0	Sri Lanka	0.89	Morocco	0.10	Haiti	0.01			
Yemen	1	2	Yemen	1.00							
Zambia	0.494	0	Congo	0.66	Tajikistan	0.15	Tanzania	0.17	Senegal	0.02	
Zimbabwe	0.391	0	Haiti	0.15	Tajikistan	0.63	Senegal	0.22			

Figures 11, 12 and 13 provide the results of the Malmquist Index conducted on years 1990, 1995, 2000 and 2008 data; the columns illustrate each country's total factor productivity change (tfpch), a measure of how much they have improved over the 8 year time period. It must be noted that the Malmquist Index was run on a different group of 80 countries than the original DEA's 104 due to the fact that data was not available for all countries for all years. Figure 11 displays the TE scores for each year for the Malquist Index, and throughout all four years twelve countries consistently received unit efficiency scores, these were Australia, Bangladesh, Costa Rica, Israel, Japan, Malta, Norway, Peru, Sri Lanka, Sweden, Switzerland and Uruguay. Meanwhile Trinidad and Topago, South Africa, Zimbabwe, China and Indonesia performed the worst on average over the entire time period. The Malmquist Index also reveals that Cuba, Zimbabwe, Zambia, Bulgaria and Ghana improved the most over the entire period while Kuwait, Benin, Iceland, Trinidad and Tobago and Nepal got worse the most over the entire time period. In addition Bolivia, Chile, China, Kenya, Peru, Senegal, Sri Lanka and Togo also improved considerably during at least two of the comparison periods, while Kuwait, Malaysia, Nepal and Iceland were the worst at improving for at least two comparison periods. There were also quite a few countries that ranked among the highest in one year and then among the lowest in another, namely Benin, Chile, Luxembourg, Mozambique, Syria, Bolivia, Tanzania, Nepal, Qatar and the United Arab Emirates. The next section of the results chapter compares three inefficient countries to their most relevant peers to understand what the inefficient countries should do to improve.

Figure 11. Malmquist Index Summary of Firm Means

firm	effch	techch	pech	sech	tfpch
Algeria	0.899	0.952	0.931	0.965	0.855
Argentina	0.98	0.944	0.941	1.041	0.925
Australia	0.968	0.921	1	0.968	0.892
Austria	0.948	0.917	1.016	0.933	0.87
Bangladesh	1	0.861	1	1	0.861
Belgium	0.969	0.918	1.003	0.966	0.889
Benin	0.831	0.825	0.827	1.004	0.685
Bolivia	0.89	0.976	0.972	0.916	0.869
Botswana	1.017	0.938	1.041	0.977	0.955
Brazil	0.886	0.945	0.947	0.936	0.837
Bulgaria	1.13	0.958	1.053	1.073	1.083
Cameroon	1.128	0.889	1.202	0.939	1.003
Canada	0.991	0.918	0.8	1.239	0.91
Chile	0.936	0.948	0.931	1.005	0.888
China	0.993	0.993	0.912	1.089	0.986
Colombia	1.011	0.949	1.04	0.973	0.96
Costa Rica	0.89	0.956	1	0.89	0.851
Cuba	1.291	0.983	1.025	1.26	1.268
Cyprus	0.909	0.919	0.989	0.919	0.836
Denmark	1.008	0.917	1.042	0.967	0.925
Dominican Republic	0.968	0.957	0.941	1.029	0.926
Ecuador	0.948	0.952	1.027	0.922	0.902
Egypt	0.932	0.94	1.05	0.887	0.876
El Salvador	0.891	0.948	0.912	0.977	0.845
Finland	0.994	0.919	1.031	0.964	0.914
France	0.962	0.917	1.051	0.915	0.882
Germany	1.029	0.917	1.158	0.889	0.944
Ghana	1.063	0.991	1.143	0.93	1.053
Greece	0.955	0.92	0.988	0.967	0.878
Guatemala	0.98	0.937	0.988	0.992	0.918
Haiti	0.951	0.832	0.956	0.995	0.791
Honduras	0.969	0.959	0.975	0.994	0.929
Hungary	1.03	0.933	1.245	0.827	0.961
Iceland	0.777	0.918	0.869	0.895	0.714
India	1.005	0.98	1.021	0.984	0.985
Indonesia	0.96	0.963	0.969	0.99	0.924
Ireland	1.098	0.922	1.083	1.014	1.013
Israel	0.958	0.923	1	0.958	0.884

Jamaica	0.889	0.948	0.977	0.91	0.843
Japan	0.95	0.917	1	0.95	0.871
Kenya	1.081	0.971	1.281	0.844	1.05
Kuwait	0.727	0.917	0.819	0.887	0.667
Luxembourg	1.026	0.917	0.986	1.041	0.941
Malaysia	0.864	0.945	0.961	0.899	0.817
Malta	1.03	0.924	1	1.03	0.951
Mexico	0.96	0.933	1.016	0.945	0.896
Morocco	0.9	0.945	0.924	0.974	0.85
Mozambique	1.356	0.727	1.353	1.002	0.987
Nepal	1	0.764	1	1	0.764
Netherlands	0.994	0.917	0.996	0.998	0.912
Nicaragua	1.035	0.971	1.143	0.905	1.005
Norway	0.977	0.917	1	0.977	0.897
Pakistan	0.971	0.947	0.974	0.997	0.919
Panama	0.992	0.952	1	0.992	0.944
Paraguay	0.961	0.954	0.971	0.99	0.917
Peru	1	0.968	1	1	0.968
Philippines	1.057	0.983	1.097	0.963	1.038
Portugal	0.901	0.92	0.972	0.927	0.829
Qatar	1.058	0.917	1	1.058	0.97
Senegal	1.049	0.938	1.042	1.007	0.984
South Africa	0.914	0.943	0.944	0.968	0.862
Spain	0.934	0.918	0.993	0.941	0.858
Sri Lanka	0.974	0.981	1	0.974	0.956
Sudan	1.271	0.814	1.219	1.043	1.035
Sweden	1.045	0.919	1	1.045	0.96
Switzerland	0.932	0.917	1	0.932	0.855
Syria	0.918	0.937	0.907	1.012	0.86
Tanzania	1.089	0.714	1.167	0.934	0.778
Thailand	0.858	0.945	0.938	0.915	0.811
Togo	1.125	0.877	1.224	0.919	0.987
Trinidad and Tobago	0.816	0.931	0.877	0.93	0.76
Tunisia	0.963	0.949	1.002	0.961	0.914
Turkey	0.919	0.942	1.001	0.918	0.865
United Arab Emirates	1.08	0.917	1	1.08	0.991
United Kingdom	1.064	0.917	1.135	0.937	0.976
United States of America	1.02	0.917	0.883	1.156	0.936
Uruguay	0.874	0.947	1	0.874	0.827

Viet Nam	0.97	0.986	1.051	0.923	0.956
Zambia	1.232	0.88	1.333	0.924	1.085
Zimbabwe	1.129	0.991	1.108	1.018	1.118

Figure 12. Malmquist Index Distances Summary for VRS TE

	1990	1995	2000	2008	Average
Mean	0.757	0.763	0.768	0.786	0.7685
Australia	1	1	1	1	1
Bangladesh	1	1	1	1	1
Costa Rica	1	1	1	1	1
Israel	1	1	1	1	1
Japan	1	1	1	1	1
Malta	1	1	1	1	1
Norway	1	1	1	1	1
Peru	1	1	1	1	1
Sri Lanka	1	1	1	1	1
Sweden	1	1	1	1	1
Switzerland	1	1	1	1	1
Uruguay	1	1	1	1	1
Cyprus	1	1	1	0.968	0.992
Spain	1	1	0.985	0.978	0.99075
Luxembourg	1	1	1	0.959	0.98975
Panama	1	0.978	0.968	1	0.9865
Cuba	0.93	1	1	1	0.9825
Bolivia	1	1	1	0.919	0.97975
Greece	1	1	0.94	0.964	0.976
Nepal	1	0.893	0.917	1	0.9525
Denmark	0.883	0.91	1	1	0.94825
Egypt	0.863	0.925	1	1	0.947
Morocco	1	0.957	1	0.788	0.93625
Ireland	0.788	0.952	1	1	0.935
Netherlands	0.866	0.968	0.914	0.856	0.901
Ecuador	0.879	0.828	0.871	0.953	0.88275
Colombia	0.82	0.8	0.916	0.922	0.8645
Qatar	1	0.454	1	1	0.8635
Chile	1	0.828	0.779	0.807	0.8535
Portugal	0.926	0.882	0.746	0.85	0.851
Austria	0.845	0.839	0.803	0.887	0.8435
United States of America	1	1	0.661	0.688	0.83725
Haiti	0.874	0.878	0.834	0.763	0.83725

