Global Capitalism and the Energy Crisis: Challenges and Opportunities Associated with a Transition to Renewables

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GLOBAL CAPITALISM AND THE ENERGY CRISIS: CHALLENGES AND OPPORTUNITIES ASSOCIATED WITH A TRANSITION TO RENEWABLES

A Thesis

Presented to

the Faculty of Social Sciences

University of Denver

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

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June 2014

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ABSTRACT

Since the Industrial Revolution, fossil fuels have provided a cheap and efficient source of energy. Reliance on fossil fuels, especially oil, supported economic growth under capitalism but also has led to climate change. As peak oil approaches, a transition towards renewable sources of energy is mandatory for ensuring future prospects of development and for reducing the effects of climate change. The transition to renewable energy sources could be made smoother if the subsidies provided to the fossil fuel industry were phased out and governments provided incentives for initial investment, financing for research and development, and direct investment. With reference to renewables, a transition to hydroelectricity, in particular small-scale hydropower plants, could decrease long-term energy costs, aid in providing a secure energy supply and reduce the effects of climate change. Energy and natural resources are a critical component of any economy, and how they are used directly influences economic growth.
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INTRODUCTION

The discovery of fire by our early ancestors marked the beginning of mankind's quest for energy. As a species, we have flourished by using the planet's natural resources as a means of survival. The search for energy sources has been apparent over the course of mankind's existence on this planet. The purpose of this thesis is to provide an in-depth analysis of the association of capitalism and oil in the global economy. In doing so, this paper will investigate the significance of peak oil and its impacts on climate change. This thesis will also discuss possible alternative sources of energy and if they are sustainable in a capital economy or what changes would need to be made to ensure the successful transition to renewable sources of energy. From the use of fire by the earliest human beings, to the significance of coal in the industrial revolution and to the role of oil in our present day capitalist economy, we have gradually become dependent on hydrocarbons for our survival.

Capitalism is the world's dominant economic system. It emerged in Europe during the 16th century (Wallerstein, 1979). Under capitalism, all components of social and economic life are esteemed by their monetary value. There is a strong positive correlation between modern economic growth and capitalism. In the last century, oil has played a crucial role in global economic growth. This is due to the fact that petroleum is used in transportation, agriculture, and the chemical and material industries. Economic growth is
fueled by increasing levels of production, trade and transportation. All three of these contributing factors to growth require oil thus linking increasing economic growth to increasing oil production and consumption (Heinberg, 2011). Heinberg (2011), in “The End of Growth”, shows that there is a close correlation between increasing levels of GDP per capita, increasing population sizes and increasing amounts of fossil fuel consumption. Further, Heinberg (2011) concludes that this pattern has only occurred during capitalism. Energy is not just a commodity; it is a key factor for economic growth.

Fossil fuels encompass different forms of energy, specifically, coal, oil and natural gas. Fossil fuels are responsible for supplying the majority of the global demand for energy. In fact, fossil fuels were the source of 78% of energy production and 82% of energy consumption in the United States in 2012 (U.S Energy Information Administration, 2013). To provide energy, fossil fuels must be burnt, resulting in the formation of CO$_2$ and water. The release of CO$_2$ into the atmosphere is a key factor in climate change. As the production and consumption of fossil fuels increases, so will the impacts of climate change. Fossil fuels are not a renewable source of energy so they are destined to be depleted. The exhaustible nature of fossil fuels possess a crucial question: what is the size of the planet's fossil fuel reserves? It is in the view of many scholars that the answer this question is subject to different answers depending on the estimates of which the main source of energy for the global economy, rates of discovery and consumption of fossil fuels (Olah et al, 2006). With particular reference to oil, this resource is finite and limited in supply, meaning that we will eventually reach a point when the demand of the resource is greater than the supply, making our need for
alternative and renewable sources of energy compelling. It is not only the non-renewable nature of fossil fuels that provides the need to search for alternative energy sources, but also the need for climate stabilization.

The price of oil has been on a steep upward trend since 2000 (Heinberg, 2011). Oil is an exhaustible resource meaning that there is a fixed amount of supply, as oil continues to be consumed; the price will increase due to the decrease in supply. Oil deposits are exhaustible and fixed. Stocks of fossil fuels decrease with consumption coinciding with an increase in price. The increase in the price of oil can be attributed to the dwindling discoveries of “super-giants” deposits coinciding with the discovery of new reserves being more difficult and expensive to develop than previous ones and also to the rise of emerging economies, such as China. The maximum point in oil production can be deemed peak oil. It is uncertain at what date we will reach global peak oil: however, it is definite that a maximum in production is inevitable. If reliance on oil remains persistent, the maximum point in oil production will also be associated with the extraction of non-conventional oil which is not only more expensive, but is also linked with increased levels of pollution. The term non-conventional oil encompasses oil deposits that do not flow through porous rock and are deposits that are rather found in clay. Due to the limited pores in clay, the flow of oil is limited. This means that unconventional methods of extraction must be used to remove the oil. Unconventional methods of extraction produce more pollution than conventional methods of extraction. Peak oil possesses not only economic threats, but it also poses environmental hazards and may accelerate climate change. As we surpass peak oil, increases in unconventional oil produced will greatly
increase the amount of carbon dioxide in the atmosphere. Increasing levels of CO$_2$ have been linked to increases in the earth's temperature, decreases in glaciers and snow cover and increases in the global mean sea level.

As the reserves of oil decrease, there will be continued demands peak level energy. This may result in movement to a substitute form of energy, such as coal. This would be more detrimental to the environment and increase the effects of climate change because coal has a longer carbon dioxide life cycle than that of oil. For this reason, it is crucial that as fossil fuels decreases we respond to energy demands and transition to a source of fuel which will be less damaging to the environment. Peak oil is inevitable; however, the way in which we transition to an alternative energy source is controllable.

It is important to look into alternative forms of energy since fossil fuels are exhaustible. Hydroelectricity is the most widely used form of renewable energy and is responsible for 16% of global electricity generation and is expected to increase 3.1% each year for the next 25 years (World Watch Institute, 2014). Hydroelectricity is produced by the energy of moving water and is most commonly collected through a dam, river or pump storage plant. Hydroelectricity is an alternative form of energy, which has an energy returned on energy invested ratio similar to oil, making it an efficient and cost effective source of energy. However, the transition to hydroelectricity from oil would imply having to alter the natural environment through the construction of dams. Such changes can be drastic; some countries however, such as China have implemented the infrastructure for hydroelectricity. Wind and solar are other forms of renewable energy which can also aid in the transition from fossil fuels to renewables. This thesis will discuss the advantages
and disadvantages associated with all three types of renewable energy sources. As the reserves of fossil fuels diminish, it is critical that we begin to transition towards renewable sources of energy.

This thesis will examine capitalism and its link to the fossil fuel industry, peak oil and climate change; in addition, it will discuss different alternative energy sources and will assess whether they are compatible with a capital based economy. In order to thoroughly investigate the above mentioned three topics, this paper has been divided into five chapters.

Chapter 1 will examine the interplay between capitalism and energy use. It will present a historical perspective on the link between the development of capitalism and the use of fossil fuels, including the role of government policies in subsidizing fossil fuels.

Chapter 2 will discuss peak oil and its implications. This chapter will explain the meaning of the term ‘peak oil’; it will look into alternative estimates and discuss the major economic and environmental implications. As peak oil marks the maximum global production of oil, it is mandatory that we undertake a transition towards renewable sources of energy.

Chapter 3 will discuss alternative sources of energy, with a particular focus on hydroelectricity due to the fact that hydropower has a high energy returned on energy invested, has a great storage capacity to wind and solar and is not subject to the same variables as wind and solar. This chapter will look at different types of hydroelectricity; conventional, pump-storage, run-of-river, tidal and underground. This chapter will also discuss if hydroelectricity is a cost effective energy alternative. Further, this chapter will
present the environmental regulations and policy implications for implementing hydropower. This chapter will also investigate other viable alternative energy sources, such as hydrogen, nuclear, solar, and wind, and will conclude with an evaluation of the effectiveness of hydro with respect to other renewable sources of energy.

Chapter 4 will examine whether an energy transition can be undertaken while capitalism remains the dominant economic system. A dramatic change in a country's energy source may also lead to a change in state of the economy. The transition to a form of reusable and clean energy may not be compatible with the current economic system and may require a shift to alternative economic institutions. This chapter will investigate what other economic systems may be compatible with renewable energy. It will also discuss whether capitalism could be reformed so that it may be made compatible with alternative energy sources.

Chapter 5 will conclude. By transitioning from fossil fuels towards renewable sources of energy, the effects of climate change could be mitigated. In this context, the conclusive chapter will also explore how the US economy may look like with a transition from fossil fuels to renewable energy.
CHAPTER 1: FOSSIL FUELS AND CAPITALISM

1.1 HISTORICAL PERSPECTIVE OF FOSSIL FUEL INDUSTRY

The use of fossil fuels has been pivotal to the growth of the global economy. The use of fossil fuels was first evident in the burning of wood by our early ancestors which eventually lead to the coal fueled industrial revolution and to the current consumption of oil and natural gas. Historically, coal has been an influential fossil fuel due to its importance in fueling the industrial revolution, which led to our current modern industrial society and capitalist economy.

The widespread use of coal for energy began in the sixteenth century. Coal was first utilized in London due to the shortage of wood caused by deforestation. The shortage of wood resulted in rising prices of timber, and caused coal to become the primary source of fuel in England during the seventeenth century. The invention of the steam engine during the eighteenth century continued to fuel the use of coal as the primary source of energy in Europe. The 'coal economy' in England emerged with the production of large scale mechanical factories in urban areas and expanded with the use of the railway as a transportation system. Although the industrial revolution spread across Europe, on the other side of the Atlantic Ocean, the United States was also in the midst of an industrial metamorphosis and economics growth.
Coal is a cheap and versatile form of energy, which is the reason why many industrial economies have historically relied on coal as a primary source of energy. In terms of reserve size, coal can be found in abundance in China, Russia and the United States. It is for this reason that these three nations had the largest industrial economy.

Coal has played a pivotal role in the global economy. In fact, there are six thousand active coal mines to date in the United States (Deffyes, 2005). Like all forms of energy, coal has advantages and disadvantages associated with its consumption and production. Coal is very energy dense and thus has a relatively low unit cost of energy (Deffyes, 2005). Coal also had significant chemical properties, which allowed it to be used in gas street lamps (Heinberg, 2011) and it also burned at higher temperatures, which allowed for the advancement of steel and iron production (Heinberg, 2011). Unfortunately, there are many negative externalities associated with the use of coal, such as, smog, acid rain, high levels of carbon dioxide and mercury poisoning (Deffyes, 2005).

It is in nation's best interest to exploit the natural resource endowments that it has in abundance. For the United States during the early nineteenth century these resources were cheap labor and wood. African slave labor and the burning of wood for energy propelled the economy of the United States during the early stages of its industrial revolution (Heinberg, 2011). By the beginning for the twentieth century, the United States had begun to witness a shortage in cheap and abundant wood resources and consequently shifted its energy dependency to coal. Coal was the first fossil fuel to be consumed and produced on a global scale (Olah, 2006); Heinberg (2011) explains that coal production peaked during the twentieth century with coal accounting for three fourths of the energy
consumption in the US at that point in time (Heingberg, 2011). Undoubtedly, coal played an integral and influential role in the global economy during the nineteenth century and was responsible for vast economic growth and productivity. However, the discovery of oil during the late nineteenth and early twentieth century shifted the source of global energy dependence.

