WORLD ENERGY SCENARIOS TO 2050: ISSUES AND OPTIONS

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Introduction

Secure, reliable and affordable energy supplies are fundamental to global economic stability and growth. The challenges ahead of us include the adequacy of energy supplies, the threat of disruptive climate change and the huge investment requirements to meet the growing global energy needs, particularly in the developing countries.

Future energy demand and supply are subject to numerous uncertainties, most of which are difficult to predict. Such as energy prices, particularly oil prices, global economic growth rate, demographic changes, technological advances, government policies and consumer behavior. In such a complex market, energy projections are primarily based on historical information. The primary objective of any energy-scenario analysis must be to analyze the main driving forces that would shape our energy future and the options ahead of us, rather than making accurate quantitative projections. According to Paul Saffo (2007) "*Whether a specific forecast actually turns out to be accurate is only part of the picture -- even a broken clock is right twice a day. Above all, the forecaster's task is to* ***map uncertainty****, for in a world where our actions in the present influence the future,* ***uncertainty*** *is opportunity.*"

There are a number of energy scenarios suggested by several organizations, including the International Energy Agency (IEA), the United States Energy Information Administration (EIA), and the World Energy Council (WEC). All scenarios foresee a substantial increase in global energy demand by 2050. The most comprehensive analysis of the world energy future was conducted by the IEA *Committee on Energy Research and Technology* (CERT). More than 5000 experts from 39 countries participated in this study. The results of this study were published by the IEA in the *"**Energy Technology Perspectives 2008-Scenarios and Strategies to 2050***." This report concludes that without dramatic changes in the way we produce and consume energy, global energy consumption will double by 2050 and CO_2 emissions will continue to rise to two-and-a-half times the current levels. This study makes major recommendations for more sustainable energy future under the ***Accelerated Technology (ACT) Scenario*** and the ***BLUE Map Scenario***.

The main purpose of this paper is to conduct a systemic exploration of possible energy futures and recommended actions. More specifically, the study will identify, define, and analyze the main driving forces of the world energy market to 2050; analyze the options suggested by the IEA; suggest a desired energy scenario; and make strategic recommendation on how to achieve this scenario by 2050.

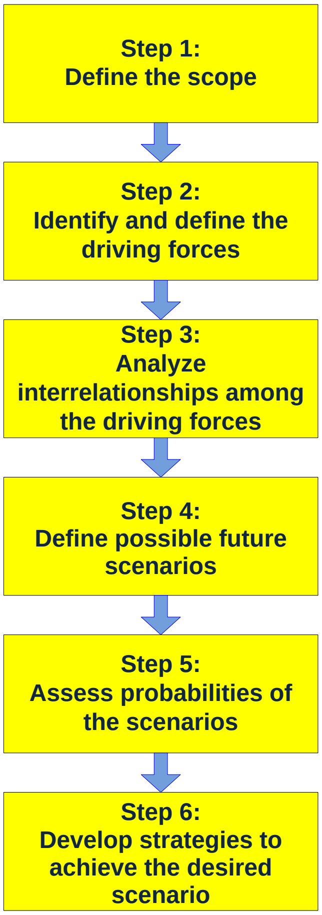
1 Scenario Planning Process

According to Peter Schwartz, “***Scenarios deal with the world of <u>facts</u> and the world of <u>perceptions</u>***,” (Schwartz, 1991). We must find answers to the following questions:

1. What are the driving forces?
2. What do you feel is uncertain?
3. What is inevitable?
4. What are the possible scenarios?

The following scenario planning steps are recommended by the author as the best way to answer the above questions. (Nezhad, 2007)

Figure 1.1: Scenario Planning Process



Step 1: Define the scope

Set the time frame and scope for energy scenario analysis. In this paper the time horizon for world energy demand and supply is to 2050.

Step 2: Identify and define the driving forces (uncertain variables)

What do we believe are the main driving forces of the energy future? We will briefly explain each force and how and why it influences world energy future. In this paper, the following nine global driving forces are considered to be the main factors that would shape world energy future:

1. *Economic Growth Rate;*
2. *Energy Consumption Growth Rate;*
3. *Investment Requirements;*
4. *Demographic Changes;*
5. *CO_2 Emissions;*
6. *Technology Development & Innovation*
7. *Global Energy Intensity*
8. *Oil Prices; and*
9. *Development of Alternative Energy Sources*

Step 3: Analyze interrelationships among the driving forces using STRUCTURE® software

The main purpose of this analysis is to understand the ***dynamics*** of the future energy markets by determining the interrelationships of the driving forces. This analysis sets the stage for developing a scenario model.

Step 4: Define possible future scenarios

In this paper, the possible scenarios are the ones suggested and analyzed by the International Energy Agency (IEA). In 2008, the International Energy Agency (IEA) published the "***Energy Technology Perspectives-Scenarios & Strategies to 2050.***" This visionary report on global energy scenarios clearly illustrates "*how to achieve a clean, clever and competitive energy future*" by 2050. It demonstrates that by employing technologies that already exist or are under development, the world could be brought onto a much more sustainable energy path. The report argues that the continuation of status quo is not sustainable due to rising demand for energy, particularly fossil fuels and unacceptable levels of CO_2 emissions. The report presents three sets of scenarios: ***Baseline***, ***ACT Map*** and ***BLUE Map*** Scenarios. The objective of this paper is to assess probabilities of these three scenarios using the driving forces presented earlier in the paper; propose a more realistic scenario for 2050; and propose strategies to reach this desired scenario. The following sections briefly explain the three scenarios suggested by the IEA.

Scenario 1: The Baseline Scenario

The ***Baseline Scenario*** (business-as-usual scenario) simply looks at the future as a continuation of past and present. Under this scenario, energy consumption will double by 2050 and CO_2 emissions will continue to rise to two-and-a-half times the current levels. This is after taking into consideration energy efficiency gains and technological progress that can be expected under existing policies.

Scenario 2: The Accelerated Technology (ACT) Scenario

In the ***Accelerated Technology (ACT) Scenario***, energy consumption will be at about 77% of the Baseline Scenario and energy-related CO_2 emissions will be reduced to their 2005 levels by 2050. This scenario also shows that by 2050, energy efficiency measures can reduce electricity demand by a third below the Baseline levels.