Argentina	0.821	0.911	0.875	0.684	0.82275
Zambia	0.422	0.837	1	1	0.81475
Hungary	0.502	0.851	0.922	0.969	0.811
Philippines	0.757	0.654	0.829	1	0.81
Germany	0.633	0.791	0.813	0.982	0.80475
Tanzania	0.63	0.573	1	1	0.80075
Senegal	0.767	0.798	0.726	0.869	0.79
United Kingdom	0.683	0.747	0.712	1	0.7855
Botswana	0.757	0.749	0.761	0.854	0.78025
El Salvador	0.856	0.785	0.808	0.65	0.77475
Turkey	0.806	0.743	0.728	0.808	0.77125
Canada	1	1	0.5	0.512	0.753
Guatemala	0.755	0.749	0.772	0.727	0.75075
United Arab Emirates	1	0.559	0.437	1	0.749
Kuwait	1	1	0.418	0.55	0.742
Bulgaria	0.574	0.702	1	0.67	0.7365
Mozambique	0.404	0.533	1	1	0.73425
Tunisia	0.728	0.708	0.758	0.732	0.7315
Benin	0.874	1	0.556	0.494	0.731
France	0.665	0.723	0.758	0.773	0.72975
Algeria	0.735	0.741	0.747	0.592	0.70375
Dominican Republic	0.847	0.614	0.624	0.706	0.69775
Brazil	0.749	0.72	0.666	0.636	0.69275
Mexico	0.666	0.651	0.725	0.699	0.68525
Cameroon	0.577	0.511	0.595	1	0.67075
Ghana	0.586	0.572	0.636	0.875	0.66725
Belgium	0.607	0.742	0.689	0.613	0.66275
Thailand	0.752	0.581	0.662	0.621	0.654
Kenya	0.463	0.482	0.646	0.973	0.641
Honduras	0.61	0.587	0.764	0.565	0.6315
Nicaragua	0.477	0.543	0.689	0.712	0.60525
Togo	0.45	0.526	0.572	0.824	0.593
Paraguay	0.621	0.54	0.621	0.568	0.5875
Syria	0.62	0.601	0.607	0.462	0.5725
Viet Nam	0.517	0.492	0.537	0.601	0.53675
Pakistan	0.551	0.565	0.497	0.509	0.5305
Iceland	0.396	1	0.328	0.26	0.496
Malaysia	0.546	0.466	0.452	0.485	0.48725
Jamaica	0.51	0.492	0.453	0.476	0.48275
Finland	0.462	0.523	0.424	0.506	0.47875

India	0.471	0.455	0.457	0.5	0.47075
Sudan	0.345	0.405	0.505	0.626	0.47025
Indonesia	0.463	0.433	0.419	0.422	0.43425
China	0.394	0.346	0.532	0.299	0.39275
Zimbabwe	0.314	0.348	0.442	0.428	0.383
South Africa	0.287	0.434	0.274	0.241	0.309
Trinidad and Tobago	0.201	0.202	0.139	0.135	0.16925

Figure 13. Malmquist Index Summaries for Total Factor Productivity Change

	1990-1995	1995-2000	2000-2008	1990-2008
Mean	0.927	0.832	0.973	0.909
Algeria	0.854	0.842	0.87	0.855
Argentina	1.056	0.761	0.983	0.925
Australia	0.921	0.809	0.951	0.892
Austria	0.891	0.819	0.903	0.87
Bangladesh	0.883	0.995	0.726	0.861
Belgium	0.866	0.807	1.007	0.889
Benin	1.367	0.348	0.677	0.685
Bolivia	0.803	1.041	0.785	0.869
Botswana	0.929	0.842	1.112	0.955
Brazil	0.91	0.717	0.9	0.837
Bulgaria	1.037	1.015	1.205	1.083
Cameroon	0.903	0.959	1.164	1.003
Canada	0.862	0.859	1.018	0.91
Chile	1.025	0.681	1.003	0.888
China	1.044	1.13	0.813	0.986
Colombia	0.955	0.884	1.05	0.96
Costa Rica	1.01	0.738	0.827	0.851
Cuba	1.28	0.942	1.693	1.268
Cyprus	0.816	0.739	0.968	0.836
Denmark	0.892	0.898	0.987	0.925
Dominican Republic	0.798	0.818	1.216	0.926
Ecuador	0.934	0.763	1.029	0.902
Egypt	1.006	0.826	0.809	0.876
El Salvador	0.894	0.791	0.853	0.845
Finland	0.831	0.883	1.039	0.914
France	0.875	0.829	0.947	0.882
Germany	0.996	0.834	1.012	0.944
Ghana	0.982	0.984	1.207	1.053

Greece	0.887	0.736	1.039	0.878
Guatemala	0.95	0.763	1.068	0.918
Haiti	0.89	0.755	0.737	0.791
Honduras	0.943	1.003	0.848	0.929
Hungary	0.876	0.966	1.049	0.961
Iceland	0.826	0.699	0.629	0.714
India	0.968	0.964	1.022	0.985
Indonesia	0.939	0.801	1.05	0.924
Ireland	1.016	0.892	1.148	1.013
Israel	0.822	0.835	1.006	0.884
Jamaica	0.971	0.672	0.917	0.843
Japan	0.83	0.763	1.044	0.871
Kenya	1.029	1.003	1.12	1.05
Kuwait	0.569	0.554	0.94	0.667
Luxembourg	1.12	0.92	0.809	0.941
Malaysia	0.816	0.735	0.909	0.817
Malta	1.054	0.971	0.841	0.951
Mexico	0.886	0.918	0.884	0.896
Morocco	0.849	0.856	0.846	0.85
Mozambique	1.255	0.998	0.766	0.987
Nepal	0.622	0.669	1.07	0.764
Netherlands	0.929	0.898	0.908	0.912
Nicaragua	0.966	0.978	1.076	1.005
Norway	0.957	0.82	0.918	0.897
Pakistan	0.942	0.858	0.961	0.919
Panama	0.874	0.736	1.307	0.944
Paraguay	0.853	0.87	1.039	0.917
Peru	1.016	0.852	1.047	0.968
Philippines	0.949	0.902	1.307	1.038
Portugal	0.798	0.747	0.956	0.829
Qatar	0.726	0.937	1.343	0.97
Senegal	1.042	0.823	1.11	0.984
South Africa	0.818	0.835	0.937	0.862
Spain	0.847	0.765	0.975	0.858
Sri Lanka	1.033	0.741	1.141	0.956
Sudan	1.191	0.99	0.939	1.035
Sweden	0.841	0.968	1.088	0.96
Switzerland	0.889	0.841	0.838	0.855
Syria	1.127	0.702	0.804	0.86
Tanzania	0.869	1.031	0.525	0.778
Thailand	0.86	0.755	0.822	0.811

Togo	1.009	0.866	1.1	0.987
Trinidad and Tobago	0.912	0.567	0.848	0.76
Tunisia	0.939	0.831	0.98	0.914
Turkey	0.882	0.754	0.975	0.865
United Arab Emirates	0.817	0.789	1.507	0.991
United Kingdom	0.912	0.876	1.165	0.976
United States of America	0.921	0.869	1.024	0.936
Uruguay	0.957	0.744	0.796	0.827
Viet Nam	1.01	0.954	0.908	0.956
Zambia	1.087	1.045	1.123	1.085
Zimbabwe	1.132	1.082	1.141	1.118

4.2 Country Comparisons

4.2.1 USA vs. Norway

The USA received a TE score of 0.636 in the DEA stage, with Norway as its highest weighted peer. Country profiles for the USA and Norway are show in figures 14 and 15 while Figures 16-21 illustrate various comparisons between the two countries. The reason the USA came out so inefficient is largely because it consumed about 1.4 times more energy per capita in 2000 than Norway did while releasing about 2.7 times as much CO2 per capita. Norway also had slightly higher levels of health, education, income and access to essentials than the USA, so there is clearly room for improvement in those areas as well; however the USA seems to be most inefficient in terms of sustainable development. To understand why this is the case it is necessary to examine both of these countries in detail with particular focus given to their respective energy and environmental policies.