It was not the discovery of oil which was the pivotal turning point for global energy consumption, but rather, the discovery of super-giant oil fields during the late nineteenth and early twentieth century. Oil had been used since 670 AD, specifically in warfare by Emperor Constantine IV and continued to be used for machinery lubrication. It was not until Edwin L. Drake dug the first commercial oil well in 1859 and unknowingly changed the future of energy dependence (Heinberg, 2011). The drilling of the first oil well allowed for petroleum to become more available as an inexpensive machinery lubricant and source of fuel for lamps. It was not until the early 1900s that petroleum was produced and consumed for the source of fuel (Heinberg, 2011). During this time, the primary demand for oil as a fuel was to power the combustion engine as well as oil boilers in ships, factories and trains (Heinberg, 2011). At this point in world history, petroleum was already being viewed as a superior and less expensive energy source than coal.

The increased production and consumption of oil marked the advent of electricity and the discovery of natural gas. The industrialized countries of the world began to incorporate the use of electricity into different facets of the economy. This electrical revolution marked the specific turning point; countries around the world had indeed
shifted their fossil fuel dependency from coal to petroleum. During this time period, the petroleum industry experienced vast changes in company ownership and new discoveries which shaped the future of oil. Oil was now being discovered in Texas, California and Oklahoma which coinciding with the turmoil in Russia made the United States the largest oil producing and exporting nation in the world during the first half of the twentieth century (Heinberg, 2011). During this time period, the major forces in the petroleum industry were: Exxon, Chervron, Mobil, Gulf, Texaco, BP, and Shell. These petroleum companies were deemed the “seven sisters” and represented a global monopoly since combined they “owned four-fifths of the known reserves outside of the US and USSR and controlled nine-tenths of the production, three-quarters of the refining capacity, two-thirds of the oil-tanker fleet, and virtually all of the pipelines” (Heinberg, 2011). The global reliance on oil is evident and to ensure that the control of this valuable fossil fuel would not be left in the hands of a few companies; national governments began to intervene in the production and consumption of this valuable energy resource.

It is evident that oil has been the source for economic growth in the United States and Europe during the early twentieth century and that petroleum has also been the spark for many international conflicts during this time period. As nations begin to exhaust their natural resource endowments, they experience a lack of supply security. When this occurs, counties will seek non-domestic sources of supply to satisfy their domestic demand. Oil has become a necessary good for individuals, businesses and for national governments. A necessary good is a normal good which has a low price elasticity of demand. This notion is illustrated in the below graph.
Figure 1.1: The Value of Fossil Fuel Net Imports from 1949-2011 in the United States

![Graph showing value of fossil fuel net imports](image)


Figure 1.1 illustrates the net imports for different fuel sources in the United States from 1949 till 2011. Net imports occur when a country imports more of a type of good than it exports. Figure 1.1 illustrates an aggregate increase in net imports of petroleum which alludes to the fact that this energy resource is a necessary good. Petroleum can be viewed as a necessary good to the individual agent because it is a key component of their daily lifestyle. Oil can be viewed as a necessary good to the public sector because nations require it as a source of national security and means to defend itself in times of war. Oil has not only reshaped the economy of the United States, but has also contributed to political, warfare, transportation and agricultural improvements in our nation.

1.2 THE ECONOMIC SIGNIFICANCE OF FOSSIL FUELS

The last two centuries were witness to the largest economic growth in the history of our planet. Most economists contribute this soar in growth to our ability to
aggressively obtain and use fossil fuels (Heinberg, 2011) in addition to the division of labor, improvements in technology and trade. Money undoubtedly plays an immense role in a capitalist economy; however, fossil fuels are also inertly linked to capitalism. One of the primary principles of capitalism is increasing economic growth. This growth is fueled by production which is dependent on energy, specifically, oil. Without energy, economies would not grow, thus alluding to the fact that oil production and capitalism are interdependent.

One of the components of capitalism is economic growth which is fueled by productivity. The most productive components of our economy; technology, machinery and equipment, trade and transportation, require a form of energy, in most cases this form of energy is oil. Under capitalism, perpetual economic growth is a realistic expectation. The growth that both the United States and Europe experienced during the nineteenth and twentieth century was a result of three different events; coal and the invention of the steam engine, the electric motor and combustion engine and the use of oil and natural gas. All three of the factors led to increased economic growth and are energy dependent.

Capitalism has been nurtured by inexpensive fossil fuel energy-- from coal during the industrial revolution to the role of oil in our current economy. Thus, to have continued economic growth and production in a capital based economy, there needs to be an abundance of cheap and accessible sources of energy. Unfortunately, in recent years the price of all kinds of fossil fuels has increased due to their finite nature. The below graph illustrates this phenomenon.
Figure 1.2 illustrates the fossil fuel production prices from 1949-2011 by sector. The four different sectors illustrated on the above graph are crude oil, natural gas, coal and a fossil fuel composite (which is equal to the price per Btu of each fossil fuel source multiplied by the total Btu of total fossil fuel production). It is apparent from figure 1.2 that since 1973, crude oil, natural gas and the fossil fuel composite have experienced an aggregate increase in production prices. This is crucial to point out because capitalism relies on the cheap and easy access to energy resource. Figure 1.2 shows that the price of all fossil fuels, with the exception of coal, has increased since 1973 thus limiting the growth of a capital based economy. Since 1965, there has been a global increase in the money spent on the production of fossil fuels and on the consumption of fossil fuels sources. This notion is reinforced in figure 1.3 below.
Figure 1.3: World Energy Consumption by Source, 1965-2011

Figure 1.3 depicts the increased universal energy consumption from 1965 till 2011. Despite the increased level of production and consumption, the price of fossil fuels is still rising which will be a limit to future global economic growth. It is crucial that the United States switches to a more abundant and less expensive form of energy if it wishes to have increased production and thus increased economic growth in future years. In order to achieve this energy transition, there need to be a modification to the role that governments have in energy markets, specifically, the energy market for fossil fuels needs to become less regulated and internalize costs.

1.3 ROLE OF GOVERNMENT AND FOSSIL FUELS

Each stage of economic development has coincided with a transition from one fuel source to another, in industrial economies this fuel source is fossil fuels. Governments
possess the ability to influence energy transitions through the implementation of policies. Government policies such as taxes and subsidies can impact the speed and nature of energy transitions. A subsidy is a form of direct or indirect government assistance to an industry or economic sector and is generally financial in nature (Harris and Roach, 2013). The implementation of a subsidy will increase the rate at which an energy resource is consumed and produced. In contrast, a tax is a form of direct or indirect financial charge or levy the government imposes on an industry or economic sector (Harris and Roach, 2013). The implementation of a tax will decrease the rate at which an energy resource is consumed and produced. Thus, energy markets do not reflect Adam Smith's notion of unregulated markets and rather reflect Keynes's views since they are heavily managed by governments.

The energy market for fossil fuels is highly regulated by the governments and it is for this reason that there has not been a transition to another source of energy, specifically, a renewable source. The global fossil fuel subsidy is projected to be $500 billion, making the government incentives provided to this sector twelve times great than the global subsidy granted to renewable forms of energy (Morales, 2010). Specifically, the International Energy Association (2013) stated that the universal subsidy provided to the fossil fuel industry amounted to $544 billion dollars in 2012, making the government aid to this sector significantly greater than previous levels. According to the Bloomberg 2010 report, universally, governments gave approximately $43 to $46 billion in financial support to renewable energy companies through the form of subsidies, specifically; tax credits, feed-in tariffs alternative energy credits (Morales, 2010).
The energy transition from fossil fuels to renewable sources of energy could be expedited if the subsidy given to the fossil fuel industry was reduced and the cost associated with the production and consumption of fossil fuels became internalized. Like most goods and services, energy prices fail to encompass the externalities associated with their use. Externalities occur in most market transactions and are the changes in utility to agents who are not involved in the transition (Sharpe, 2013). Externalities are positive or negative in nature, thus governments are able to internalize their impacts through the implantation of subsidies or taxes. A subsidy would be provided to an industry or economic sector through an exchange in a market transaction that provides a benefit or positive externality to society. A tax would be levied to an industry or economic sector through an exchange in a market transaction that provides a cost or negative externality to society. By removing the misrepresentative subsidy universally provided to the fossil fuel industry and instead taxing the industry for the negative externalities it imposes (i.e.: climate change, pollution, etc.), the transition to renewable and greener sources of energy can be facilitated.

During the 2009 summit meeting in Pittsburg, G20 leaders agreed upon an initiative to phase out the subsidy granted to the fossil fuel industry; this was the first time that there was a global movement to lessen government aid to the coal, oil and natural gas sector. Unfortunately the movement to phase out fossil fuel subsidy has been slow and a target date has not been set. The 2009 G20 summit has encouraged nations to transition to renewable sources of energy; however, phasing out the fossil fuel subsidy has been lagged due to political, economic and social hurdles (International Energy Association, 2013).
Countries such as Germany, the United States and China have made sticking progress by increasing the subsidy provided to the renewable energy sector. Specifically, since 2009, Germany has been provided $10 billion in the form of feed-in tariffs and subsidies to their renewable sector. Other European countries have also contributed an additional $10 billion in subsidies towards renewable energy, China has contributed $2 billion towards renewable energy (which is a low figure since it fails to take into account low interest loans provided to renewable energy projects) and the United States has provided approximately $18 billion in subsidies to the renewable energy sector. It is evident that there is a universal shift towards renewable energy in the form of feed-in tariffs and subsidies despite the stagnant progress to phase out the global fossil fuel subsidies.

In order to increase the energy transition from fossil fuels towards renewable sources of energy, the International Energy Association has increased the availability of data concerning this distorting subsidy and hopes to reduce it by providing transparency (International Energy Association, 2013). Further, since 2009 the World Bank, IEA and OECD have composed two reports which detail the universal subsidies provided to all energy sources and also countries that have begun to phase out the fossil fuel subsidy. The below table is from the second report: “The Scope of Fossil Fuel Subsidies in 2009 and a Roadmap for Phasing out the Fossil Fuel Subsidies” and illustrate the selected nation’s subsidy phase out plan.
Table 1.4: Selected Plans for Subsidy Phase Out

<table>
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<tr>
<th>Country</th>
<th>Description of Announced Plans</th>
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<tr>
<td>Angola</td>
<td>Cut gasoline and diesel subsidies in September, 2010, leading to a price increase of 50% and 38$ for gasoline and diesel respectively.</td>
</tr>
<tr>
<td>Argentina</td>
<td>Proposes to reduce household subsidy for propane gas as natural gas access is expanded.</td>
</tr>
<tr>
<td>China</td>
<td>Oil production prices were increased to a weighted basket of international crude prices in 2008. Natural gas prices increased by 25% in May 2010. China has already removed preferential power tariffs for energy-intensive industries.</td>
</tr>
<tr>
<td>Egypt</td>
<td>Plans to eliminate all energy subsidies to all industries by the end of 2011.</td>
</tr>
<tr>
<td>India</td>
<td>Abolished gasoline price regulation in June 2010 and plans to do the same for diesel. The price of natural gas paid to producers under the regulated price regime was increased by 230% in May 2010. State owned Coal India Ltd. Announced that it would benchmark its premium grade coal to world prices.</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Plans to reduce spending on energy subsidies by 40% by 2013 and fully eliminate fuel subsidies by 2014. Electricity tariffs were raised by 10% in July 2010. Has an ongoing program to phase out the use of kerosene in favor of LPG</td>
</tr>
<tr>
<td>Iran</td>
<td>Plans to replace subsidies energy pricing with targeted assistance to low-income groups over the period of 2010-2015. Reforms call for the prices of oil products, natural gas and electricity to rise to market-based levels.</td>
</tr>
<tr>
<td>Malaysia</td>
<td>In July 2010, announced reductions in subsidies for petrol, diesel and LPG as the first step in a gradual subsidy-reform program</td>
</tr>
<tr>
<td>Mexico</td>
<td>Subsidies to gasoline and diesel are expected to disappear by the end of 2010, and the gap of LPG prices is expected to close in 2012.</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Plans to remove subsidies on petroleum products by December 2010, or latest end of 2011.</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Plans to phase out electricity subsidies and has implemented a tariff increase of around 20% in 2010.</td>
</tr>
<tr>
<td>Russia</td>
<td>Natural gas prices for individual users are to continue increasing toward international levels through 2014 based on the balancing of revenues from domestic and export sales. Pricing in the wholesale electricity market is scheduled to be fully liberalized in 2011.</td>
</tr>
<tr>
<td>South Africa</td>
<td>Plans to increase electricity tariff by approximately 25% per year over 2010-2013</td>
</tr>
<tr>
<td>UAE</td>
<td>Commenced reducing gasoline subsidies in April 2010 and plans to bring them in line with international market levels. Diesel prices are already largely deregulated.</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Raised gas price for households and electricity generation plants by 50% in August and plans to raise them by another 50% from April 2011.</td>
</tr>
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Source: IEA World Energy Outlook, 2010

It is evident from table 1.4 that there have been global plans by select nations to phase out the fossil fuel subsidy and progress towards alternative sources of energy. In order to
achieve this goal, governments must corporate to internalize costs of energy resources so that markets are not distorted.