Scenario 3: The BLUE Map Scenario

In the ***BLUE Map Scenario***, energy consumption will be about 67% of the Baseline Scenario and the CO_2 emissions will be 50% lower than the 2005 levels. This scenario explores the least-cost solutions to achieve this goal and limit the risks of severe climate change. To meet the objectives of the BLUE Scenario, we must develop and implement far-reaching new policies to substantially "decarbonize" power generation.

Both the ACT and BLUE Scenarios require extensive use of renewable energy resources which would provide 35% and 46% of the total power generation requirements. IEA report states that these scenarios are not predictions; rather they are the ***"least-cost pathways that may be available to meet energy policy objectives, given a certain set of optimistic technology assumptions."*** Table 1.1 summarizes these three scenarios.

Table 1.1: IEA Scenarios to 2050

Scenarios	**Energy Demand (Mtoe/yr)**	**CO_2 Emissions (Giga tons)**	**CO_2 Concentrations (ppm)**	**Investment Requirement** (Trillion US$-2005 Value)	**Distinguishing Characteristics**
2005 Actual Value	7,748	27	385		
Baseline	15,683	62	550	254	Business-as-usual
ACT Map	12,076	27	485	271	• High energy efficiency
BLUE Map	10,553	14	450	299	• High energy efficiency • Extended use of biofuels and EVs

Step 5: Assess probabilities of these scenarios for each internal and external force using DECIDE 2000® software

This step includes a systematic analysis of the driving forces and the proposed scenarios using a Decision Support Software developed by the author. The probability of each scenario is assessed and a desired scenario is proposed using the “*expected value*” of the scenarios.

Step 6: Develop strategies to achieve the desired scenario

At this stage, a desired world energy scenario will be selected and strategies to achieve this scenario are identified and prioritized.

2 Driving Forces of World Energy Supply and Demand

The Major driving forces of world energy demand and supply could be clustered into nine groups as follows:

1. *Economic Growth Rate;*
2. *Energy Consumption Growth Rate;*
3. *Investment Requirements;*
4. *Demographic Changes;*
5. *CO_2 Emissions;*
6. *Technology Development & Innovation;*
7. *Global Energy Intensity;*
8. *Oil Prices; and*
9. *Development of Alternative Energy Sources*

Some of these forces are more predicable than others. For example, population growth rate is more certain than the technology innovation rate. The following sections provide a more detailed explanation of each driving force.

2.1 Economic Growth Rate

World economy grew 5.2% in 2007 to $66 trillion (PPP). But it grew at a slower rate of 3.4% in 2008. Global economy is expected to decline by 1.4% in 2009, but with strong government policies, it could grow as high as 2.5% in 2010 (IMF, July 2009).

Growth in emerging and developing economies is expected to slow sharply from 6¼ percent in 2008 to 2 percent in 2009, under the drag of falling export demand and financing, lower commodity prices, and much tighter external financing constraints (especially for economies with large external imbalances).

Figure 2.1: World Economic Growth Rates (%)

Source: International Monetary Fund (IMF), World Economic Outlook: Crises and Recovery, April, 2009
http://www.imf.org/external/pubs/ft/weo/2009/01/

In all IEA scenarios, world economy is expected to grow at an annual average rate of 3.3% until 2050 quadrupling world GDP to about $227 trillion. The economic growth rates in developing countries are expected to be much higher than the developed ones. For example, European and Japanese economy will double and the North American economy will grow to 2.5 times its current levels. But in some developing countries such as China and India GDP could grow as high as ten-fold between now and 2050. Higher economic growth means higher standard of living for the global community. Global average per-capita GDP is expected to grow by 187% to $24,400 by 2050.

As people's income improves, so does their demand for goods and services as well as energy. This will put an unsustainable pressure on natural resources and on the environment unless energy demand is decoupled from economic growth and more renewable resources are used.

2.2 Energy Consumption Growth Rate

As shown in Table 2.1, world energy consumption would double under the ***Baseline Scenario***. Even under the most optimistic scenario (BLUE Map Scenario), world energy consumption will grow at a rate of 0.7% per year as shown in Table 2.2.

Table 2.1: World Total Energy Consumption in 2005 and the three Scenarios for 2050 (Mtoe/yr)

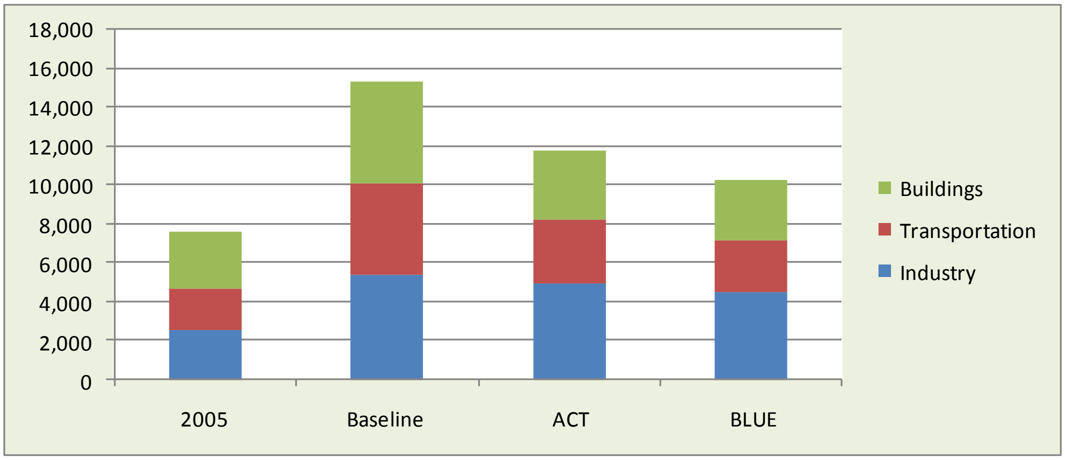
	2005	Baseline	ACT Map	BLUE Map
Total end-use	7,748	15,683	12076	10553

Table 2.2: World Energy Consumption growth rate (%/yr)

Sectors	Baseline	ACT Map	BLUE Map
Industry	1.7	1.5	1.3
Transportation	1.8	1.0	0.5
Buildings	1.3	0.4	0.2
Non-energy use	1.9	1.9	1.4
Total end-use	1.6	1.0	0.7

Energy demand will continue to grow in all sectors between now and 2050. The highest growth rate will be in transportation, followed by industry and buildings as shown in Figure 2.2.