Figure 14. USA Profile

United States (2000)	
Population, total	282,162,411.00
GDP (constant 2000 US$)	9,898,800,000,000.00
Land area (sq. km)	9,161,920.00
Consumption of commercial energy in kg of oil equivalent per capita	8,056.50

Figure 15.Norway Profile

Norway (2000)	
Population, total	4,490,967.00
GDP (constant 2000 US$)	168,288,531,891.20
Land area (sq. km)	304,280.00
Consumption of commercial energy in kg of oil equivalent per capita	5,759.50

For starters the USA and Norway have a lot in common, not only do they both produce around the same amount of GDP but they also have a similar percent of GDP due to agriculture, CO2 emissions due to gaseous fuel consumption, percent of land considered forest area and percent of population considered urban. However by looking at Figure 16 it becomes fairly obvious that there are stark differences in the two countries' approaches to energy policies. The most notable difference is probably Norway's commitment to renewable energy sources, particularly hydroelectric. Norway receives ~4.34 times as much of the energy it consumes from renewable sources than the USA, and produces nearly 16% more power from hydroelectric sources. The USA's use of coal may present the most glaring difference between the two nations, since the USA producing ~1047 times as much of its energy from coal sources as Norway.

Although the USA does seem to do better on some measures, it does not appear to be enough to offset the gap between the two countries' consumption habits. Interestingly, Norway gets close to double as much of its GDP from industry as the USA does, and industry tends to be very dirty work. Meanwhile the USA also relies much more heavily on the services sector of its economy than Norway, a fact that clearly has not alleviated its pollution problems.

Figure 16 also illustrates the drastic difference between the USA's and Norway's approach to fuel pricing. It shows that the pump price in 2010 for gasoline in the US was just ~36% that of Norway's while the price for diesel was ~42% that of Norway's. Prices are so low in the USA compared to Norway largely because they vary greatly in their taxation policies. Total state and federal fuel taxes in the USA as of January 2013 are 48.8 cents per gallon of gasoline (12.9 ¢/L) and 54.4 cents per gallon of diesel (14.4 ¢/L)(

"Improving the Fuel Economy of Road Vehicles" 2012). Norway on the other hand chooses to heavily tax its oil consumption, for instance in 2007 taxes accounted for 63% of the fuel price at gas stations due to a $1.42 USD per liter tax on RON petrol ("The European Union Automotive Fuel Economy Policy"). This difference in their approach to pricing is most likely a key reason that Norway's fossil fuel consumption is ~58% less than that of the USA.

The difference between Norway and the USA can be summed up as this; Norway is a well-developed country that has embraced the concept of sustainable development while the USA is a similarly well-developed country that has viewed sustainability as more of an afterthought of growth. The USA can look to emulate Norway's success in sustainable development by first improving its energy production processes, specifically by using less coal and more renewable resources. Policymakers could also achieve significant efficiency gains by improving residential and commercial energy standards, codes and habits ("Progress Implementing the IEA25 Energy Efficiency Policy Recommendations" 2011, "Analyzing Our Energy Future, Some Pointers For Policymakers" 2007). Higher fuel economy standards as well as higher taxes on petroleum products would also help the USA become more energy efficient. While the USA has made recent strides in the right direction, particularly reducing the share of electricity produced from coal in favor of natural gas, there are still many areas it can and should improve on to become more energy efficient and ensure its development is as sustainable as possible ("An International Comparison of Energy and Climate Change Policies Impacting Energy Intensive Industries in Selected Countries" 2012, World Bank Database).

Figure 16. USA vs. Norway Energy Data

Indicator Name	USA	Norway
Alternative and nuclear energy (% of total energy use)	10.8	46.8
CO2 emissions from gaseous fuel consumption (% of total)	22.3	22.0
CO2 emissions from gaseous fuel consumption (kt)	1274964.6	8547.8
CO2 emissions from liquid fuel consumption (% of total)	40.6	61.5
CO2 emissions from liquid fuel consumption (kt)	2317907.0	23861.2
CO2 emissions from solid fuel consumption (% of total)	36.2	10.5
CO2 emissions from solid fuel consumption (kt)	2070963.9	4074.0
CO2 emissions from electricity and heat production, total (% of total fuel combustion)	47.1	30.6
CO2 emissions from electricity and heat production, total (million metric tons)	2685.3	10.3
CO2 emissions from manufacturing industries and construction (% of total fuel combustion)	11.7	24.0
CO2 emissions from manufacturing industries and construction (million metric tons)	665.5	8.1
CO2 emissions from other sectors, excluding residential buildings and commercial and public services (% of total fuel combustion)	0.8	5.4
CO2 emissions from other sectors, excluding residential buildings and commercial and public services (million metric tons)	44.2	1.8
CO2 emissions from residential buildings and commercial and public services (% of total fuel combustion)	10.4	4.4
CO2 emissions from residential buildings and commercial and public services (million metric tons)	595.1	1.5
CO2 emissions from transport (% of total fuel combustion)	30.0	35.6
CO2 emissions from transport (million metric tons)	1708.1	11.9
Electricity production from coal sources (% of total)	52.9	0.1
Electricity production from hydroelectric sources (% of total)	6.3	99.5
Electricity production from natural gas sources (% of total)	15.8	0.1
Electricity production from nuclear sources (% of total)	19.8	0.0
Electricity production from oil sources (% of total)	2.9	0.0
Electricity production from oil, gas and coal sources (% of total)	71.6	0.2

Electricity production from renewable sources, excluding hydroelectric (% of total)	1.9	0.2
Fossil fuel energy consumption (% of total)	85.9	54.2
Forest area (% of land area)	32.8	30.6
Urban population (% of total)	79.1	76.1
Agriculture, value added (% of GDP)	1.2	2.1
Industry, value added (% of GDP)	23.4	42.0
Manufacturing, value added (% of GDP)	15.9	10.6
Services, etc., value added (% of GDP)	75.4	56.0
Pump price for gasoline (US$ per liter, data for 2010)	0.8	2.1
Pump price for diesel fuel (US$ per liter, data for 2010)	0.8	2.0