1.4 CONCLUSION

Universal economic growth is attributed to easy access to cheap sources of energy; historically oil and coal. The use of fossil fuels in the Industrial Revolution has been a turning point for economic and social growth. Coal played a pivotal role in the global economy from the seventeenth to eighteenth century and paved the way for the combustion of oil. There has been a close relation between the use of energy and economic growth. This is due to the fact that energy sources fuel productivity which increases gross domestic product and thus economic growth in a capital based economy.

Due to the immense importance of fossil fuels in the current economic system, governments have intervened in energy markets by imposing significant subsidies which encourage continued production and consumption and distort market prices. It is imperative that the relative costs of fossil fuels including climate change accelerate governments’ reductions to subsidies to oil, coal and natural gas. This will internalize the real costs associated with the continued use of finite resources and facilitate a transition in energy towards a renewable resource.
CHAPTER TWO: THE ECONOMIC AND ENVIRONMENTAL EFFECTS OF PEAK OIL

2.1 INTRODUCTION

Under capitalism, economic transitions occur through markets in which there is a demand and supply side involving buyers and sellers. The objective of the system is to maximize profits or to have a surplus value. In a capital based economy, an increase in economic growth requires corresponding increases in economic activity. Most economic activity is fueled by energy; specifically, fossil fuels. This implies that an increase in economic growth requires an increase in the production and consumption of fossil fuels. Even though not all countries use oil as their main source of energy consumption, it is still considered to be the world's primary energy source. This is critical because it signifies that peak oil will affect the global economy.

Oil reserves were formed by geological processes millions of years ago and are typically found in underground reservoirs (Hirsch, 2005). Oil reservoirs differ drastically in size, location and depth. The oilfields which possess the largest reserves of crude oil are called “super-giants” (Heinberg, 2011). The majority of these “super-giants” deposits were found during the 1930s through the 1960s; such reservoirs were endowed with approximately a billion barrels of crude oil. This means that during their peak producing years, the “super-giant” oil reservoirs would produce approximately hundreds of
thousands of barrels to millions of barrels daily (Heinberg, 2011). The economic concept of “best-first” or “low-hanging fruit principle” can be applied to the extraction of oil (Heinberg, 2011). Due to their immense size, “super-giants” were the first oil reservoirs to be discovered, the first to be developed and also the longest lived. Figure 2.1 is Colin Campbell's graph and illustrates the concept of best-first and it's relevance to global oil discoveries.

Figure 2.1: The Growing Gap of Regular Conventional Oil Globally

The last universal discovery of a “super-giant” crude oil reservoir was in 1968 (Hirsch, 2011), making the continued exposition of “super-giants” limited and the discovery of new oil fields more challenging and expensive.

Oil is a valuable resource for many reasons. Oil is liquid in nature, making the associated transaction costs relatively low compared to other sources of energy,
specifically; coal, gasses and methane. Oil is also extremely energy dense (37 MJ/kg), making the amount of energy stored in the per unit space greater than coal (24 MJ/kg), wood (16.2 MJ/kg) and natural gas (38MJ/kg). Oil is also considered to be a valuable resource because it can be easily refined and be substituted for a variety of applications, such as; transportation, heating and the production of agriculture and chemicals.

When investigating the value of an energy source, it is important to take into account the energy return on energy invested (ERoEI). The energy return on energy invested is the usable acquired energy divided by the energy expended. The ERoEI is most often applied to the energy that is required to find and produce oil and the energy that is required to grow, harvest and produce biofuels. It is important to note that the ERoEI does not measure the efficiency of an energy source, but rather it determines the net energy analysis. The goal of energy efficiency is to expel the minimum amount of energy to required to produce goods and services. In contrast, net energy analysis is a scientific method which compares the amount of energy that is delivered to society from a specific source of fuel and the amount of energy that is required to obtain the source of fuel. Figure 2.2 and 2.3 below illustrates the ERoEI for different renewable and non-renewable resources.
Table 2.2: EroEIs for Various Energy Resources for the United States

<table>
<thead>
<tr>
<th>Resource: Fossil Fuels</th>
<th>EroEI (X:1)</th>
<th>Resource: Other</th>
<th>EroEI (X:1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and gas, 1930</td>
<td>100</td>
<td>Hydropower (renewable)</td>
<td>100</td>
</tr>
<tr>
<td>Oil and gas, 1970</td>
<td>30</td>
<td>Wind Turbines (renewable)</td>
<td>18</td>
</tr>
<tr>
<td>Oil and gas, 2005</td>
<td>14.5</td>
<td>Photovoltaic plates (solar)</td>
<td>6.8</td>
</tr>
<tr>
<td>Imported oil, 2005</td>
<td>18</td>
<td>Corn-based ethanol (biomass)</td>
<td>5.4</td>
</tr>
<tr>
<td>Imported oil, 2007</td>
<td>12</td>
<td>Flat plate (solar)</td>
<td>1.9</td>
</tr>
<tr>
<td>Natural gas, 2005</td>
<td>10</td>
<td>Concentrating collector (solar)</td>
<td>1.6</td>
</tr>
<tr>
<td>Coal, 2000</td>
<td>80</td>
<td>Biodiesel (biomass)</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Source: Murphy, D. J., & Hall, C. A. S., 2010

Figure 2.3: ERoEI for Various Energy Resources in the United States

Source: Murphy, D. J., & Hall, C. A. S., 2010

It is in a nation's best economic interest to exploit the resources that have the highest ERoEIs. When oil was initially discovered its ERoEI was estimated to be around 100. This means that it typically required one barrel of oil to discover and extract 100 barrels
of oil. Figure 2.2 and 2.3 depict that from 1930-2005, the ERoEI for oil has decreased. This may be due to the decreasing number of oil discoveries coinciding with increased technology and extraction costs (Heinberg, 2011).

If a resource has an ERoEI of less than one it is considered to be an energy sink, making the marginal cost of extraction greater than the marginal user cost. As the ERoEI of energy sources decrease, there appears to be a related increase in the proportion of the economy devoted to the same amount of net energy of the resources. This is due to the fact that as the ERoEI decreases, there must be a coinciding increase in productive efforts to obtain the same amount of energy from that resource. This is generally seen when the resource in question is nonrenewable and finite. Further, as the ERoEI of a main energy source decreases to less than or equal to one, the relative value of main energy sources compared to alternatives increases. This signifies that it is important to look at the ERoEI when comparing alternative resources.

There are different ways to measure the value of net energy for different resources. Critics of using the ERoEI state that it is an inaccurate measure because there is no agreed upon standard of what activities should be included. This is because there are no boundaries to the ERoEI system making it difficult to know the extent of the activities that should be included. For instance, there is no agreed upon standard of the energy costs in the form of transportation to and from the energy resource be included in the ERoEI measurement. Further, there is debate into how far probing should go into the standard of what activities should be included in the calculation. This debate encompasses different arguments, such as, if the energy input to build infrastructure required to transport the
energy source should be taken into account in the ERoEI calculation. Arguments against the ERoEI further state that in some cases, the form of energy input is not equivalent to the form of energy output (coal to ethanol). Further, the equation for energy returned on energy invested fails to take into account the factor of time. Renewable sources of energy increase in relative value over time; this is not taken into account in the ERoEI calculation. If an energy source is increasing in value over time, it should be reflected in the ERoEI of the resource.

Capitalism demands the use of energy in the form of fossil fuels for continued economic growth. As the supply of this finite resource decreases with a continued increase in demand, the associated ERoEIs for fossil fuels will likely decline making the price of oil in the market place increase. A decline in the supply of oil is associated with the peaking of the production of fossil fuels, a notion which can be deemed peak oil. As the global economy progresses past peak oil, there will be an inevitable reliance on non-conventional oil and other forms of energy which have a lower market price and a higher ERoEI. The transition to other sources of energy, such as, non-conventional oil and coal are not only associated with economic costs but also environmental costs.

2.2 Peak Oil

The global demand for oil is undeniably growing and it is inevitable that we are going to eventually reach the global maximum in the production of this exhaustible resource. A maximum point in the world's production of oil can also be called peak oil. Peak oil is a term used to describe the point in which the production of fossil fuels
reaches a maximum rate, before an inevitable decline and does not refer to the total exhaustion of petroleum resources (Heinberg, 2011). The production of oil will not cease at this maximum rate but rather it will slowly decline over decades. Many countries have already witnessed a peak and decline in their individual oilfields. Specifically, countries such as the United States, Norway, Great Britain, Indonesia, Oman and Mexico have all already seen a decrease in their national production of oil (Heinberg, 2011). It is evident that world oil peaking will occur; the timing of this event, however, is uncertain.

There are many different scientific approaches to measure the phenomena deemed peak oil. Scientific measurement approaches such as; asymmetric models, Gaussian models, logistic models and Lorentz distribution models have all been used to estimate when the peak in the fossil fuels will occur and thus to predict the future trend of oil production. The model which has been used most often by economists and research analysts to approximate the future trend of fossil fuel production is the Hubbert model. The Hubbert model can also be referred to as the Hubbert peak theory and has been used to calculate the global peak in oil production and also regional peaks in oil production.

M. King Hubbert first presented this model in his 1956 paper concerning nuclear energy and fossil fuels. The Hubbert curve is a probability density function which depicts the approximation of a resource over time and can be illustrated in the below graph.
Figure 2.4 portrays a single-Hubbert approach for a nonrenewable resource, which is finite in supply. There are three key elements depicted in figure 2.4. The first is a gradual rise from zero resource production with an exponential increase in the production of the resource. The second element is a peak in production which illustrates the maximum point in the production of the finite resource. The third element of the above graph is an exponential decline in the production of the resource until the resource is depleted. The Hubbert curve can be described by the below equation, as discussed by Maggio, G., & Cacciola, G. (2012).

\[
P = \frac{2 P_M}{1 + \cos h \left[ b \left( t - t_M \right) \right]}
\]

In this equation, the oil production is represented by \( P \) at time \( t \). The three parameters in the above equation are \( P_M \), \( T_M \) and \( b \) and represent the maximum point in oil production, the year the peak will occur and a constant slope parameter, respectively. The shape of this curve is determined by production techniques, the availability of competing resources.
and government regulation on the production and consumption of the finite resource. Due to such factors, the shape of the Hubbert curve is often variable. This approach is known as a single-Hubbert approach, due to the single production cycle and corresponding single peak. Two other Hubbert models are the multi-Hubbert approach and the multi-Hubbert variant approach. The multi-Hubbert approach is characterized by several cycles and production peaks in the production of an exhaustible resource. The multi-Hubbert variant approach takes into account factors of both the single-Hubbert and multi-Hubbert approach while incorporating a new constant.