Figures 2.2: Energy Consumption by Sector for 2005 and the three scenarios (Mtoe/yr)



2.2.1 Energy Use in Buildings

Energy use in buildings currently account for about 40% of global total final energy consumption. Of this, 45% is consumed in OECD countries, 10% in countries in transition, and around 46% in developing countries.

Buildings consumed 2,914 Mtoe of energy in 2005. The residential and service sectors accounted for 2,569 Mtoe of this, with residential sector accounting for 2/3 and service sector 1/3 of this energy use.

Energy demand in the buildings sector increases from 2,914 Mtoe in 2005 to 5,257 Mtoe in 2050 in the Baseline scenario, or 1.3% increase per year. The residential sector accounts for about 60% of this growth rate and the service sector about 30%. The remainder is from agriculture, fishing, etc.

According to the *World Business Council for Sustainable Development (WBCSD),* energy use in buildings can be cut by 60 percent by 2050. This is equivalent to the total energy consumed in today's transportation and industrial sectors combined. But this will require immediate action to transform the building sector (WBCSD, 2009).

Unlike consumer goods, buildings can last for decades, even centuries. More than half of the existing building stock will still be standing in 2050. Buildings are much more frequently renewed than replaced.

Energy consumption in buildings is highly influenced by local climate and cultures, and even more so by individual users. Energy demand in the residential sector is driven by demographics, geography, income and cultural factors. The average household in China is estimated to have had 6.7 lights in 2003, as compared to 40 lights in the average Swedish household.

Rising household incomes and an urban construction boom in China have pushed up energy use in buildings while in India, rising incomes and growing numbers of households are also pushing up demand. In China, rising incomes and the increased urbanization of a middle class have also spurred the beginning of a substantial switch from solid fuels (biomass and coal). In India, however, the shift is away from traditional biomass, wastes and animal dung to commercial fuels such as kerosene, LPG, and electricity.

In 2005, the building sector consumed 57% of all electricity, making buildings the largest electricity consumer. During the same year, 28% of the building sector's energy needs were met by renewable, mainly traditional biomass in developing countries.

Electricity demand in the residential sector is projected to continue to grow at an annual average rate of 2.7%, increasing its share from 19% to 36% between 2005 and 2050. Non-biomass renewable, predominately solar, grow rapidly from a low base between 2005 and 2030, but more slowly thereafter.

Heat consumption increases at 1.5% per year, gas consumption at 1.3% per year and oil consumption at 1% per year. Coal consumption declines at 1% per year.

Cooling demand is set to grow rapidly in the residential sector in the Baseline scenario, but from a very low level.

Energy efficient appliances and lighting and better building envelop play a key role in the ACT Map scenario. In the BLUE Map scenario, heat pumps and solar heating increases the emission reduction in the building sector further.

Savings in space and water heating account for around 60% of the savings in each scenario in the residential sector, while the same end use account for around half of the savings in the service sector due to the relatively greater importance of the savings from lighting and other electrical uses in the service sector.

The thermal performance of windows has improved greatly through the use of multiple glazing layers, low-conductivity gases (argon in particular) between glazing layers, low emissivity coatings on one or more glazing surfaces, and the use of very low conductivity framing materials such as extruded fiberglass. Windows are available with heat losses of only 25% to 35% of standard non-coated double glazed windows.

The efficiency of hot-water systems can be improved in several ways, from installing hot-water cylinder insulation to installing condensing boilers or heat pumps. Solar hot water heating systems, depending on the location, could provide as much as 60% to 70% of domestic hot-water needs, and perhaps up to 50% of the hot-water needs of service sector buildings.

Demand-Side Management (DSM) tools can play an important role in reducing CO_2 emissions from peak electricity generation where supply-side options are expensive. DSM influences the amount or pattern of energy use-for example, by reducing demand during peak periods when energy-supply systems are constrained.

2.2.2 Industrial Sector

Manufacturing industry accounts for more than one-third of global energy use and CO_2 emissions. The iron and steel, and cement industries represent about half of industry’s emissions.

In the Baseline scenario, energy consumption in industry grows from 2,564 Mtoe in 2005 to 5,415 Mtoe in 2050. Final energy consumption in 2050 is 9% lower in the ACT scenario and 17% lower in the BLUE scenario. While changes in the energy mix are relatively small in the ACT Map scenario, coal and oil use are significantly lower in the BLUE Map scenario, which is partly compensated for by increased use of biomass.

The application of the best available technologies worldwide would result in a savings of some 19% to 32% of current CO_2 emissions in this sector. This includes improvements to steam supply systems and motor systems, which offer efficiency potentials of 15% to 30%. Industrial CHP can complement new process designs that reduce heat demand per unit of output. Industrial emissions can also be reduced using CO_2 capture and storage (CCS), especially in the production of chemicals, iron and steel, cement, and paper and pulp.

2.2.3 Power Sector

Electricity production is responsible for 32% of total global fossil fuel use and 41% of energy-related CO_2 emissions today. Improving energy efficiency of electricity production therefore offers a significant opportunity to reduce the world's dependence on fossil fuels and in so doing helps to combat climate change and improve energy security.

Overall, 40% of world's electricity comes from coal and 20% from gas. In South Africa and Poland the share of coal in power generation is above 90%. In China and Australia it is close to 80%, as in India, where it is more than 66%, UK 40%, US and Japan about 20%. The age of a country's power plants, will be an important factor, as the current efficiency of most coal-fired power plants is well below state-of-the-art.

In the Baseline scenario, global electricity production increases by 179% between 2005 and 2050, making electricity the fastest-growing component of total energy demand. Coal-based generation is forecast to be 252% higher than in 2005. It accounts for 52% of all power generation. Gas-fired power generation increases from 20% today to 23% in 2050. Nuclear decreases to 8%, hydro decreases to 10%, and wind increases to account for 2.5% of all power generation.