Figure 17. USA vs. Norway Health over Time

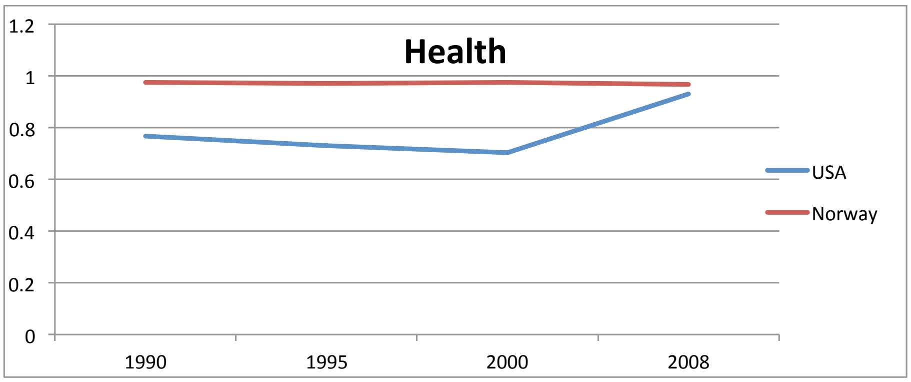


Figure 18. USA vs. Norway Education over Time

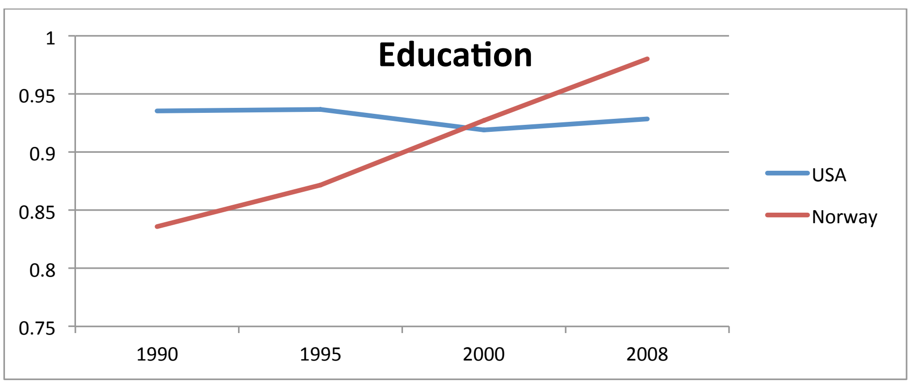


Figure 19. USA vs. Norway Income over Time

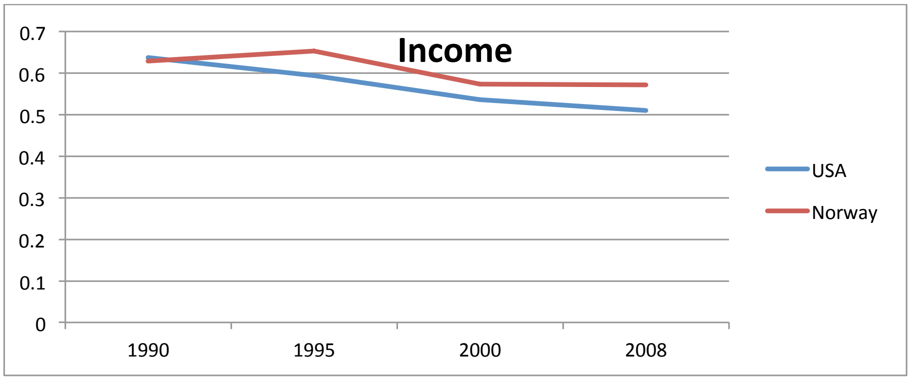


Figure 20. USA vs. Norway Environment over Time

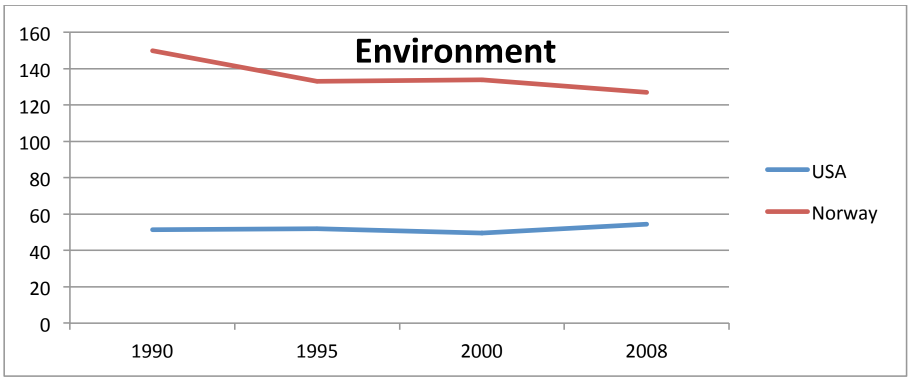
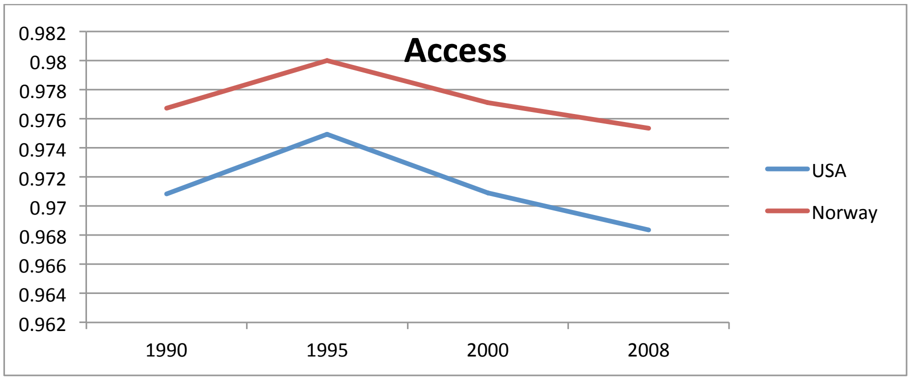


Figure 21. USA vs. Norway Access to Essentials over Time



4.2.2 Egypt vs. Albania

Albania appears more efficient than Egypt in DEA test done with 2000 data, largely because Egypt received an education index score that was 70% less than Albania's, but its health and income levels were significantly lower as well. Country profiles for the Egypt and Albania are show in figures 22 and 23 while Figures 24-31 illustrate various comparisons between the two countries. A closer look at data on the two countries reveals that Albania ranks higher particularly in measures of early education. Figure 24 illustrates that Albania has substantially more children enrolled in its preprimary and primary schools, while Egypt leads in its secondary and tertiary enrollment. Albania's adult literacy rate in 2001 was almost 99%, in 2005 Egypt's was barely above 71%. Albania also has a better teacher to student ratio than Egypt, all this despite the fact that Egypt actually spends a higher percentage of its GDP on education than Albania. Egypt has made progress, within the last ten years it has increased its primary enrolment rate to almost 95%, however its adult literacy rate has stayed mostly the same. Issues in education still remain especially when it comes to access for women and poor and rural families ("Education"). Egypt should focus on improving its early education programs both in terms of enrollment and quality.

Figure 22. Egypt Profile

Egypt (2000)	
Population, total	67,648,419.00
GDP (constant 2000 US$)	99,838,540,997.32
Land area (sq. km)	995,450.00
Consumption of commercial energy in kg of oil equivalent per capita	667.80

Figure 23. Albania Profile

Albania (2000)	
Population, total	3,071,856.00
GDP (constant 2000 US$)	3,686,649,387.03
Land area (sq. km)	27,400.00
Consumption of commercial energy in kg of oil equivalent per capita	575.00

In terms of health, Figure 25 demonstrates that Albania consistently ranks higher than Egypt. The two countries have similar levels of immunizations for most diseases, and Egypt actually has more physicians per 1000 people, however Albania spends a little more of its GDP on healthcare and has significantly higher survival rates. The area where Egypt seems to need the most improvement is infant care, when compared to Albania, Egypt's level of prenatal care, infant mortality and maternal deaths are far too high. This could be due to the fact that in Albania a full 63% more births are attended by skilled health staff than in Egypt and it could also be related to the fact that Egypt's adolescent fertility rate is 3.6 times that of Albania's. As far as income in the two countries is concerned, Figure 26 indicates that much of the reason Albania has a slightly higher income per capita than Egypt is because Albania has significantly higher prices. The last difference worth noting is that although Egypt and Albania consume close to the same amounts of energy per capita, Egypt emits a little over 1.5 times as much carbon dioxide per capita as Albania. This can mostly be explained by Figure 27, which shows that Egypt uses oil and gas to produce most of its electricity, while Albania uses almost entirely hydroelectric sources.

Figure 24. Egypt vs. Albania Education Data

Indicator Name	Egypt	Albania
Adjusted net enrollment rate, primary (% of primary school age children)	93	99
Children out of school, primary	605,868	2,119
Literacy rate, adult female (% of females ages 15 and above, Egypt data for 2001, Albania data for 2005)	98	59
Literacy rate, adult male (% of males ages 15 and above, Egypt data for 2001, Albania data for 2005)	99	83
Literacy rate, adult total (% of people ages 15 and above, Egypt data for 2001, Albania data for 2005)	99	71
Literacy rate, youth female (% of females ages 15-24, Egypt data for 2001, Albania data for 2005)	99	79
Literacy rate, youth male (% of males ages 15-24, Egypt data for 2001, Albania data for 2005)	99	90
Literacy rate, youth total (% of people ages 15-24, Egypt data for 2001, Albania data for 2005)	99	85
Primary completion rate, total (% of relevant age group)	94	102
Primary education, duration (years)	5	4
School enrollment, preprimary (% gross)	11	44
School enrollment, primary (% net)	90	99
School enrollment, secondary (% net, data for 2001)	77	69
School enrollment, tertiary (% gross, data for 2003)	28	16
Scientific and technical journal articles	1,433	7
Secondary education, duration (years)	6	8

Figure 25. Egypt vs Albania Health Data

Indicator Name	Egypt	Albania
Adolescent fertility rate (births per 1,000 women ages 15-19)	55	15
ARI treatment (% of children under 5 taken to a health provider)	66	83
Births attended by skilled health staff (% of total)	61	99
Health expenditure per capita (current US$)	76	75
Health expenditure, private (% of GDP)	3.2	4.1
Health expenditure, public (% of GDP)	2.2	2.3
Health expenditure, total (% of GDP)	5.4	6.4
Immunization, DPT (% of children ages 12-23 months)	98	97
Immunization, measles (% of children ages 12-23 months)	98	95
Incidence of tuberculosis (per 100,000 people)	26	23
Number of infant deaths	64,000	1,000
Number of maternal deaths	1,800	21