In his initial model, M. King Hubbert made predictions concerning the longevity of the coal, oil and natural gas resources. He concluded that in the United States (excluding Alaska), crude oil would reach it maximum point in production near the end of the 1960s and that natural gas would reach its maximum peak in production approximately a decade after. Hubbert further estimated that petroleum would reach its accumulation in production around the year 2000, or about 30 years hence. Hubbert predicted that the global peak oil would occur around the early 1990s.

It is important to note that it is extremely difficult to not only estimate the date of peak oil in the United States, but even more so to predict the date of the global maximum production point in oil. This is due to the fact that global production can not be fitted into a single-Hubbert approach and requires a more intensive model. There are many petroleum producing regions around the world, each area has its own maximal rate of production implying that each region must be studied individually. There have been
attempts to combine Hubbert curves for various petroleum producing regions, the most noted of which being Colin Campbell's adaptation of the Hubbert model.

Colin Campbell is a petroleum geologist who studied future oil production. In the view of Collin Campbell, the Hubbert model underestimated the rate of oil production during later phases of extraction. In his work, Collin Campbell introduced two major changes to Hubbert's previous model. The changes being that (i) fitted the curves on a nation by nation basis and (ii) based curve fittings on depletion analysis. In doing so, Collin Campbell's models do not assume the historic rate of oil will be symmetric-- the rate at which oil production increased towards the peak does not need to match the rapidity at which it declines after the peak and further, that the peak of production need not occur when half of the oil has been produced.

In both of their models, M. King Hubbert and Collin Campbell make predictions of the future rates of fossil fuel production. Unfortunately both of the models have their flaws, indicting the difficulty of estimating the year that peak oil will occur. This is because numerous factors come into play when determining the year that global oil peaking will occur. Such dynamic factors are: uncertainty due to problems in measurement, pricing variations, demand elasticity, political influences, technological advances and geological complexities (Hirsch, 2005). The initial calculation needed to be made to determine a projection for peak oil is the summation of the output of the world's existing reserves combined with the summation of the not yet discovered reserves. This calculation is exceptionally tedious to predict not only because all of the advanced and
not yet discovered oilfields are in contrasting stages of development, but also because there are variability and biases present in the data. This notion is illustrated in figure 2.5 below.

Table 2.5: Projections of the Peaking of World Oil Prices

<table>
<thead>
<tr>
<th>Projected Date</th>
<th>Source of Projection</th>
<th>Background &amp; Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-2007</td>
<td>Bakhitari, A. M. S.</td>
<td>Iranian Oil Executive</td>
</tr>
<tr>
<td>2007-2009</td>
<td>Simmons, M. R.</td>
<td>Investment banker</td>
</tr>
<tr>
<td>After 2007</td>
<td>Skrebowski, C.</td>
<td>Petroleum journal editor</td>
</tr>
<tr>
<td>Before 2009</td>
<td>Deffeyes, K.S.</td>
<td>Oil company geologist</td>
</tr>
<tr>
<td>Around 2010</td>
<td>Campbell, C. J.</td>
<td>Oil company geologist</td>
</tr>
<tr>
<td>After 2010</td>
<td>World Energy Council</td>
<td>World Energy Council</td>
</tr>
<tr>
<td>2010-2020</td>
<td>Laherrere, J.</td>
<td>Oil company geologist</td>
</tr>
<tr>
<td>2016</td>
<td>EIA nominal case</td>
<td>DOE analysis/ information</td>
</tr>
<tr>
<td>After 2020</td>
<td>CERA</td>
<td>Energy consultants</td>
</tr>
<tr>
<td>2025 or later</td>
<td>Shell</td>
<td>Major oil company</td>
</tr>
<tr>
<td>No visible peak</td>
<td>Lynch, M. C.</td>
<td>Energy economist</td>
</tr>
</tbody>
</table>

Source: Hirsch, R.L., Bezdek, R., & Wendling, R., 2005

Evidently, the projected dates for when the peaking of the world oil production will occur are highly volatile and difficult to predict. Possible explanations for the different forecasts of peak oil are: use of data sources, lack of data transparency, use of different frameworks, model assumptions and the inclusion or exclusion of conventional reserves (Verbruggen and Marchohi, 2010). The above forecasts are all similar in the sense that
they believe peak oil is inevitable whether we have reached the maximum in oil production or not.

Peak oil is a theory, as with all theories individuals have presented arguments which discredit it. Arguments against the notion of peak oil state that technology will improve and enhance oil production in existing fields and aid in discovering new oil reservoirs. Although this may be true, it is important to take into account the cost of developing and implementing new technologies along with the time associated with locating new oil deposits. As both of these variables increase, the energy and monetary costs invested into developing new technologies will in turn decrease the ERoEI. This may make enhancing oil productions and locating new deposits uneconomical. Another argument which discredits the concept of peak oil states that, past forecasts of oil shortages have been incorrect, so future predictions may also be incorrect. Although predictions about the maximum production of oil may not occur at the date they have been estimated to, it is naïve to believe that we will not reach a global and local maximum in the production of this finite resource.

2.3 Peak Oil and Climate Change Implications

It is tempting to think that the slow depletion of fossil fuels as a result of reaching peak oil may actually improve the current state of the environment. As sources of fossil fuels decrease, there may be fewer emission of carbon dioxide into the environment and thus a gradual decrease in the greenhouse effect (Heinberg, 2006). This statement is incorrect. The gradual depletion of oil may not have a positive impact on the environment
but rather, it may have many negative impacts, especially if coal replaces oil as a source of energy.

There are numerous factors which increase temperatures on this planet, such as; CFCs, nitrous oxide and carbon dioxide (Murphy, 2008). Carbon dioxide can be deemed the most influential factor since it contributes to 65% of the increase in atmospheric temperatures (Aleklett, 2012). If the amount of carbon dioxide emissions increases, there will be a coinciding increase in the amount of infrared radiation captured and redirected back into the atmosphere, resulting in an increase in the greenhouse effect and an inevitable increase in global warming (Aleklett, 2012). The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for reporting and accessing information related to human-induced climate change and levels of carbon dioxide concentration. This panel came to fruition in 1988 with the influence of two United Nations organizations; the World Meteorological Organization (WMO) and the United Nations Environmental programme (UNEP) (Murphy, 2013). The Intergovernmental Panel of Climate Change “assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change” (IPCC, 2013). According to the IPCC 2013 report on climate change, since 1980, each of the last three decades has been successively warmer at the Earth's surface than the later. The report further states, that under a medium confidence interval, that 1983-2010 was likely the warmest time period on the Northern Hemisphere since the 1400s. The increase in the global surface temperatures has been the result of increasing levels of carbon dioxide emissions; CO$_2$ emissions have increased by 40% since pre-industrial
times. This increase in carbon dioxide emissions is the result of the use of fossil fuels as a source of energy and from land use and land use changes. With movement towards peak oil and a condescending increase in the production of this source of energy, there has been has been a mirrored increase in carbon emissions from fossil fuel combustions.

Specifically, carbon dioxide emissions as a result of fossil fuel combustion have increased at an aggregate rate of $2.0 \pm 0.1$ ppm year$^{-1}$ from 2001-2011 which is 54% above their 1999 level (IPCC, 2013). This notion is represented in figure 2.6 below.

Figure 2.6: Carbon dioxide, Methane and Nitrous Oxide Emissions in the US, 1960-2011

![Figure 2.6: Carbon dioxide, Methane and Nitrous Oxide Emissions in the US, 1960-2011](image)

Source: International Panel on Climate Change, Annual Report, 2013

Figure 2.6 illustrate carbon dioxide, methane and nitrous oxide emissions from 1960 till 2011, respectively. The increase in global surface temperatures as a result of the constant increase in carbon dioxide emissions from the combustion of fossil fuels has many
negative implications on the environment, such as; the increase in atmospheric and ocean temperatures decreases in the amount of snow and ice and increased sea levels.

The IPCC deem it virtually certain that ocean temperatures have increased from 1971 to 2010, specifically 0.11 degrees Celsius (0.09-0.13) per decade in surface waters (75 meters and above). In addition to increases in ocean temperatures, the increase in carbon dioxide emissions has also affected sea levels. It is estimated that the global mean sea level has increased by 0.19 (0.17-0.21) meters from 1901 to 2010. This statistic is based off of the mean tide gauge records and satellite data. According to the IPCC 2013 report on climate change, ice sheets in Greenland and Antarctica have significantly been loosing mass since the 1980s. The Arctic Sea ice and the spring snow cover in the Northern Hemisphere have continued to decease; there has also been global shrink in glaciers. All of the three mention climate changes have been proven to a strong confidence interval. It is evident that global temperatures have been increasing since the 1980s and authorities at the International Panel on Climate Change deemed the above mentioned changes unique when compared to previous data from past centuries and millennia.

The demand for peak levels of energy will continue as we move past the maximum point of oil production. It is an economic principle that as the demand for a good increases and the supply of a good decreases, the price of the good will increase. This law is applicable to oil. During the early stages of oil exploration, the price of oil was appropriately twenty dollars per barrel in 1948 (Bloomberg, 2013). As the supply of oil has dwindled due to increased demand, the price of oil has increased to appropriately
one hundred dollars per barrel (Bloomberg, 2013). Due to the increase in the price of oil, consumers may demand an alternative and less expensive form of energy, which may be coal. In this instance, coal can be viewed as a substitute good. As result of a change in conditions, substitute goods will replace each other in use, meaning that they have a positive cross elasticity of demand. Thus, implications for a constant demand with a mirrored decrease in supply of a resource may be movement to other energy resource. This alternative source of energy may be coal. If efforts are made to increase the use of coal due to the decrease in available oil, more greenhouse gasses will be admitted than in previous years. This will increase the effects of climate change and global warming.

When the world reaches peak oil, the production of fossil fuels will gradual taper off. When this happens, efforts may be made to increase the usage of other sources of energy in order to offset the energy shortages from oil. When investigating the impacts that different energy resources have on the environment, many researchers use an approach called life-cycle assessment rather than solely relying on the carbon dioxide emissions. Life-cycle assessment is a method which incorporates all stages of a product’s life cycle in order to better assess the environmental impacts the product posses. This type of methodology has also been deemed cradle-to-grave analysis since it analyzes the environmental impacts associated with each stage of production: extraction, manufacturing, distribution, production, recycling... etc. Coal has a greater lifecycle greenhouse gas emission than that of oil, which means that a switch to coal as a result of a decrease in the supply of oil will result in more carbon dioxide being emitted into the environment. The below table illustrates this notion.
Table 2.7: Energy Source and Estimated gCO₂/kWh

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity/ Configuration/Fuel</th>
<th>Estimate (gCO₂e/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectricity</td>
<td>3.1 MW, reservoir</td>
<td>10</td>
</tr>
<tr>
<td>Hydroelectricity</td>
<td>300 kW, run-of-water</td>
<td>13</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>80 MW, parabolic trough</td>
<td>13</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Polycrystalline silicone</td>
<td>32</td>
</tr>
<tr>
<td>Diesel</td>
<td>Various generator and turbine types</td>
<td>778</td>
</tr>
<tr>
<td>Heavy Oil</td>
<td>Various generator and turbine types</td>
<td>778</td>
</tr>
<tr>
<td>Coal</td>
<td>Various generator types with scrubbing</td>
<td>960</td>
</tr>
<tr>
<td>Coal</td>
<td>Various generator types without scrubbing</td>
<td>1050</td>
</tr>
</tbody>
</table>


As one can deduce from figure 2.7, coal has the greatest gCO₂e/kWh estimate compared to any other energy source. For this reason, it is crucial that as we move past peak oil that we transition to an alternate source of energy other than coal. Such a transition is necessary to ensure climate stabilization.