Already available clean coal technologies can make a significant contribution to containing the growth of CO_2 emissions from power generation. Use of advanced steam cycle or integrated gasification combined-cycle (IGCC) technologies could raise the average efficiency of coal-fired power plants from 35% today to 50% in 2050.

Power generation using natural gas is competitive with coal at today's price for natural gas and coal in many regions of the world. The average efficiency of natural gas-fired power plants increased from 35% in 1992 to 43% in 2005. Most of the improvement in efficiency was a result of the introduction of large combined-cycle units, which now accounts for 38% of global gas-fired capacity. Today, natural gas combined-cycle (NGCC) power plants are often preferred over conventional coal-fired plants due to: 1) efficiency achievements topping 60%; 2) lower capital costs of $600 to $750 per KW, compared with $1400 to $2000 per KW for a typical coal-fired plant; 3) shorter construction times; and 4) lower emissions: NGCC plants emit less than half the CO_2 emissions of similarly rated coal-fired plants.

Cogeneration, or combined heat and power (CHP), is the simultaneous utilization of useful heat and power from a single fuel source. CHP plants can convert 75% to 80% of the fuel resource into useful energy, with some plants reaching overall efficiencies of 90% or more. Almost any fuel is suitable for CHP.

The role of natural gas in power generation increases moderately in the ACT scenarios but declines in the BLUE scenarios where deeper emission cuts are needed.

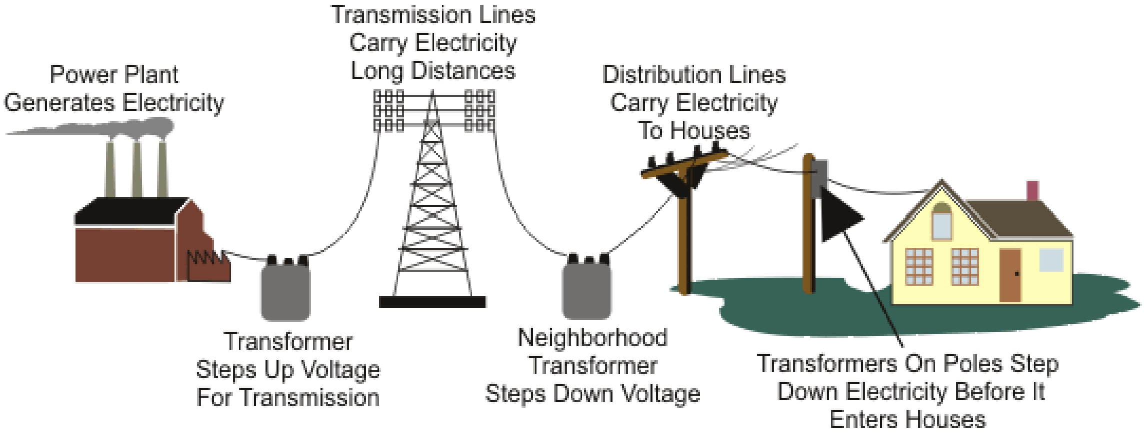
Natural gas fuel cells for distributed generation or back-up power are currently used in demonstration projects or niche applications. Fuel cells and other emerging decentralized power generation technologies are expected to raise overall fuel efficiencies, but require further RD&D.

The share of renewable energy sources in electricity generation increases from 18% in 2005 to 35% in 2050 in the ACT scenario and to 46% in the BLUE scenario. To cope with increasing amounts of variable renewable, electricity grids will need to be improved and electricity storage technologies will need to be deployed on a large scale. Electricity cannot be stored directly (except for in small-scale capacitors), but it can be transformed into other types of energy that can be stored. In batteries, for example, electricity is transformed into chemical energy. In pumped-storage hydropower systems, it is transformed into potential energy. Electricity can also be converted for storage as compressed air or in flywheels.

With the exception of wind technology, the largest share of deployment for new power generation technologies is expected to take place in the United States. Europe will dominate deployment of wind technologies in the early phase, but widespread uptake will require a greater market uptake in the United States and China.

Electricity, once generated, is transferred long distances through transmission lines and distribution systems to end users as shown in Figure 2.3. A significant amount of energy is lost in transmission and distribution (T&D) systems. In the electric sector, these losses are called '*line losses'* and while some are due to technical factors such as line heating, theft of electricity also can contribute to losses.

Figure 2.3: Electricity Generation, Transmission, Distribution and End Use



Source: Energy Information Administration (EIA)
http://www.eia.doe.gov/basics/electricity_basics.html

Transmission and distribution (T&D) losses need to be given more attention, especially in developing countries where important opportunities exist to reduce these losses. The average loss through transmission and distribution varies among countries, representing from 5 to 25% of total power production.

Given the high cost and inefficiency of T&D systems, decentralized power generation has received considerable attention. They have a potentially important role to play in rural and remote areas. In the BLUE Map, decentralized, building-integrated PV systems account for a significant share of power generation. As 80% of the world population will live in the cities in 2050, the market for decentralized power generation will depend on its success in urbanized environments.

2.2.4 Transportation Sector

Transportation sector accounts for more than half of oil used worldwide and nearly 25% of energy-related CO_2 emissions. In the Baseline scenario, energy demand in the transport sector increases by 120% between 2005 and 2050. Global transport energy demand in 2050 exceeds 4,700 Mtoe. Oil products provide 75% of this, and liquid synfuels produced from gas and coal account for about 22%. Biofuels, both biodiesel and ethanol, only contribute 3%. The fastest growth is expected to come from air travel, road freight and light-duty vehicles.

In the BLUE Map, transport-wide CO_2 emissions are reduced overall to about 30% below the 2005 level by 2050.

Decarbonizing the transport sector is a major challenge. Demand for automobile travel is projected to increase more than threefold, while freight will grow at an even faster rate. Efficiency gains of 30% to 50% available with conventional technology will be insufficient to outweigh demand growth. Biofuels, electricity from the grid and clean hydrogen are the three CO_2 free energy carriers that can be used in this sector. All three need further development.