Number of neonatal deaths	23,000	1,000
Number of under-five deaths	79,000	2,000
Physicians (per 1,000 people)	2.1	1.4
Pregnant women receiving prenatal care (%)	53	95
Survival to age 65, female (% of cohort)	76	88
Survival to age 65, male (% of cohort)	68	78

Figure 26. Egypt vs. Albania Income Data

Indicator Name	Egypt	Albania
Adjusted net national income (annual % growth)	3.2	9.8
Consumer price index (2005 = 100)	78	86
GINI index, data for 2005	32	33
GNI growth (annual %)	5.2	8.5
Wholesale price index (2005 = 100)	66	80

Figure 27. Egypt vs. Albania Energy Data

Indicator Name	Egypt	Albania
Alternative and nuclear energy (% of total energy use)	2.9	22.3
CO2 emissions from electricity and heat production, total (% of total fuel combustion)	33.7	10.3
CO2 emissions from electricity and heat production, total (million metric tons)	34.1	0.3
CO2 emissions from gaseous fuel consumption (% of total)	28.8	0.7
CO2 emissions from gaseous fuel consumption (kt)	40751.4	22.0
CO2 emissions from liquid fuel consumption (% of total)	60.4	94.2
CO2 emissions from liquid fuel consumption (kt)	85389.8	2845.6
CO2 emissions from manufacturing industries and construction (% of total fuel combustion)	27.6	17.0
CO2 emissions from manufacturing industries and construction (million metric tons)	27.9	0.5
CO2 emissions from other sectors, excluding residential buildings and commercial and public services (% of total fuel combustion)	0.2	17.3
CO2 emissions from other sectors, excluding residential buildings and commercial and public services (million metric tons)	0.2	0.5
CO2 emissions from residential buildings and commercial and public services (% of total fuel combustion)	10.5	8.3
CO2 emissions from residential buildings and commercial and public services (million metric tons)	10.7	0.3
CO2 emissions from solid fuel consumption (% of total)	2.2	2.3
CO2 emissions from solid fuel consumption (kt)	3146.3	69.7
CO2 emissions from transport (% of total fuel combustion)	28.0	47.4

CO2 emissions from transport (million metric tons)	28.4	1.5
Electricity production from coal sources (% of total)	0.0	0.0
Electricity production from hydroelectric sources (% of total)	17.5	97.0
Electricity production from natural gas sources (% of total)	53.7	0.0
Electricity production from nuclear sources (% of total)	0.0	0.0
Electricity production from oil sources (% of total)	28.6	3.0
Electricity production from oil, gas and coal sources (% of total)	82.3	3.0
Electricity production from renewable sources, excluding hydroelectric (% of total)	0.2	0.0
Fossil fuel energy consumption (% of total)	93.9	58.4
Forest area (% of land area)	0.1	28.1
Urban population (% of total)	42.8	41.7
Agriculture, value added (% of GDP)	16.7	29.1
Industry, value added (% of GDP)	33.1	19.0
Manufacturing, value added (% of GDP)	19.4	11.4
Services, etc., value added (annual % growth)	7.0	7.5
Pump price for diesel fuel (US$ per liter, data for 2010)	0.3	1.4
Pump price for gasoline (US$ per liter, data for 2010)	0.5	1.5

Figure 28. Egypt vs. Albania Health over Time

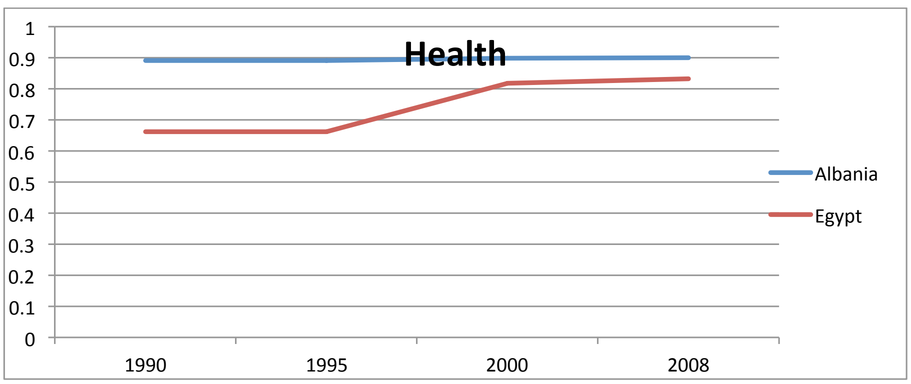


Figure 29. Egypt vs. Albania Education over Time

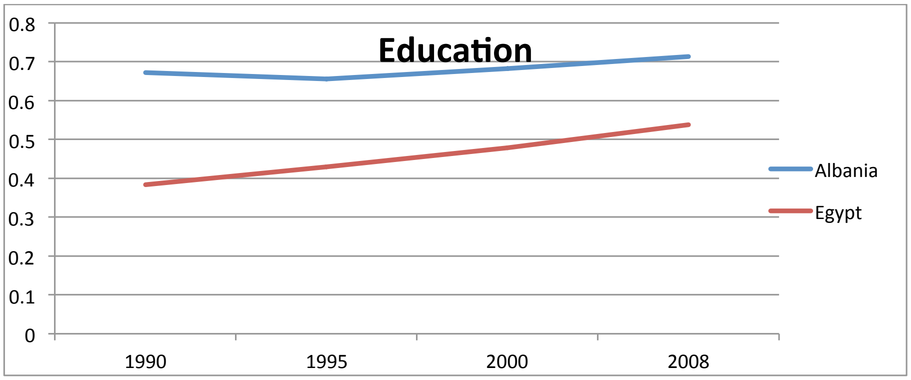


Figure 30. Egypt vs. Albania Income over Time

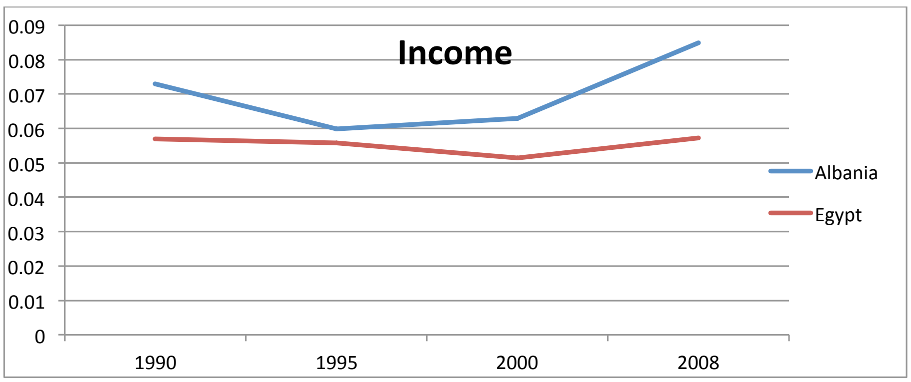


Figure 31. Egypt vs. Albania Environment over Time

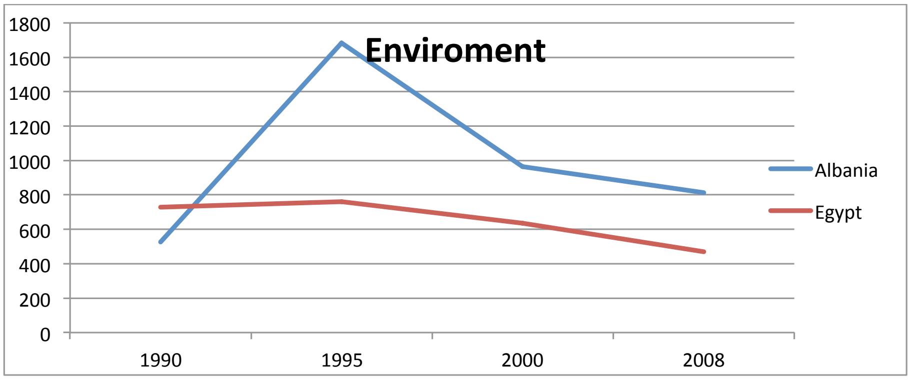
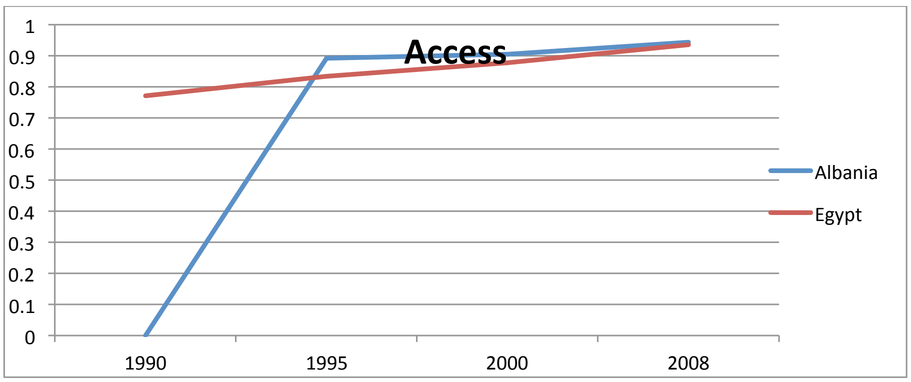