It is critical to not only take into the account the economic impact of oil depletion, but also the environmental consequences of peak oil. With the demise of the “super-giant” oil reserves and the depletion of higher-quality oilfields there will undoubtedly be a shift towards the extraction of lower-quality ores and deposits. This shift will have implications on the state of the environment due to the fact that lower-quality deposits may be located in remote and environmentally sensitive regions of the globe. Such areas
include but are not limited to; oil drilling in the Beaufort and Chukchi Seas, oil drilling in the Arctic National Wildlife Refuge, tar sands production in Alberta, and shale oil production in the Rocky Mountains (Heinberg, 2011). Oil extraction in ecologically sensitive regions have an economic threat and environmental threat. If just one of the above mentioned areas results in a industrial accident, it could result in devastating universal impacts equal or greater than the Deep Horizon blowout (Heinberg, 2011). In order to keep our environment and economy in their present state, it is crucial that we transition to an alternative and renewable source of energy as we progress past peak oil.

Peak oil, will result in economic and environmental risks if there is not transitive to an alternative, safe and renewable source of energy. Peak oil signifies a point in which carbon dioxide emissions will increase, resulting in heightened effects to climate change. Earth's surface temperatures will continue to increase, oceans will continue to rise and ocean temperatures will continue to warm. Further, there will be a continued decrease in glaciers, arctic ice and snow cover in the Northern Hemisphere. Human activities, specially, the combustion of oil and other fossil fuels are the contributing factor to climate change. With movement towards and past peak oil, it is vital that we incorporate a renewable source of energy into our lifestyle, to not only minimize future dependence on coal, but also to mitigate the increasingly negative effects of climate change.

2.4 CONCLUSION

In conclusion, peak oil has received public attention since 2003 due to continuously increasing oil prices. The date when peak oil will occur is a controversial topic due to the
lack of general agreement upon data sources, forecasting frameworks and model assumptions. There will be some point in the future the tipping point at which the global supply of oil will no longer be able to satisfy the world demand. The economic exploration of oil reservoirs has shifted from nearby and easy reserves to far and complex reserves. We are nearing the maximum world production of conventional oil, or perhaps may have already reached peak oil. There are numerous economic, environmental and health risks associated with the global maximum production of oil. Peak oil may result in deforestation, an increase climate change due to the burning of coal as a replacement for oil and economic devastation if ecologically sensitive areas are damaged due to the extraction of lower quality oil reservoirs. With movement towards peak oil, it is crucial to the well-being of humanity that we transition towards safe, renewable and alternative sources of energy. The path towards the maximum rate in the production of fossil fuels, peak oil, has been influenced by many different factors and global events. This makes the trend line very elastic and difficult to predict. It is inevitable that we will reach a maximum production of oil (if we have not already) and that this peak will undoubtedly be coincided with a decline in the rate of oil production. How we respond to peak oil and the route down the peak is of vital importance. Peak oil is a huge determinant of our economic stability. Therefore, it is crucial that we start moving away from fossil fuels toward alternative clean forms of energy. Given the current state of climate change, a universal transition to a clean and renewable source of energy cannot be postponed.
CHAPTER THREE: RENEWABLE ENERGY: AN ANALYSIS OF HYDROELECTRICITY AS A CASE STUDY

3.1 RENEWABLE ENERGY OPTIONS

The use of renewable energy dates back past pre-industrial times, and is currently one of the primary sources of energy in many countries. Renewable energy sources include wind, hydro and solar. Windmills and watermills have harnessed energy to grind grain, press oil and pump water. Wind energy has been used to move ships, transport vast amounts of people and commodities. The use of wind as a renewable source of energy dates back thousands of years. Wind was used by the Egyptians in 2000 BC as a source of energy to move sail boats and ships (Olah, 2006). On the land, wind was used by the early Mediterranean and Eastern civilizations as a way to pump water and grind mill. The use of windmills as a renewable source of energy is present today; however, it was not until the 1990s that there was a dramatic shift towards this form of energy (Olah, 2006). This transition occurred due to the increasing price of oil and improvements in wind turbine technology. The utilization of wind as a source of power has dramatically increased over the last several years due to technology advancements in wind turbines. Global wind powered electricity generation increased from 104 billion kilowatt hours in 2005 to 617
billion kilowatt hours in 2013 (Energy Information Administration, 2013). The historical increase in the use of wind for energy is shown in figure 3.1.

Figure 3.1: World Wind Power Installed Capacity


Figure 3.1 shows that the European Union is responsible for the majority of wind energy development, specifically, Denmark, Germany and Spain with predicted future use in Brazil, Canada, Australia and China (Olah, 2006).

When implementing any type of energy resource, it is crucial to take into account the positive and negative aspects of the power source. Wind energy currently accounts for 1% of the total electricity generated in 2009 (Energy Information Administration, 2010). After the construction of windmills, wind energy does not emit any form of greenhouse gasses or any form of pollution. Thus wind energy has extremely limited environmental
impacts (Olah, 2006). Wind energy can be extremely variable; a slight change in wind speed can dramatically decrease energy output. If wind speeds were to decrease by half there would be a decrease in energy output by a factor of 8 (Olah, 2006). It is important to note that the opposite is also true; if average winds speeds doubled, there would be an increased in energy output by a factor of 8. For this reason, it is important that average wind speeds are taken into consideration, especially the rate at which wind speeds may change during the seasons. Other negative aspects associated with this type of renewable energy source are that they can be noisy and often they are not considered to be aesthetically pleasing.

Solar energy is another form of renewable energy that has also dramatically increased in use during the last several years, specifically the global use of solar energy has increased from 0.068 quadrillion btu in 2006 to 0.320 quadrillion btu in 2013. The sun is a vast nuclear fusion reactor which delivers large quantities of solar energy to our planet. Specifically, solar radiation before entering the atmosphere has a power density of approximately 1370 W m$^{-2}$, half of this energy is able to reach the earth’s surface (Olah, 2006). Most of the solar energy is then absorbed by the oceans and other bodies of water. The amount of solar energy that arrives on surface levels depends on seasonal variation and cloud coverage. Further, both wind and solar energy have critical storage problems and thus energy sources are not always able to ensure a steady supply of energy (Trainer, 2007).

The most commonly used type of solar energy is electricity from photovoltaic conversion and is the conversion of sunlight into electricity. This form of electricity has
many positive aspects. It is easy to maintain and install, solar energy systems do not produce any pollution or greenhouse gases, and solar cells can be installed in most areas. The use of photovoltaic energy has increased by 59 PV§ in 1992 to 212 PV§ in 2012.

Figure 3.2: Evolution of Annual Photo Power Systems Installations (MW)

Figure 3.2 shows a dramatic and steady increase in the use of solar cells from 1992 till 2012. The transition to solar energy is evident, however, there are negative aspects associated with this form of renewable energy. Like wind, solar energy is variable and limited to day light which ranges by location, cloud coverage and season (Olah, 2006). Similar to wind, solar energy has a limited storage capacity and is only able to store energy for 24 hours after it has been harnessed (Trainer, 2007). The most pressing issue regarding PV solar energy are the costs associated with generating electricity, specifically,
it costs anywhere from $0.30-$0.80 per kWh of electricity which makes the ERoEI equate to 6.8. A permanent transition to this form of energy will be limited unless there is government intervention or an increase in technology, which dramatically reduces the prices associated with the use of electricity from photovoltaic conversion.

The use of renewable energy sources decreased with the increasing availability of cheap oil and did not gain global attention until the oil shock of 1973. The oil crisis of 1973 occurred when the Organization of Arab Petroleum Exporting Countries (OPEC), declared an oil embargo and prohibited trade with Canada, the United Kingdom, Japan, the Netherlands and the United States as a result of foreign involvement in the Yom Kippur War (The United States Department of State, 2013). Shortages in the supply of oil have caused prices to increase from 3USD/barrel to 12USD/barrel (CBC, 2007). This increase in price prompted governments to search for alternative energy sources, invest in energy efficiency and consequently decrease their dependence on oil. This increased the development of renewable and alternative sources of energy through government incentives, tax credits and subsidies. During the 1980s, the oil embargo was removed after Secretary of State, Henry Kissinger, negotiated for the removal of Israeli troupes in Sinai. Such actions decreased the advancement towards renewable sources due to the decrease in the price of oil. As the price of oil and the awareness of the need to reduce emission to stabilize the climate have increased in recent years, the use of renewable energy sources has gained global attention.

Universal concerns regarding the issues surrounding climate change have increased over the last few years due to the fact that the effects of global climate change
are strikingly apparent. There have been universal dramatic increases in carbon dioxide emissions from the combustion of fossil fuels during the twentieth century (Harris and Roach, 2013). Increases in carbon dioxide and greenhouse gases have changed the global climate by increasing atmospheric temperatures, raising sea levels, decreasing snow and ice coverage and increasing the intensity of storms and precipitation. Climate change is a universal phenomenon which can no longer be ignored. As a way of decreasing carbon dioxide and greenhouse gas emissions, governments have begun to implement policies which promote the transition to sources of energy which have significantly less CO₂ emissions. This has created an increasing universal awareness of renewable sources of energy.

Renewable sources are responsible for 13.1% of global energy; with hydroelectric providing 56%, wind providing 28%, biomass wood providing 8%, biomass waste providing 4% and geothermal providing 3% and solar providing 1% (Energy Information Administration, 2013). This section of the thesis focuses on the use of a specific type of renewable energy sources, hydroelectricity. Hydroelectricity is discussed because the energy returned on energy invested is significantly higher with hydroelectricity ~100 than that of wind power ~18 and solar energy ~6.8. Further, hydro power is not subject to the same supply variables that wind and solar are making it the most commonly used universal source of energy. In addition, hydroelectricity is the most used source of renewable energy, specifically, hydropower provides 3,288 Twh to the planet annually in the form of electricity, which is the equivalent of 16.3% of global electricity generation (International Energy Agency, 2010).
Figure 3.3 illustrates the top ten hydroelectric power producing countries globally, which are responsible for two-thirds of the world hydropower generation (International Energy Association, 2010). The top five countries that produce hydropower are China, Canada, India, the United States and Russia, respectively. With respect to the global production of hydropower, China produces 18%, Canada produces 12%, Brazil produces 12%, the United States produces 11% and Russia produces 9% of the universal shares in hydropower generation (International Energy Association, 2010). The top five nations which produce the largest global percentage of hydroelectricity differ from the countries that produce the largest percentage of their electricity through hydropower; Paraguay, Uruguay, Norway, Brazil and Iceland, respectively (CIA World Factbook, 2003), implying that such nations have already begun to transition towards hydroelectricity as a primary source of energy. As Figure 3.1 illustrates, the use of hydropower has increased by
approximately 50% since 1990; China experienced the greatest increase in hydropower generation (International Energy Agency, 2010).

Hydropower is energy that is harnessed from moving water, such as rivers, lakes or manmade dams. Dams are the most used source for generating hydropower, and derive electricity by the flow of water from a reservoir, down a tunnel and away from the dam (reservoir). Turbines are placed in the tunnel and capture kinetic energy from flowing water. The kinetic energy is then changed to mechanical energy through the turbine rotations. The rotating turbines power a generator, which converts the previously mentioned mechanical energy into electricity (International Energy Agency, 2010). Figure 3.4 illustrates how moving water is transformed into electricity. The amount of energy captured and converted into electricity depends on the amount of water following from the reservoir past the control gate.