Rail accounts for a small share of transport energy use and GHG emissions (3%), but it holds potential for significant growth in the future, particularly in the developing world. IEA estimates show that if 25% of all air travel in 2050 under 750 km were shifted to high-speed rail travel, around 0.5 Gt of CO_2 per year could be saved. Similarly, if 25% of all trucking over 500 km were shifted to rail, about 0.4 Gt of CO_2 could be saved per year. This would require a dramatic increase in rail infrastructure investment around the world.

High Speed Rail (HSR) is typically defined as steel-on-rail operation with cruise speeds exceeding 200 km/h. HSR exists in Europe, Japan, Taiwan, and the east coast of US. The energy use of HSR is one-third to one-fifth that of airplane and car energy us per passenger-kilometer.

Airlines and aircraft manufacturers have a strong incentive to improve aircraft energy efficiency, as fuel costs represent a significant (and rising) share of their operating expenses.

Alternative fuels are likely to play an important role in getting to very low GHG emissions levels in transport by 2050. Over the next 10 to 15 years, the most cost-effective are likely to be biofules, particularly cane ethanol from Brazil and perhaps other developing countries.

The use of hydrogen for transport would provide variety of benefits: very high fuel efficiency; near zero pollution from vehicle operation; and near zero greenhouse gases if the hydrogen is produced from low-GHG sources or with carbon capture. Its drawbacks include a shorter range than for liquid fuelled vehicles, possibly long refueling times and costs. It is 2 to 3 times the cost of gasoline.

It is unlikely that a commercial, widespread system of hydrogen fuels for most modes of transport will emerge much before 2030, due to technical hurdles, high costs and extensive infrastructure equipments. For hydrogen to play a significant role, there need to be massive changes to both vehicle design/production practices, and to fuel production, distribution, and delivery systems. The use of hydrogen and fuel cells appears most likely for cars, buses and urban-duty trucks. The rail sector could also be a user of hydrogen.

Vehicle electrification is re-emerging as a potentially viable long-term option. Plug-in hybrids offer a potential near-term option as a means of transition to full electric vehicles. But battery costs are still 2 to 3 times as high as they need to be commercially viable.

2.3 Investment Requirements

To meet global energy needs by 2050, IEA estimates total cumulative investment of at least $254 trillion between 2005 and 2050 (in 2005 dollar value). This figure represents only 6% of cumulative global GDP over this period. Figure 2.4 and Table 2.3 summarizes investment needs in each scenario.

Figure 2.4: Cumulative Investment Needs for the Three Scenarios between 2005 and 2050

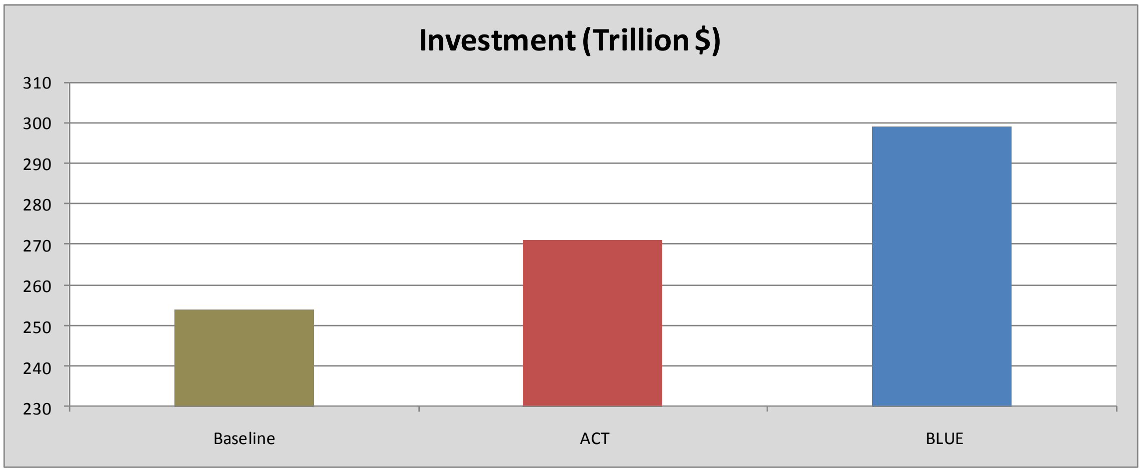


Table 2.3: Cumulative Investment Needs for the Three Scenarios between 2005 and 2050

Scenarios	Investment (Trillion $)	% of Cumulative Global GDP
Baseline	254	6
ACT	271	6.4
BLUE	299	7.1

Most of the investment is expected to be on the demand side. The investment needs on the demand side is much higher in the ACT Map and BLUE map compared to the Baseline scenario. Additional demand-side investments in the ACT Map and BLUE Map will result in significant energy savings as shown in Figure 2.5 and Table 2.4.

Figure 2.5: Energy Savings as a result of additional Investments in the ACT and BLUE Scenarios between 2005 and 2050

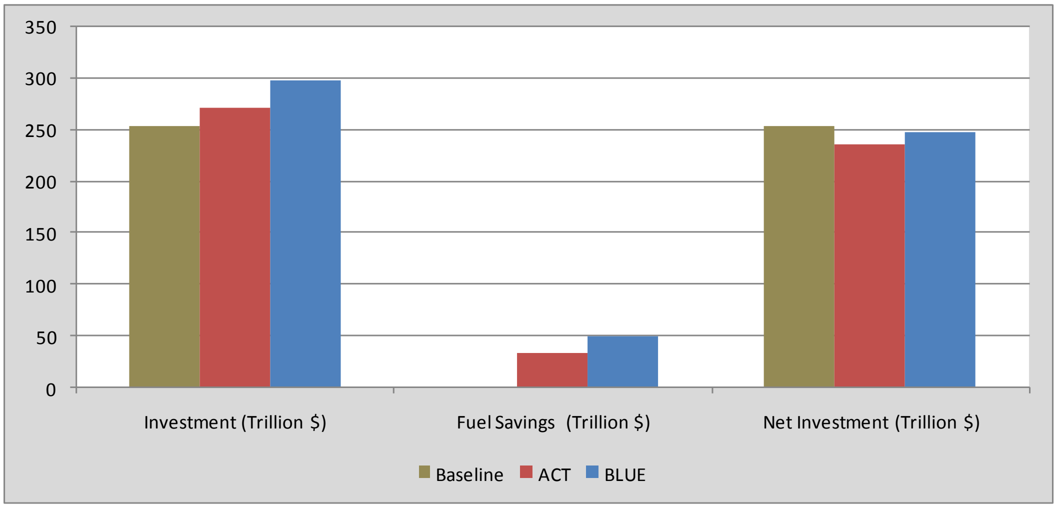


Table 2.4: Energy Savings as a result of additional Investments in the ACT and BLUE Scenarios between 2005 and 2050