Figure 32. Egypt vs. Albania Access over Time



4.2.3 Malaysia vs. Uruguay

Figure 33. Malaysia Profile

Malaysia (2000)	
Population, total	23,414,909.00
GDP (constant 2000 US$)	93,789,736,842.11
Land area (sq. km)	328,550.00
Consumption of commercial energy in kg of oil equivalent per capita	2,018.80

Figure 34. Uruguay Profile

Uruguay (2000)	
Population, total	3,300,847.41
GDP (constant 2000 US$)	22,823,255,805.97
Land area (sq. km)	175,020.00
Consumption of commercial energy in kg of oil equivalent per capita	936.70

The data from 2000 shows that Malaysia used about 2.2 times as much energy as Uruguay to obtain about 0.58 times as much GDP, and in the process generated nearly 3 times as much CO2. Country profiles for the Malaysia and Uruguay are show in figures 33 and 34 while Figures 35-41 illustrate various comparisons between the two countries. One explanation for why Malaysia uses so much more energy than Uruguay, demonstrated in Figure 35, is because Malaysia relies much more heavily on industry and manufacturing than Uruguay, both of which are typically very energy intensive forms of production. Figure 5 also shows that Malaysia emits more CO2 in nearly every sector of its economy than Uruguay does, largely because Malaysia uses natural gas to produce most of its energy while Uruguay uses predominantly hydropower. It is also worth noting that the pump price of gasoline and diesel in Uruguay is just over 2.5 times that in Malaysia, partly due to the environmental taxes Uruguay has in place.

Malaysia underperformed somewhat significantly in education as well, where it scored around 11% less than Uruguay. Neither of the two countries did particularly well in terms of education when compared to the entire sample of countries, and they actually shared similar results for many of the measures in Figure 36, however Uruguay did rank higher in terms of preprimary and tertiary school enrollment. From the evidence available it seems reasonable to conclude that Malaysia should look to improve its levels of sustainable and educational development by shifting toward more renewable energy sources and by improving enrollment in preprimary and tertiary schools.

Figure 35. Malaysia vs Uruguay Energy Data

Indicator Name	Malaysia	Uruguay
Alternative and nuclear energy (% of total energy use)	1.3	19.6
CO2 emissions from electricity and heat production, total (% of total fuel combustion)	42.7	13.7
CO2 emissions from electricity and heat production, total (million metric tons)	48.2	0.7
CO2 emissions from gaseous fuel consumption (% of total)	39.3	1.2
CO2 emissions from gaseous fuel consumption (kt)	49713.5	62.3
CO2 emissions from liquid fuel consumption (% of total)	44.6	92.3
CO2 emissions from liquid fuel consumption (kt)	56508.5	4895.4
CO2 emissions from manufacturing industries and construction (% of total fuel combustion)	26.0	17.3
CO2 emissions from manufacturing industries and construction (million metric tons)	29.4	0.9
CO2 emissions from other sectors, excluding residential buildings and commercial and public services (% of total fuel combustion)	0.3	10.6
CO2 emissions from other sectors, excluding residential buildings and commercial and public services (million metric tons)	0.3	0.6
CO2 emissions from residential buildings and commercial and public services (% of total fuel combustion)	3.5	12.7

CO2 emissions from residential buildings and commercial and public services (million metric tons)	3.9	0.7
CO2 emissions from solid fuel consumption (% of total)	6.9	0.1
CO2 emissions from solid fuel consumption (kt)	8753.1	3.7
CO2 emissions from transport (% of total fuel combustion)	27.5	45.8
CO2 emissions from transport (million metric tons)	30.9	2.4
Electricity production from coal sources (% of total)	11.1	0.0
Electricity production from hydroelectric sources (% of total)	10.1	92.9
Electricity production from natural gas sources (% of total)	73.6	0.0
Electricity production from nuclear sources (% of total)	0.0	0.0
Electricity production from oil sources (% of total)	5.2	6.6
Electricity production from oil, gas and coal sources (% of total)	89.9	6.6
Electricity production from renewable sources, excluding hydroelectric (% of total)	0.0	0.5
Fossil fuel energy consumption (% of total)	92.6	65.2
Forest area (% of land area)	65.7	8.1
Urban population (% of total)	62.0	91.3
Agriculture, value added (% of GDP)	8.6	7.0
Industry, value added (% of GDP)	48.3	24.5
Manufacturing, value added (% of GDP)	30.9	14.1
Services, etc., value added (% of GDP)	43.1	68.5
Pump price for diesel fuel (US$ per liter, data for 2010)	0.6	1.4
Pump price for gasoline (US$ per liter, data for 2010)	0.6	1.5

Figure 36. Malaysia vs. Uruguay Education Data

Indicator Name	Malaysia	Uruguay
Adjusted net enrollment rate, primary (% of primary school age children, data for 2005)	96	98
School enrollment, preprimary (% gross)	51	64
School enrollment, primary (% net, data for 2005)	96	97
School enrollment, secondary (% net, data for 2006)	70	66
School enrollment, tertiary (% gross)	26	34
Children out of school, primary (data for 2005)	136646	7755
Literacy rate, adult female (% of females ages 15 and above, data for 2010)	91	98
Literacy rate, adult male (% of males ages 15 and above, data for 2010)	95	98
Literacy rate, adult total (% of people ages 15 and above, data for 2010)	93	98
Literacy rate, youth female (% of females ages 15-24, data for 2010)	98	99

Literacy rate, youth male (% of males ages 15-24, data for 2010)	98	98
Literacy rate, youth total (% of people ages 15-24, data for 2010)	98	99
Primary completion rate, total (% of relevant age group, data for 2005)	99	96
Primary education, duration (years)	6	6
Secondary education, duration (years)	7	6
Scientific and technical journal articles	460	156