Figure 3.4: Inside a Hydropower Plant

Source: Charlton Media Group, 2008
Hydropower is not solely limited to dams; there are five main sources of hydroelectricity generation; storage schemes, run-of-river schemes, pumped storage, tidal and underground. A storage scheme is similar to the above diagram and is a form of a hydroelectric project which captures energy through movement of a turbine which powers a generator. In storage schemes, a dam encloses the water to form a reservoir and the turbine is located in this reservoir. Run-of-river schemes capture energy through natural flowing rivers and divert water to a powerhouse which contains a turbine and a generator. Both run-of-river and storage schemes are known as diversion schemes because they channel water from a natural reservoir, dam or river to a powerhouse in which electricity is produced through kinetic and mechanical energy. Pumped storage differs from storage and run-of-river schemes because it utilizes two reservoirs to meet energy demands. Specifically, during periods of low demand, water is pumped from the lower to upper dam. In contrast, at points of high demand, water is released from the upper to lower dam. Tide hydropower planets harnesses energy from the daily rise and fall of the ocean. This type of hydropower planet is relatively predictable and thus can provide a source of energy during period of high demand. There are three main types of tidal hydropower, specifically, tidal barrages, tidal fences and tidal turbines. Tidal barrages are typically implemented at a water inlet and use gates to control the flow of water in or out of a basin. Tidal fences are located in channels and direct all the passing water through a turbine. Tidal turbines are essentially underwater wind turbines and capture energy through the movement of a turbine which is rotated by current changes. Like most sources of energy, tidal hydropower has negative components associated with its use.
Tidal power can be damaging to marine life, specifically large marine animals and can also influence navigation and recreation (Energy Information Administration, 2012). Underground hydropower stations are the least common type of hydropower planet and collect energy through large height difference in natural waterways, specifically, waterfalls and mountain lakes. Underground hydropower stations are located beneath the earth’s surface and collect water through and underground tunnel from the high water location to the lower reservoir.

3.2 Cost-effectiveness of Hydroelectricity

A few of the primary reasons that there has not been a dramatic shift towards renewable sources of energy is due to the costs associated with such a transition and the role that government subsidies have in supporting fossil fuels. This is due to the fact that renewable energy sources often possess a high initial investment cost, making the short-term cost of fossil fuels is less than the short-term cost of renewable energy sources. The global consumption of fossil fuels is estimated to be around 80% of all energy supplies, due to the fact that such sources provide energy at the lowest relative cost (Harris and Roach, 2013). The uses of renewable energy sources, such as hydropower, are unattractive because implementing them requires capital and major investments.
In the long-term, renewable energy sources are more cost-effective when compared to conventional energy sources, such as oil\(^1\). This is because the operation and maintenance costs associated with renewable energy sources are lower than the operation and maintenance costs associated with conventional energy sources (Olah, 2006). Specifically, as renewable energy sources are used over the long-term, they are not subject to price increases since they are not finite and not destined to be depleted (Olah, 2006). It is for this reason that renewable sources of energy are often more cost-effective than traditional sources of energy.

The Organization for Economic Co-operation and Development (OECD) conducted a study, which investigated the investment costs required for a transition to hydroelectricity. The OECD was established in 1961 to promote economic development and world trade. Thirty-five nations comprise this organization and are committed to democracy and market economy. When discussing the economics of renewable energy resources, a membership to the OECD plays a critical role. This is because through membership, countries are able to share experiences, compare policy framework, and “help governments foster prosperity and fight poverty through economic growth and financial stability” (Organization for Economic Co-Operation and Development, 2013). The International Energy Agency conducted an investigation regarding the investment costs for different sized hydropower projects in OECD countries through the Implementing Agreement for Hydropower Programs and Technologies. This agreement

\(^1\) Cost-effectiveness is a comparison between two or more courses of action. This type of analysis compares the relative costs and outcomes of the courses of action. A course of action is cost-effective if it produces the most profits and net advantages at the lowest cost in the long-term (Bleichrodt and Quiggin, 1999).
was implemented to increase the advancement of hydropower worldwide through awareness, knowledge and support (International Energy Association, 2010). Table 3.5 illustrates the investment costs for hydropower facilities of various sizes in OECD nations.

Table 3.5: Classification of Hydropower

<table>
<thead>
<tr>
<th>Category</th>
<th>Output/unit</th>
<th>Storage</th>
<th>Power Use (load)</th>
<th>Investment Cost (USD M/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>&lt; 10 MW</td>
<td>Run-of-river</td>
<td>Base load</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Medium</td>
<td>10-100 MW</td>
<td>Run-of-river</td>
<td>Base load</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Medium</td>
<td>100-300 MW</td>
<td>Dam and Reservoir</td>
<td>Base and Peak</td>
<td>2 to 3</td>
</tr>
<tr>
<td>Large</td>
<td>&gt; 300 MW</td>
<td>Dam and Reservoir</td>
<td>Base and Peak</td>
<td>&lt; 2</td>
</tr>
</tbody>
</table>

Source: IEA Hydropower Implementing Agreement, 2011

The reason that hydropower plants have varying initial investment costs is due to the fact that each particular project has individual parameters affecting costs, such as; location, project scale (range: 0.1 MW-10,000 MW), size of reservoir, financing options, use of power for base and/or peak load, and benefits of production (i.e. flood control, irrigation, etc.) (International Energy Association, 2010). The operations and maintenance cost associated with the hydropower plants is relatively low when compared to their initial and investment costs. The operations and maintenance cost for hydropower plants is 5-20 US cents per megawatt hour for large plants and 10-40 US cents per megawatt hour for a small plant.
When implementing a new hydropower plant, or any type of new energy source, it is crucial to take into consideration the costs and benefits associated with such a transition. Mainstream economists use cost-benefit analysis in order to account for the positive and negative effects of an environmental policy and investment. In doing so, they determine at what point the marginal social cost of the activity is equal to the marginal social benefit of the activity and thus when social welfare is maximized. This concept is illustrated in figure 3.6 below.

**Figure 3.6: Marginal Social Cost and Marginal Benefit**

![Marginal Social Cost and Marginal Benefit](image)

Source: Harris and Roach, 2013

The marginal social cost curve in figure 3.6 is upward sloping due the assumption that production is cheaper initially and that costs increase as production increases. The marginal social benefit curve is downward sloping due to the diminishing utility from consumption (Harris and Roach, 2013). The optimal solution in figure 3.6 is where the marginal social cost curve and the marginal benefit curve intersect and is denoted by A*.

This represents the level of activity that should be implemented in order to maximize
social welfare (Harris and Roach, 2013). Cost-benefit analysis is the typical decision making approach used in neoclassical economics to evaluate most types of environmental policy and investment.

With the construction of a hydropower plant, governments, policy makers and economists need to account for different costs and benefits of different factors, which involve economic benefits, the economic costs, the environmental costs and the benefits associated in the recreational value of the area (Harris and Roach, 2013). Economics benefits of the construction and maintenance of a dam are flood control, the provision of hydropower and the provision of water for irrigation. The economic costs of a dam are the construction costs and maintenance costs. The environmental costs associated with the construction and maintenance of a dam includes impacts on the local wildlife and the relocation of communities. With the construction of a dam, the recreational value of the area changes. In order to determine the optimal allocation of resources and where the marginal social cost curve intersects with the marginal benefit curve, all of the above mentioned activities need to be assigned a monetary value.

With the construction of any type of project, including the construction of a hydropower plant, there are different types of values which must be taken into consideration, specifically, the use value and non-use value. The first type of value is use value and has a direct component and an indirect component (Harris and Roach, 2013). Direct components of use value are explicitly associated with a market price while indirect components are use values that are associated with the land and not explicitly with a market price. The second type of value is non-use value, there are three different
aspects of non-use value; existence value, option value and bequest value. Existence value measures the value of different species of animals and plant life and thus emphasizes the importance of biodiversity (Harris and Roach, 2013). Option value measures the value of an area of land by remaining unchanged and leaving the option of the construction of a dam to future generations. Bequest value is the value of leaving the land preserved for future generations (Harris and Roach, 2013). The above mentioned types of values need to be calculated into a monetary form of value in order for a cost-benefit analysis to be conducted. Converting the above mentioned factors into monetary values is consistent with the environmental economics approach towards environmental issues since the costs and benefits are internalized into the market system.

Different techniques are used to estimate values of the factors of interest when implementing an environmental project or investment. Specifically, factors can be converted into monetary values through a contingent evaluation survey, hedonic regression techniques, travel costs analysis and production possibilities. Contingent evaluation surveys measure an agent's willingness to pay to leave the area unchanged by not constructing a project or willingness to accept payment to have the construction of the project (Harris and Roach, 2013). Contingent evaluation surveys are randomized and often times agent's willingness to accept is greater than an agent's willingness to pay. Hedonic regression techniques consist of the use of econometric models which take into account environmental factors through property values. Travel cost analysis assess the value of an environmental area by conducting a survey which evaluates how much an agent has spent in order to visit the environmental area and thus explains the costs of a
certain area by means of the costs that are experienced by the user. Production possibilities measures engineering costs which need to be factored into the costs of production. Production possibilities differs from the above three technique because it focuses on the production side rather than the demand side. When considering environmental policies and investment it is important to look at multiple periods of time in order to determine the long term impacts. The present value of future costs and future benefits must be consider through discounting when conducting a cost-benefit analysis over multiple periods (Harris and Roach, 2013).

Despite the positive aspects of cost-benefit analysis, there are problems associated with this type of examination. Advocates against the use of cost-benefit analysis state that findings based on cost-benefit analysis may be inaccurate. This is due to the fact that is difficult to assign dollar terms to components that do not have a monetary value. This often makes obtaining a reliable estimate extremely variable and difficult. Cost-benefit analysis attempt to monetize the value of environmental resources, the value of communities or the value of human life and the improper of a monetary value will dramatically skew results (Harris and Roach, 2013). If the results of the cost benefit analysis are imprecise, a project could be determined to be valuable when it may actually end up costing money or being damaging in the long-term. Or, a project may not be undertaken even though it may have actually benefited the community and economy. This means that the estimates and results provided by cost-benefit analysis may not actually portray public preferences. Alternatives to cost-benefit analysis are cost-effective analysis and positional analysis. Cost-effective analysis is policy tool which calculates the least-
cost approach for achieving a goal (Harris and Roach, 2013). In contrast, positional analysis is a policy tool that considers economic valuation with equity, social priorities and individual rights and does not take into account monetary conditions to arrive at a decision. It is important to use more than one form of examination to determine the costs and benefits of an energy transition.

3.3 ENVIRONMENTAL EFFECTS OF HYDROELECTRICITY

Regardless of whether or not the energy source that is being implemented is renewable or finite in nature, it is vital that social and environmental implications are accounted for to ensure that all positive and negative impacts are addressed. Specifically, positive impacts must be compensated through tax credits and subsidies and negative impacts must be mitigated and avoided (International Energy Agency, 2010).

When undergoing an energy transition, it is important to take into account the potential benefits as well as the negative downsides. Hydropower is not only a renewable source of energy but is also extremely energy dense. Hydroelectricity has the largest ERoEI of any renewable resources at approximately 100 units to one. This makes the energy returned on energy invested for hydroelectricity comparable to that of conventional oil during the 1930s (Murphy & Hall, 2010). Hydropower plants are able to provide electricity at lower costs when compared to other renewable sources.

The installation of hydropower plants not only provides large quantities of electricity at low costs, but also is associated with positive economic and environmental impacts. Investing in hydropower can aid a nation in flood control, irrigation, provide

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drinking water, and improve navigation (Olah, 2006). The cost and benefits of
hydropower must be considered before construction. Hydropower plants are capable of
providing millions of individuals with energy in the form of electricity and thus can
modernize many developing countries by providing safe and affordable energy. By
transitioning from fossil fuels towards hydroelectricity, pollution will decrease and CO$_2$
levels will decrease. When deciding to implement this renewable form of energy, such
areas of contention include whether the hydropower plant will “enhance economic equity
among citizens, protect the lives and property of citizens from floods and droughts, secure
the rights of citizen with respect to expropriation of land to be inundated and protect the
environment concerning; air, land, water and biodiversity” (International Energy Agency,
Renewable Energy Essentials, page 3, 2010). Decisions to facilitate the construction of a
hydropower plant should be made on a case by case bias since each nation has variable
economic, social and environmental benefits and impacts to account for.