Scenarios	Investment (Trillion $)	Fuel Savings (Trillion $)	Net Investment (Trillion $)
Baseline	254		254
ACT	271	34.7	236.3
BLUE	299	50.6	248.4

Transportation sector dominates investment needs in all scenarios. In the Baseline scenario, it accounts for about 84% of total investment. Transportation dominates the demand-side investments due to the high unit costs of cars, trucks, ships and planes and huge increases in their use, particularly in developing countries. Figure 2.6 and Table 2.5 show that the Investment needs in the ACT and BLUE scenarios are much higher than the Baseline, the reason being heavier investments in expensive hybrid and plug-in vehicles. In the BLUE scenario, fewer conventional vehicles will be sold and more electric vehicles (EVs) and hydrogen fuel cell (HFC) vehicles will be used.

Figure 2.6: Cumulative Investments Needs in the Transportation Sector between 2005 and 2050

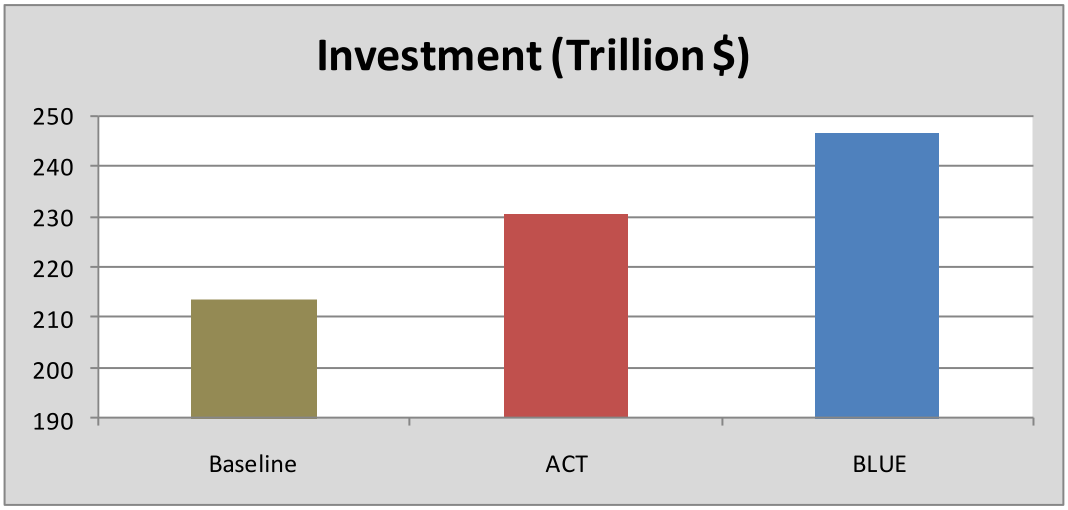


Table 2.5: Cumulative Investments Needs in the Transportation Sector between 2005 and 2050

Scenarios	Investment (Trillion $)
Baseline	213.36
ACT	230.36
BLUE	246.36

Investments in the electricity sector including generation, transmission and distribution, vary significantly in the three scenarios as shown in Figure 2.7 and Table 2.6. In the ACT scenario, energy efficiency reduces electricity demand growth, reducing the need for new generation capacity and expansion of the transmission and distribution systems. However, in the BLUE scenario, increased electrification requires additional investment in the power sector.

Figure 2.7: Cumulative Investments Needs in the Electricity Sector between 2005 and 2050

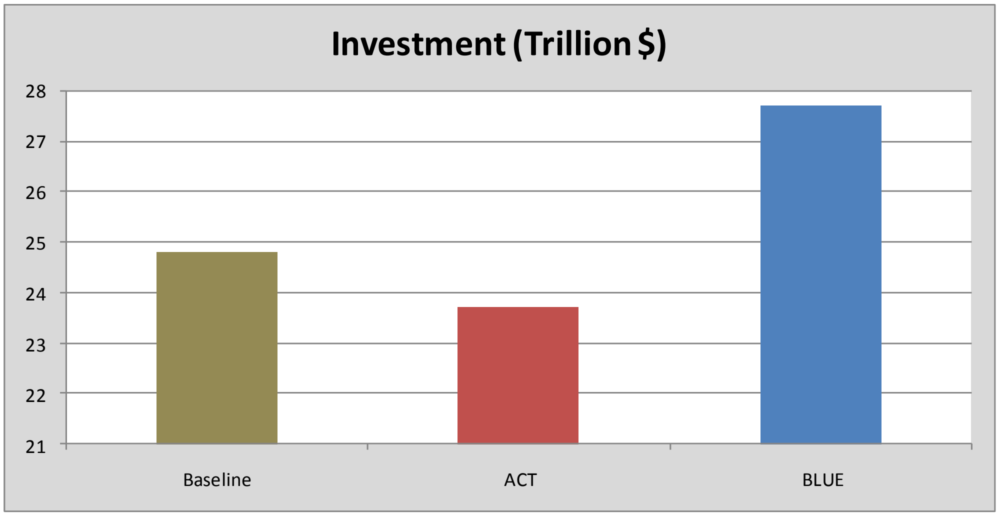


Table 2.6: Cumulative Investments Needs in the Electricity Sector between 2005 and 2050

Scenarios	Investment (Trillion $)
Baseline	24.8
ACT	23.7
BLUE	27.7

Investments in the building sector also vary in the three scenarios as shown in Figure 2.8 and Table 2.7. Both the ACT and BLUE scenarios require additional investments in the building envelop, efficient heating, cooling and lighting systems, and efficient appliances.