Figure 37. Malaysia vs. Uruguay Health over Time

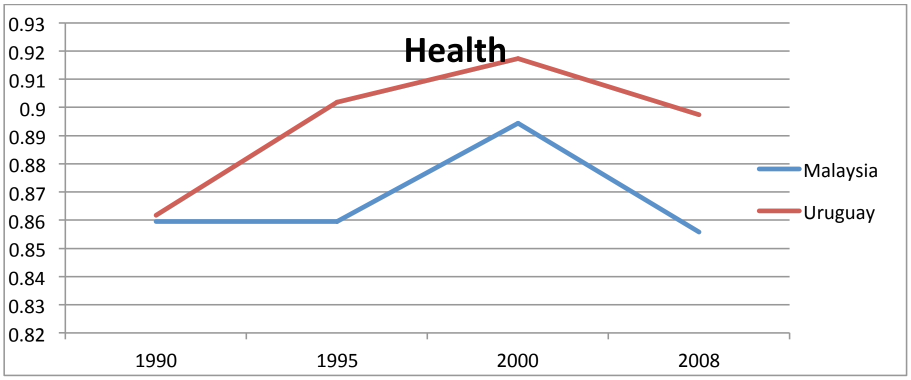


Figure 38. Malaysia vs. Uruguay Education over Time

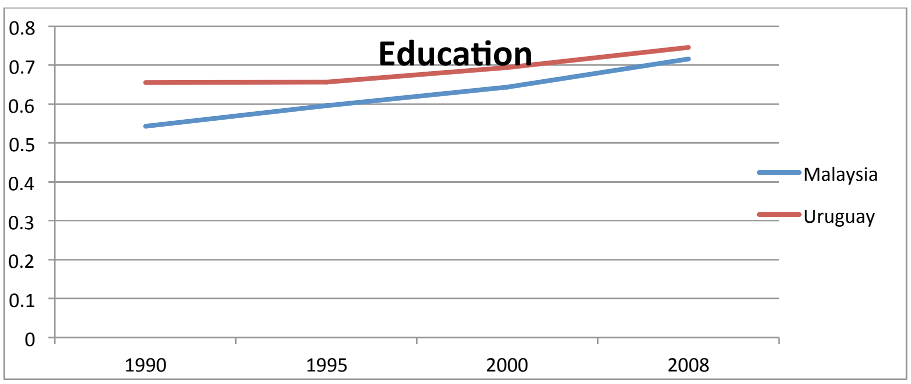


Figure 39. Malaysia vs. Uruguay Income over Time

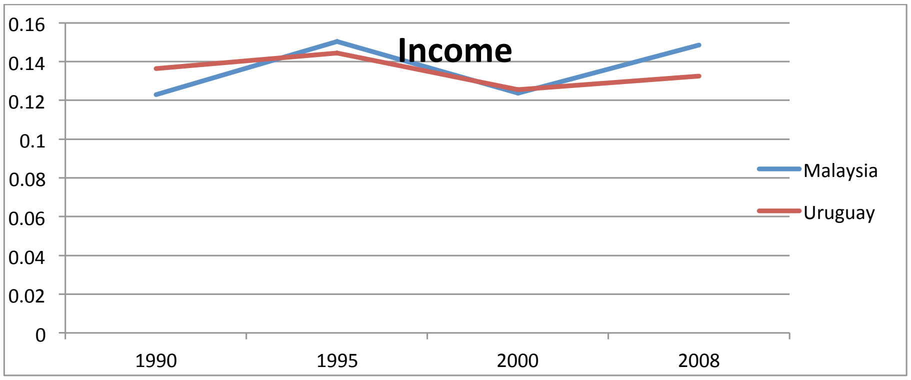


Figure 40. Malaysia vs. Uruguay Environment over Time

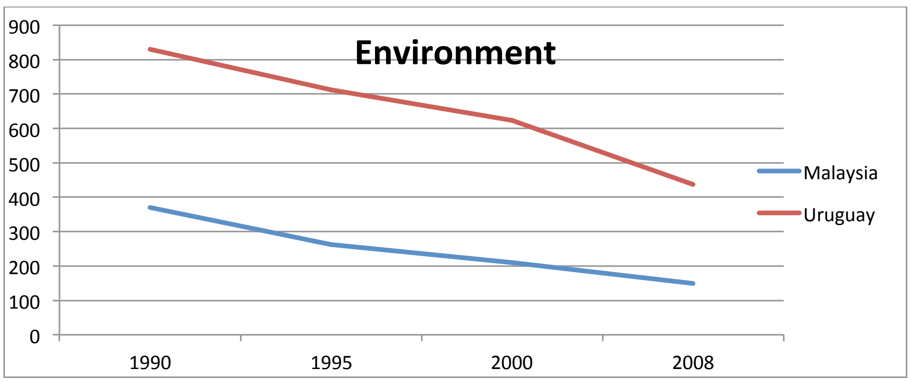
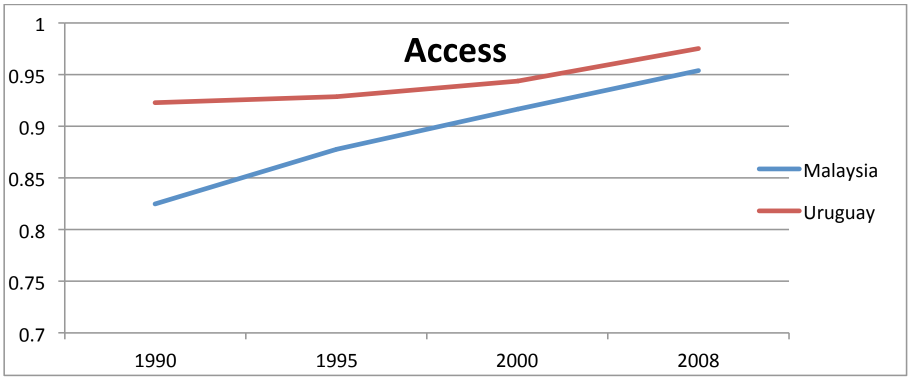


Figure 41. Malaysia vs. Uruguay Access over Time



Chapter 5: Conclusion

5.1 Concluding Remarks

This study helps to fill the gap between research on energy efficiency in terms of GDP and research on eco-efficiency in terms of environmental pollution. It evaluates the energy efficiencies of individual countries using a DEA approach with energy consumption as the sole input and health, education, income, access to essentials and pollution as the outputs. This paper then analyzes pairs of countries to determine what inefficient countries can learn from their efficient peers. This method produces fairly actionable policy recommendations for the countries studied in depth, as well as useful information on those only covered in the DEA.

5.2 Interpretation of findings

Many of the most efficient countries in this paper also scored highly in some of the studies discussed in the literature review chapter, including Switzerland, Sweden, Norway, Denmark, Latvia, Tanzania, Ireland, and Japan. Among the least efficient countries South Africa was the only one to score similarly in the surveyed literature, while Luxembourg and Malta were efficient in this model despite appearing inefficient in terms of renewable energy development. Figures 15-19 illustrate the basic relationship between energy consumption and each of the study's output variables, particularly that there is much variation in output achieved on the low end of energy consumption and those countries that use more energy do tend to have higher levels of development, however the gains from higher energy use tend to level off after a certain point.

This paper demonstrates how countries are able to gain insights into how they can and should improve by comparing themselves to similar counties that are using their energy more efficiently. For instance when the USA is compared to Norway it becomes apparent that although the two countries have relatively high standards of living, the USA is much further behind in terms of sustainable development. Therefore the USA could improve its energy efficiency by emulating many of Norway's energy policies. Comparing Egypt to Albania shows that Egypt should focus on improving its early education system, healthcare leading up to, during and after births as well as changing to more renewable energy sources. The comparison of Malaysia to Uruguay concludes that Malaysia should also invest in more renewable energy sources in addition to improving enrollment in its preprimary and tertiary schools.

5.3 Further Research

This paper is a starting point in the effort to bring together research on different forms of energy efficiency and development. Further research could use other forms of analysis such as factor decomposition or regression to investigate these issues more thoroughly. More research should also be done with DEA using different or more data, and incorporating aspects that this study was unable to include such as income inequality, political system, various other variables that may affect development in addition to other measures of sustainable development and pollution. Even extremely similar DEA analyses can offer new insights by selecting different sets of countries for in-depth comparisons than this paper did. Since this paper was not able to analyze data from more recent years than 2008, it would also be worthwhile for further research to take these years into account, particularly because that is when the global recession began, and it would be interesting to see how that has affected global energy efficiency efforts.

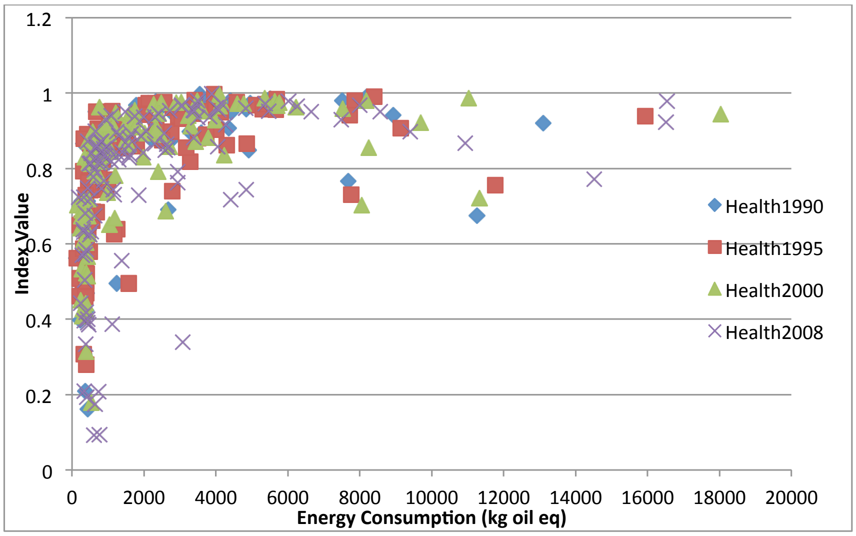
Appendix

Appendix 1. Descriptive Statistics (2000 data)