Arguments against the use of hydropower plants, specifically large-scale plants,
state that they produce many negative externalities. Large scale hydropower plants
produce large quantities of electricity; however, the implementation of such plants may
require the construction of large dams and reservoirs. Critics of hydropower electricity
believe that the production of such plants may interfere with existing ecosystems and
reduce biodiversity. Further, arguments against the production of large scale hydropower
plants state that they may modify water quality and create ecosystem damages by
displacing and damaging local populations, in particular poor communities (Olah, 2006).
The least environmentally damaging hydropower plants are run-of-river schemes due to their size, which ranges from 10 to 30 MW. Run-of-river schemes lower the environmental footprint since they require limited or no storage capacity; this feature also makes them susceptible to seasonal fluctuations in water flow. If properly addressed during the planning phase, the above mentioned environmental and social concerns can be successfully mitigated. By realizing potential damages and concerns before implementation, actions can be taken to ensure that they are minimized or avoided. When implementing any type of hydropower, environmental and social factors should be taken into account with the economic components in order to minimize the potential negative externalities associated with construction and production.

3.4 Moving to Hydroelectricity: Policy Recommendations

Due to the fact that renewable energy sources possess large short-term cost and thus deter initial investment, it is critical that governments incentivize an energy transition to a renewable source. Governments can achieve a shift from fossil fuels to renewable sources through research funds, tax credits, subsidies and other incentives. Monetary incentives can be provided to renewable energy sources by shifting the 544 billion dollars subsidy provided to the fossil fuel industry and redirecting it towards sustainable sources of energy. This means that it is crucial for governments to reevaluate their current incentive programs and to erect reliant and substantial renewable energy initiative and policies.
Undoubtedly, it is in a nation's best interest to possess a secure supply of energy resources and to protect themselves from any short-term and sudden price fluctuations. By nature, neither the form of energy, nor the source of supply is completely invulnerable (Marshall and Robinson, 1984). The economic term 'security of supply' is used in a relative sense and can be defined by the exemption from any sudden shortages and supply interferences (Marshall and Robinson, 1984). Governments aim to achieve energy security in order to protect themselves from any unforeseen changes in price, which would impact the country's economic and social structure. Governments should aim to maximize the utility of energy resources by improving their energy security.

It is important to note the difference between the economic concepts of security of supply and self-sufficiency. Advocates for energy self-sufficiency often promote an import-minimizing policy, which would provide energy independence by decreasing reliance on foreign sources of energy and thus significantly reduce source disruptions (Marshall and Robinson, 1984). Proponents of energy self-sufficiency argue that domestic sources of supply are more secure than foreign sources of supply. It is important to note that this is not always the case; domestic sources of supply are subject to some of the same price interferences as foreign sources of supply. Indigenous sources of supply can be affected by industrial action, accidents and civil unrest. By only depending on indigenous sources of energy, governments and national economies are making themselves more susceptible to increased leverage by domestic firms, increased privatization, increased monopoly power and an increase in labor unions (Marshall and Robinson, 1984). For this reason, it is imperative that policies for renewable and nonrenewable sources of energy
encourage domestic and foreign reliance in order to ensure energy supply in times of both domestic and foreign supply disturbances.

Whether the source of energy is renewable or finite, nations should rely on both foreign and domestic sources of supply. The solution for maximizing a nation's security of supply should be to: (i) willfully distribute market power through rigid internal and external regulations; (ii) diversify energy sources by type and supplier; and (iii) by having multiple sources of energy (Marshall and Robinson, 1984). Diversify energy sources by type and supplier will ensure that nation's economic and social structure will not be damaged by a short-term shortage in the supply of a type of energy. If a country has multiple sources of energy which are located domestically and in foreign nations, governments and national economies should be able to protect themselves from both domestic and foreign shortages of an energy supply.

As an energy resource, hydropower has a high storage capacity and can be adjusted to sudden fluctuations in energy demand. Large scale hydropower projects are also less susceptible to seasonal changes in supply. This is due to the fact that storage schemes and pumped storage have reservoirs which enable plants to provide electricity during times of low water supply levels thus providing energy security by means of a secure supply. Large scale hydropower plants are able to be a reliable source of energy supply, however, there are negative implications associated with the production of large scale dams and reservoirs. For this reason, policy recommendations should be made to offset or reduce the impact of the negative effects associated with large scale hydropower production.
Policy framework should support expanding hydropower through smaller systems in order to reduce the negative implications associated with large scale hydro production. This is due to the fact that smaller hydro facilities typically have modest and localized effects on the environment (Olah, 2006). Governments and national economies should support policies which encourage run-of-the-rive schemes over large-scale dams and reservoirs. This will lower the environmental impacts of production and provide a source of electricity to isolated communities in poorer nations (Olah, 2006). By transitioning towards “small-hydro” as a source of electricity, governments and national economies will also be able to promote policies that encourage more than one type of renewable resource.

As previously mentioned, energy security can be enhanced by governments and national economies promoting energy policies which encourage the diversification of energy resources. With a focus on small scale hydropower production, there is opportunity for energy diversification through wind and solar power. A transition to renewables, which encourages the use of solar, wind and small hydro will increase the overall energy supply. In terms of construction, hydropower is much more energy demanding than solar and wind, meaning that hydropower requires more energy resource for construction and implementation. A transition from large-scale hydro towards small-hydro will aid in decreasing energy resources required for construction. Incorporating solar and wind with small scale hydropower will further decrease the energy resources required from construction and thus reduce the amount of carbon dioxide emitted into the environment through implantation. Renewable energy is capable of providing energy
security if governments and nation economies are able to ensure the appropriate conditions for a security of supply—willfully distributing market power, promoting “small-hydro” over larger plants and diversifying energy sources by incorporating solar and wind power.

3.5 CONCLUSION

Hydropower is a flexible, reliable and efficient source of electricity. Water has been effectively harnessed as a source of energy over the last 100 years and will continue to be a source of energy in decades to come. There are a variety of different types of hydroelectricity making it possible to implement hydropower plants in different locations and environments. Governments and national economies should promote “small-hydro” through policy measures that aim to minimize negative environmental effects. Further, government and national economies can increase the security of supply by providing policy regulations which encourage willfully distributing market power, promoting “small-hydro” over larger plants and diversifying energy sources by incorporating solar and wind power. A transition to renewable sources of energy will also help mitigate environmental damages, the effects of climate change and associated costs. Renewable energy sources have a lower maintenance costs, operational costs and is cost-effective in the long-term when compared to conventional energy sources. A transition towards renewables is necessary given the current state of climate change. By developing small hydropower facilities and reducing electrical energy generated through the combustion of
fossil fuels, there will be significantly less greenhouse gasses, methane and carbon dioxide emitted into atmosphere.
CHAPTER FOUR: ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS:

THE DIFFERING PERSPECTIVES

4.1 ENVIRONMENTAL ECONOMICS

Energy sources are a critical component of any economy and how they are used directly influences economic sustainability and growth. A transition to renewables is mandatory given the current state of the climate and the finite nature of fossil fuel reserves. A transition towards renewable energy sources should include the use of “small-hydro”, wind power and solar power. A diversification in renewable energy sources will enhance security of supply, aid in reducing environmental and social impacts associated an energy transition, and decrease the effects of climate change. A transition from fossil fuel energy sources and towards renewable energy resources requires a shift in resource use. The use of environmental and natural resources is often investigated from two different perspectives; environmental economics and ecological economics.

Environmental economics supports mainstream perspective of economics. Under this approach, economic concepts and models are applied to the environment and the environment is viewed as an extension of the market. Specifically, the traditional economic perspective uses models and theories to address issues such as the allocation on nonrenewable resources overtime, common property resources, public goods and externalities (Harris and Roach, 2013). Environmental economics focuses on the
allocation of nonrenewable resources overtime by analyzing the implications of different depletion rates and discount rates overtime. Under the traditional economic approach, common property resources and public goods are investigated since such resources are publicly owned and thus behave differently in the market place than resources which are privately owned. Environmental economics also focuses on externalities and the third party effects that they posse. Under environmental economics, externalities can be internalized to the market in order to increase efficiency and reach resource optimization.

The traditional economic perspective uses an economic valuation to assign monetary values to environmental and natural resources so that they can become part of the functioning of markets. Economic valuation allows environmental and natural resources to enter into market transactions, making it possible for them to be included in market-orientated economic analysis. When externalities are minimized the economy will be more efficient and the market price will reflect both private and social costs (Harris and Roach, 2013).

Under the notion of environmental economics, there is a no limit to economic growth due to the possibilities provided by technological improvement. Under the this approach, economic growth is defined conventionally by increases in final goods and services produced within a nation’s boundaries during a period of time (GDP). According to environmental economics it is possible to pursue an increase in GDP while mitigating environmental impacts. The equation below is commonly used in neoclassical economics
to illustrate how standards of living can continue to increase while environmental impacts are reduced (Erlich and Holden, 1971).

\[ I = P \times A \times T \]

In the above equation, environmental impacts are denoted by I and are the products of population, affluence (measured by per capita GDP), and technology, respectively. Under the neoclassical framework, the variable regarded as population in the above equation will be increasing due to the fact that population growth cannot be controlled (Chertow, 2000). The variable denoted as affluence will also always be increasing since the ultimate goal of neoclassical economics is progress and for this to occur there must be increases in economic growth and GDP. The variable described as technology denotes how resource intensive economic growth and production are. The key belief concerning the sustainability of capitalism under the neoclassical frame is that if population and affluence are both increasing, technological improvements can more than compensate for the increases in population and affluence (Chertow, 2000). Through improvements in technological efficiency, intensive resource production can be reduced, implying that increases in technology would make the environmental impacts decrease. Thus, the IPAT equations illustrates how it is possible to have increasing economic and population growth while at the same time decreasing impacts on the environment and proves the sustainability of capitalism under the neoclassical framework.

Consistent with the implications of the IPAT equation, neoclassical economics believes that decoupling is possible: the notion on the basis of which it is possible to decouple growth from the use of environmental resources (Harris and Roach, 2013).
Term decoupling was defined by the OECD and through the definition breaks the link between negative environmental impacts and economic growth (Harris and Roach, 2013). When discussing decoupling, it is important to make the distinction between relative decoupling and absolute decoupling. Relative decoupling is the decline in ecological intensity per unit of economic output (Jackson, 2009). In contrast, absolute decoupling is an increase in economic activity associated with an overall decrease in environmental impacts (Harris and Roach, 2013), in which there is a decline in resource impacts in complete terms (Jackson, 2009). The crucial difference between absolute decoupling and relative decoupling is that absolute decoupling ensures ecological sustainability. Jackson (2009) and the United Nations (2011) have investigated the evidence for relative and absolute decoupling through empirical studies. Both sources found evidence for relative decoupling, however, evidence for absolute decoupling was not observed. Jackson (2009) believes that reasons for this are that absolute decoupling is not apparent only absolute decoupling would ensure ecological sustainability and thus that absolute decoupling only holds certain for local and visible environmental effects, such as; smoke and river water quality. The United Nations (2011) believes that lack of empirical evidence for absolute decoupling can be attributed to differences in how developed and developing countries use resources. Jackson (2009) states that one of the few ways to achieve absolute decoupling is by decreasing throughput and by a “massive technological shift; a significant policy effort; wholesale changes in patterns of consumer demand; a huge international drive for technology transfer to bring about substantial reductions in resource intensity right across the world” (Jackson, 2009, page 75).
(2011) believe that to achieve absolute decoupling there must be ambitious policies must be set in place (Harris and Roach, 2013). The lack of empirical evidence for absolute decoupling illustrates that environmental economics does not fully account for natural resource depletion. Since there is no evidence of absolute decoupling; therefore, dematerialization is not occurring despite massive improvements in technology and alternative approach to environmental economics should be considered.

4.2 ECOLOGICAL ECONOMICS

Ecological economics follows the heterodox view of economics and focuses on the global biosphere and views the economy as a portion of the broader ecosystem (Harris and Roach, 2013). The ecological perspective believes that an economic valuation does not fully account for the value of natural and environmental resources and instead that analyses should be altered to take into account energy flows, carrying capacities and ecological balances (Trainer, 2010). Ecological economists measure growth by changes in “throughput” rather than by increases in GDP. Defined, “throughput” is raw materials and energy which flow from internal sources into the economy and back into the environment as a form of waste (Harris and Roach, 2013).