Figure 2.8: Cumulative Investment Needs in the Building Sector between 2005 and 2050

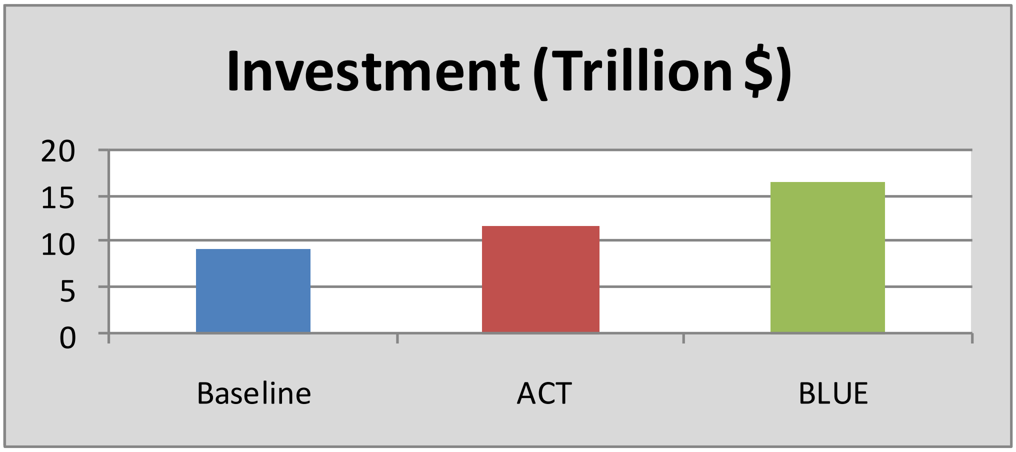


Table 2.7: Cumulative Investment Needs in the Building Sector between 2005 and 2050

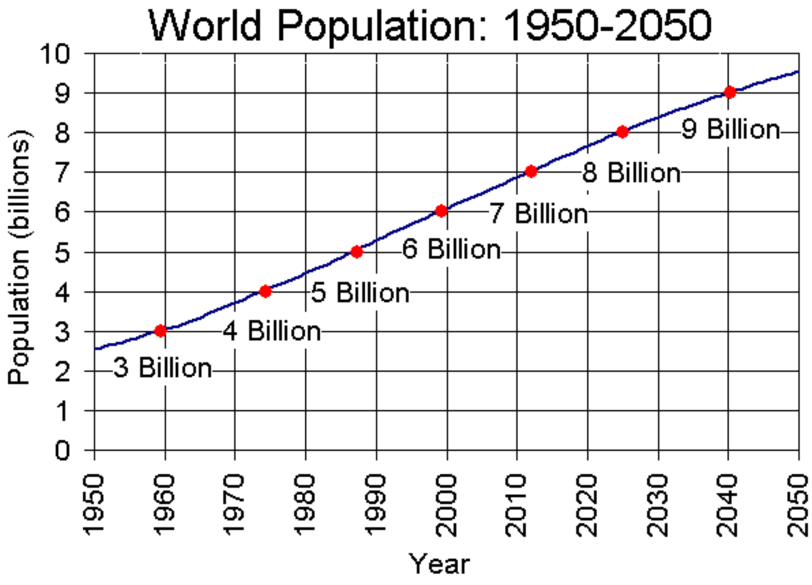
Scenarios	Investment (Trillion $)
Baseline	9.1
ACT	11.7
BLUE	16.5

According to the IEA report, more than half of these investments are needed after 2030.

2.4 Demographic Changes

Population is one of the key determinants of energy consumption. It influences demand for goods and services, housing, and transportation. World population increased from 3 billion in 1959 to 6.75 billion in 2008. The U.S. Census Bureau's latest projections imply that population growth will continue but at a slower pace well into the future, as shown in Figure 2.9. The world population is projected to grow to 9.2 billion by 2050, peaking soon afterward at 9.8 billion before falling to 5.5 billion by 2100 (World Federation of UN Associations, 2008). China, India and the transition economies will together account for about 1/3 of the world population in 2050.

Figure 2.9: World Population: 1950-2050



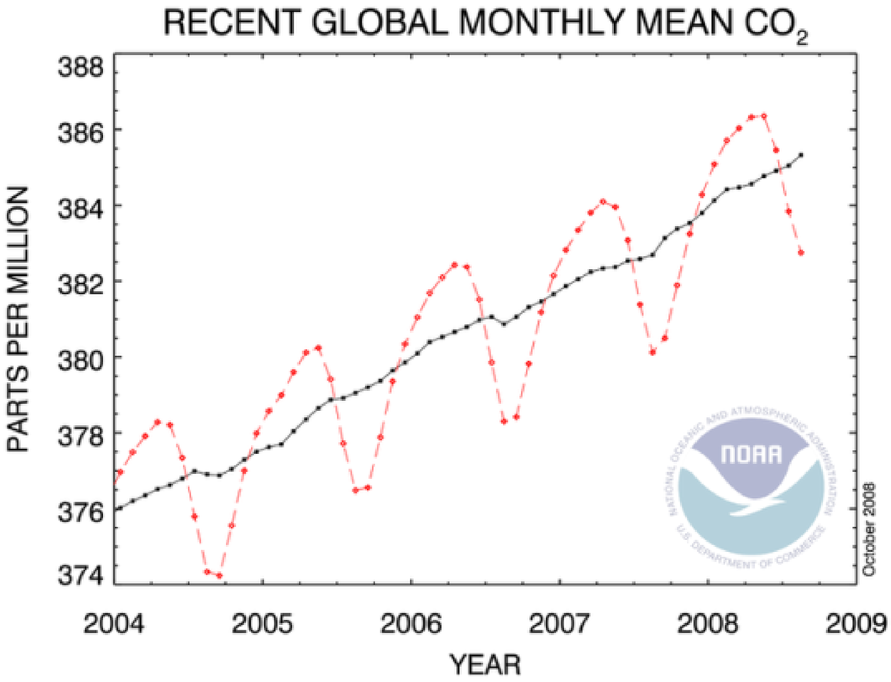
Source: U.S. Census Bureau, International Data Base, December 2008 Update.