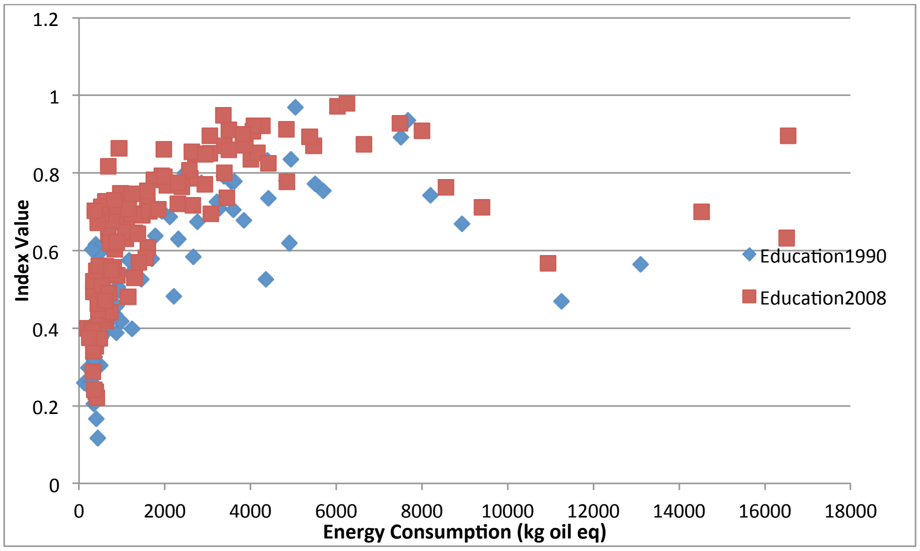
Variable	Energy	Pollution	EPI (Environmental Performance Index)	HDI (Human Development Index)
Made up of			provided seperately	provided seperately
Units	consumption of commercial energy in kg of oil equivalent per capita	metric tons of CO2 emissions per capita	index points	index points
Source	Europa World Comparative Statistics	EPI database	EPI database	HDI database
Mean	2360.62	5371.28	50.12	0.62
Std Dev	2709.29	6158.07	9.30	0.19
Max	18029.40	39145.16	76.17	0.91
Min	143.60	32.95	25.58	0.22
Nobs	170	136	132	194
Variable	GDP	Health	Health	Education
Made up of		Life expectancy at birth	child mortality	Expected Years of Schooling (of children)
Units	per capita in current prices	years	% likely to die before age 5	years
Source	Europa World Comparative Statistics	HDI database	HDI database	HDI database
Mean	7724.68	66.77	0.02	11.11
Std Dev	12262.38	10.12	0.03	3.44
Max	75606.20	81.20	0.11	18.00
Min	86.80	39.80	0.00	2.20
Nobs	203.00	194.00	194.00	194.00
Variable	Education	Income	Acess to Essentials	Acess to Essentials
Made up of	Mean years of schooling (of adults)		Access to drinking water	Access to sanitation

Units	years	GNI per capita in PPP terms (constant 2005 international $)	% of population	% of population
Source	HDI database	HDI database	EPI database	EPI database
Mean	6.93	10325.64	83.25	69.59
Std Dev	2.87	12551.00	19.13	30.85
Max	13.00	74894.00	102.00	102.00
Min	0.90	214.00	21.00	7.00
Nobs	194.00	231.00	232.00	232.00

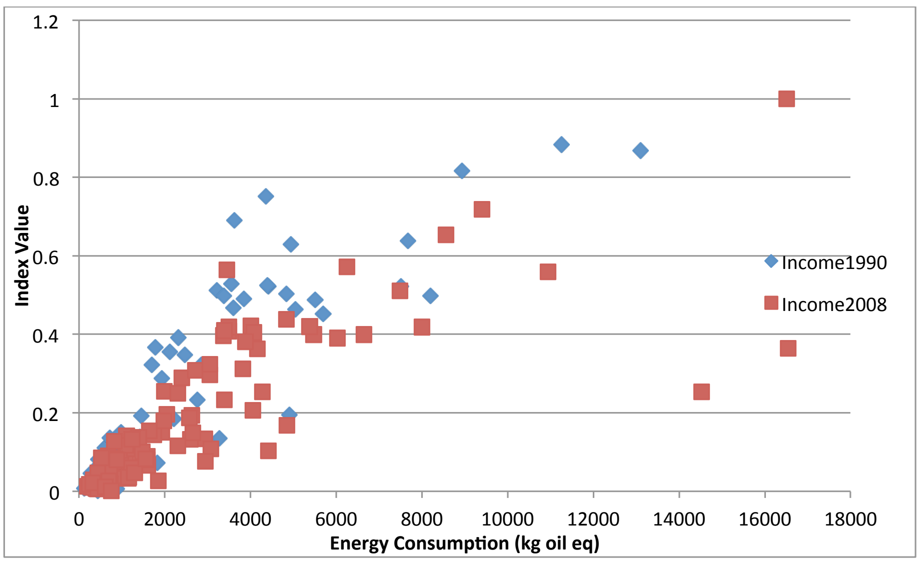
Appendix 2. Health Over Time



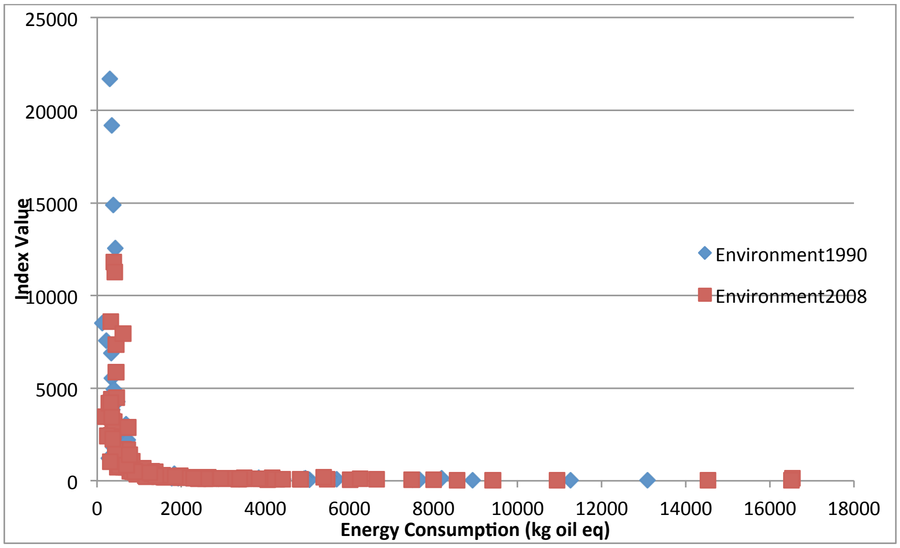
Appendix 3. Education Over Time



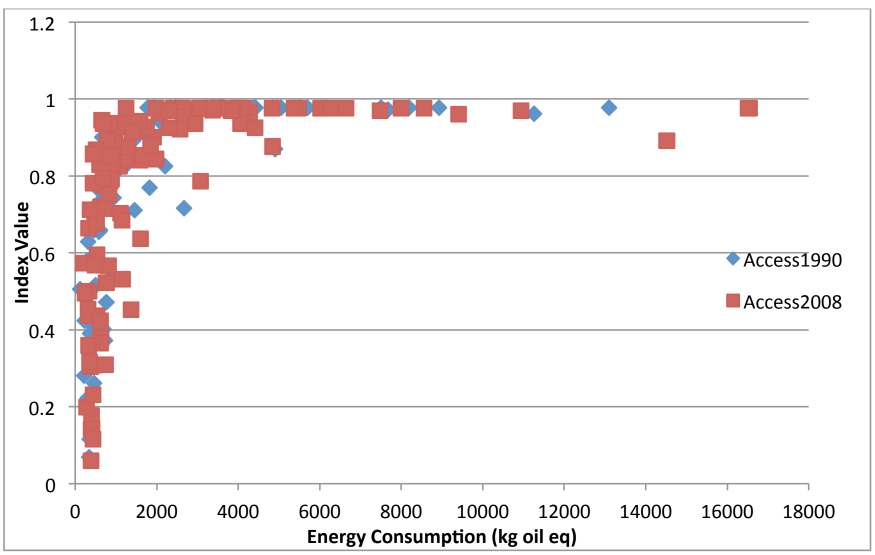
Appendix 4. Income Over Time



Appendix 5. 1/Pollution Over Time



Appendix 6. Access to Essentials Over Time



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