Under the perspective of ecological economics, there is a limit to economic growth due to resource scarcity and the capacity of the environment to absorb waste and pollution. Under this perspective, ecological economists stress the importance of energy resources since all systems require energy for growth; natural systems require solar energy and the current economic system requires fossil fuels, specifically, oil. Ecology
economics investigates issues concerning the availability and environmental implications of energy use (Harris and Roach, 2013).

Inevitably according to ecological economics, there is a limit to growth (Heinberg, 2011). Under capitalism, competition is a dominant component of the economic system and nations prevail through the accumulation of capital and the maximization of profits (Li, 2008). The increasing use of natural capital in economies leads to increasing consumption of energy resources and other material inputs of production (Li, 2008). As we approach the global maximum point of production for oil, coal and natural gas there will need to be a transition towards renewable sources of energy; some economists however believe that renewable energy source will not be able to accommodate energy demand of our economy. Figure 4.1 below illustrate the historical and projected energy consumption from 1965-2050 according to Li (2008).

Figure 4.1: World Primary Energy Consumption: Historic and Projected, 1965-2050

![Graph of world primary energy consumption](source: Minqi Li, 2008)

Figure 4.1 indicates that once the commodities and materials that provided energy and the
sources of expansion are consumed; growth in a capital based economy will decrease until it’s stagnant. Thus according to the ecological economic perspective, capitalism is not sustainable because there cannot be continued economic growth (Li, 2008). Zero or low economic growth would reject the key element of a market-based economy; endless growth and profit maximization.

Figure 4.2: World Economic Growth: Historical and Projected, 1965-2050

![Graph showing historical and projected economic growth](image)

Source: Source: Minqi Li, 2008

Figure 4.2 illustrates the global historic and projected economic growth, with the y-axis measuring the annual growth rate of GDP. Figure 4.2 shows that after fossil fuel production peaks, there will be a steady decline in GDP and economic growth (Li, 2008). This implies that without a continuously increasing energy supply, capitalism will fail and it may be mandatory transition to an alternative economic system.
The IPAT formula is an equation commonly used in environmental economics to illustrate that economic growth and decreases in environmental impacts can simultaneously occur. Critics of this formula believe that it is over simplified and that interdependencies exist between the variables. Minqi Li is a critic of such a framework and uses the IPAT equation to prove that increases in economic growth and decreases in environmental impacts can not simultaneously occur. Equations 4.3 through 4.8 depict that ecological sustainability is not possible with increases in economic growth.

Equation 4.3:  \[ I = P \times A \times T \]

Equation 4.4:  \[ I = \{I_1, I_2, I_3, \ldots I_i, \ldots I_n\} \]

Equation 4.5:  For \( i = 1, 2, 3, \ldots n \), \( \Delta I_i \leq 0 \) and \( I_i \leq [\text{max}] I_i \)

Equation 4.6:  \[ I_i = \sum_{j=1}^{m} I_{ij} Q_j \]

Equation 4.7:  For \( i = 1, 2, 3, \ldots n \), \([\text{min}] I_{ij} > 0\) and/or \([\text{min}] I_{2j} > 0\) and/or \( \ldots [\text{min}] I_{nj} > 0\)

Equation 4.8:  \[ Y = P \times A = \sum_{j=1}^{m} P_j Q_j \]

Source: Minqi Li, 2008

The above equation 4.3 denotes the determinants of environmental impact which is denoted by \( I \). The three components of this equation are \( P, A, T \) and represent population, economic output per capita (affluence) and environmental impact per unit of output (technology), respectively (Li, 2008). In this equation, both population and affluence increase as a result of capital accumulation. Ecological sustainability requires a decrease in the consumption of finite resources and a consumption of renewable resources that is below or equal to the rate at which they regenerate (Li, 2008). For ecological sustainability, environmental impacts must remain at a constant level. For this to be true
in equation 4.3, $P \times A$ must increase at the same rate that $T$ decreases. Thus, there must be a decrease in the environmental impact per unit of output towards zero. Equation 4.4 takes into account the varying types of environmental impacts and for overall sustainability all of the varying impacts must be minimized no matter what their substitutability is. Equation 4.4 illustrates this notion. For every type of environmental impact, the change in the “ith” kind of environmental impact over time is equal to or less than zero. The environmental impact over time is also less than or equal to the maximum sustainable level of the “ith” kind of environmental impact, which is a constant (Li, 2008). This concept is depicted in equation 4.5. Equation 4.6 illustrates that environmental impact is equal to the sum of the level of economic output of an industry ($Q_j$) and the “ith” kind of environmental impact per unit of output per industry $I_{ji}$, 2008). In equation 4.6, the industry “j” is considered, where $j=1, 2, 3, ..m$ and thus $I_{ij}$ represents the environmental impact per unit of economic output for industry $j$ (Li, 2008). Equation 4.7 illustrated that for any industry; at least one type of the total environmental impacts has a minimum positive impact per unit of economic output (Li, 2008). This means that no matter what changes occur to technology that $I_{ij}$ is not able to decrease past $[\text{min}] I_{ij}$. The final equation 4.8 in which the total level of economic output is represented by $Y$ and the price index is represented by $P_j$. Equation 4.8 shows that if there was an endless accumulation of capital that ecological sustainability would be disrupted (Li, 2008) and thus that under ecological economics, capitalism is not sustainable.
4.3 Conclusion

Undoubtedly, natural resources and environmental resources are a key component to all economic systems because they provide energy and economic growth. How finite and renewable resources are used directly impacts the present and future growth of economic systems. Environmental and ecological economics have differing views of the relationship between economic growth and the global climate crisis.

Under the environmental approach, the key indicator of economic growth is increases in GDP. Factors which increase economic growth under this approach are (i) increases in the capital stock which corresponds to increases in productivity and (ii) advancements in the technological progress. According to environmental economics, the issue of energy is viewed as secondary and thus it is not a primary element of economic growth. Natural resources and energy resources are not taken into account in the circular flow diagram. Rather, environmental economics accounts for natural resources by valuation approaches and thus incorporates them into the market by the assignment of monetary values.

According to environmental economics, endless economic growth is possible through decoupling. Environmental economists believe that it is possible to have increases in population and affluence with simultaneous decreases in environmental impacts. Environmental economists believe that endless economic growth is possible while minimizing the implications of climate change by continuously advancing technology so that resource intensity and resource use is reduced.

The ecological approach believes that the global biosphere has a subset of cycles, such as, the carbon cycle, water cycle, organic cycle and the nitrogen cycle. Under this
The economic system becomes a subsystem of the biosphere and the environment becomes a sink or a source since it contributes both outputs and inputs to the expanded circular flow model. Ecological economics accounts for natural resources by analyzing changes in throughput and the carrying capacity of the environment. This economic approach emphasizes the importance of energy resources in economic systems, specifically; energy resources and the carrying capacity of the environment are key constraints for economic growth. Ecological economics rejects the notion that it is possible to have increases in GDP and to have simultaneous decreases in environmental impacts due to the lack of empirical evidence for absolute decoupling. According to ecological economics, environmental growth can become compromised by the overuse and deterioration of energy and natural resources.

Given the current state of climate change and the exhaustibility of fossil fuels, a transition to renewable sources of energy is mandatory. Environmental economists would argue that such a transition is not necessary due to the notion of decoupling; the separation between increases in economic growth and increases in environmental impacts. Environmental economics would argue that a transition to renewable sources of energy would decrease economic growth since renewables are not as cheap as fossil fuels. Under this notion, renewables would not be able to provide as substantial increases in productivity, gross domestic product and economic growth as fossil fuels have. In contrast, ecological economics would support the transition to renewable sources of energy since it would increase the sustainability of economic growth. Ecological economists would state that a transition to renewable sources of energy would increase
economic growth since there would be a decrease the use of finite energy resources and environmental resources. Once a transition from fossil fuels to renewable sources of energy has occurred, the long-term sustainability of the current economic system and future economic growth are subject to debate under ecological and environmental economics.
CONCLUSION

The Industrial Revolution marked the advent of global economic growth due to the vast availability of fossil fuels, specifically, coal and oil. The objective of a market-based economic system is to maximize profits. In a capital based economy, the access to cheap forms of energy increased productivity, which led to rapid increases in economic growth. Due to the correlation between economic growth and fossil fuel consumption, governments and economics have regulated the energy market in ways that encourage the production of oil, specifically through government incentives, such as, subsidies aggregating to 544 billion US dollars (International Energy Association, 2013). Fossil fuels are finite and nonrenewable resource, which means that they are inevitably subject to depletion. The production and consumption of oil will continue due to government aid and the lack of alternative energy resources.

As the consumption of oil continues to increase, the global supply will undoubtedly decrease due to the non-renewable nature of this finite resource. The decline in oil reserves is correlated with the global peaking of oil production, a phenomena which is known as peak oil. Due to the variability in different scientific measurements of peak oil, economists and research analysts debate when global peak oil will occur with estimates ranging from 2006 till after 2025. Regardless of when this event will happen, the movement past global peak oil will be associated with a search for unconventional oil
sources or a transition to other forms of energy. A transition to unconventional sources of oil will and decreases the ERoEI of oil will lead to increasing prices in the market place. Further, a transition in fossil fuel energy sources, such as coal and unconventional oil, are associated with economic and environmental costs.

The slow exhaustion of fossil fuel resources will be detrimental to the economy and environment if we do not timely transition to alternative and renewable sources of energy. The gradual depletion of oil will be damaging to the environment if coal replaces oil as a sources of energy. This is due to the fact that coal has greater carbon dioxide emissions associated with its use when compared to oil. Increasing levels of carbon dioxide emission in the environment will increase the effects of climate change. Due to the current state of climate change, it is crucial that with movement past peak oil, that we transition to alternative and renewable energy sources.

There are three main types of renewable energy sources, which are able to supplement the reliance on fossil fuels for electricity: wind, hydro and solar. In the global economy, hydropower is the most commonly used type of renewable source of energy due to the fact that it has high ERoEI when compared to that of solar and wind, making it a more energy dense and cost-effective source of energy. By eliminating the subsidy provided to the fossil fuel industry and transitioning the government aid towards the renewable energy sector, the implementation and use of renewables will increase. Governments and national economies can enhance the already existing security of supply of energy by implementing policies which promote internal and external regulation to distribute market power, policies which encourage “small-hydro” over large scale hydropower
productions and diversifying energy sources by encouraging the use of solar power and wind power with “small-hydro”. Governments and national economies should promote policies that encourage the use of solar and wind power along with hydropower. This will increase a nation’s security of supply through energy source diversification. Further, such policies should also encourage the use of “small-hydro” as a way to mitigate the negative consequences associated with large scale hydropower production. A transition towards renewable sources of energy will reduce electricity generated through the combustion of fossil fuels and therefore significantly reduce the amount of carbon dioxide emitted into the atmosphere and their effects on climate change.

Energy resources are a critical component of any economy and how they are consumed directly influences current and future economic progress. A transition to renewable energy sources is necessary given the current state of climate change, the exhaustible nature of fossil fuels and preservation of the environment. Once an energy transition has occurred, growth under our current economic system is debated under environmental and ecological economics. Environmental economists consider the issue of energy as secondary to economic growth. According to environmental economics, increases in economic growth and decreases in environmental impacts are simultaneously possible if advancements in technology occur. In contrast, ecological economists believe that endless economic growth on a finite planet is not possible. This is because they consider energy and the carrying capacity of the environment as key constraints for economic growth. Once a transition towards renewable sources of energy, such as,
“small-hydro”, wind power and solar power is made, there is a debate if the economic system in place witness increases in growth in years to come.
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