Demographic changes such as age, income, and geographic distribution of the population also affect the growth of energy consumption. Global demography is expected to change over the next forty years. More than 80% of humanity is expected to live in urban areas by 2050. Also, there will be a continuing trend towards fewer people per household. Thus, the global number of households is projected to grow faster than population growth. Population growth, fewer people per household, urbanization, and the trend towards larger household floor area are all key drivers of growth in demand for energy services. Today, about 2 billion people do not have access to commercial forms of energy and another billion have only periodic unreliable access. This number is expected to decline to 0.5 billion by 2050.

2.5 CO_2 Emissions

One of the major global challenges in the coming decades is how to maintain universal availability of commercial energy services with minimum damage to the environment. According to a report by the *Intergovernmental Panel on Climate Change* (IPCC, 2007), about 69% of all CO_2 emissions are energy related and about 60% of all greenhouse emissions can be attributed to energy production and consumption. The CO_2 concentration in the atmosphere is about 385 parts per million (ppm), and is rising by about 2 ppm per year. Figure 2.10 shows recent upward trends in CO_2 concentration in the atmosphere.

Figure 2.10: Recent Trends in CO_2 Concentration in the Atmosphere

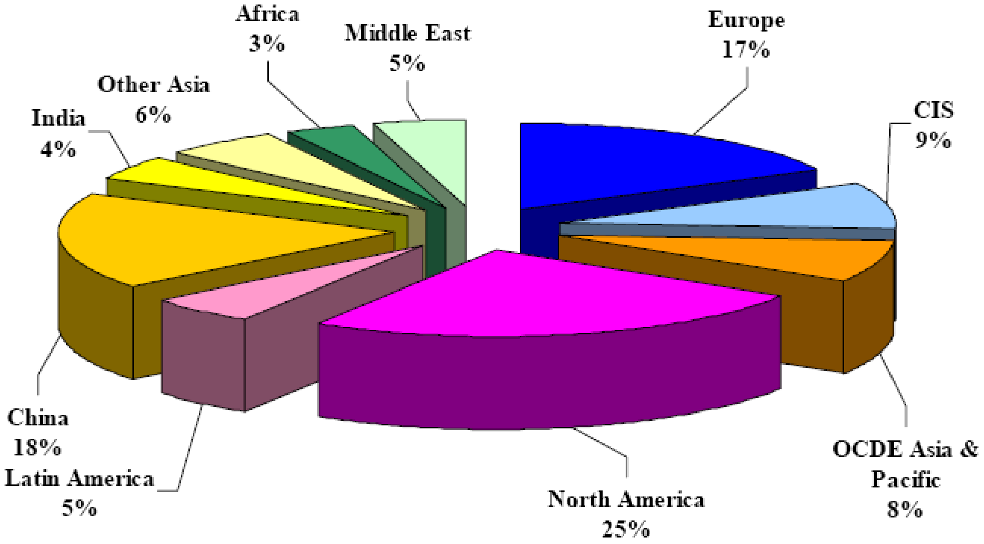


Source: U.S. Department of Commerce | National Oceanic and Atmospheric Administration
Earth System Research Laboratory | Global Monitoring Division
http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html

The IPCC report warns that if current trends in CO_2 emissions continue, global average temperature could rise by 6 ^{o}C. The consequence would be significant change in all aspects of life and irreversible change in the natural environment. Thus, there is an urgent need to mitigate greenhouse gas emissions in order to confine global warming to between 2 and 2.4 ^{o}C.

Developed regions are the largest emitters of CO_2 from fuel combustion. As shown in Figure 2.11, North America, Europe, the Commonwealth of Independent States (CIS), Asia Pacific OECD together account for 54% of the world total CO_2 emissions, whereas they represent only one fifth of the world population. China is the main emitter in the developing regions with 18% of total global emissions (WEC, 2008-EE).

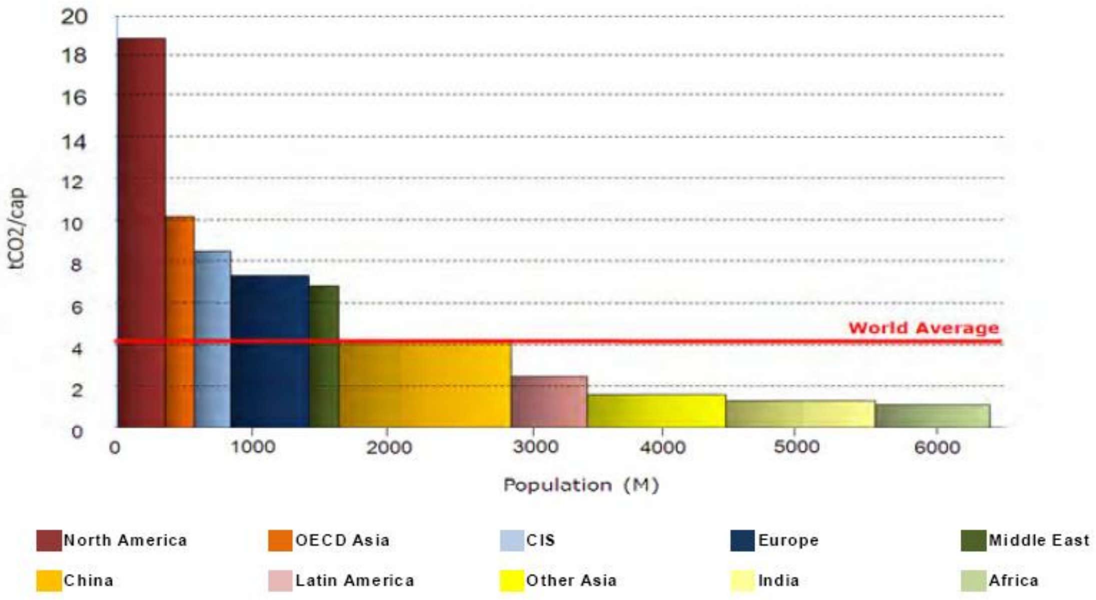
Figure 2.11: Distribution of world CO2 emissions from energy use (2006)



Source: WEC, 2008-EE

Figure 2.12 shows that per capita CO_2 emissions in North America is more than four time higher than the global average.

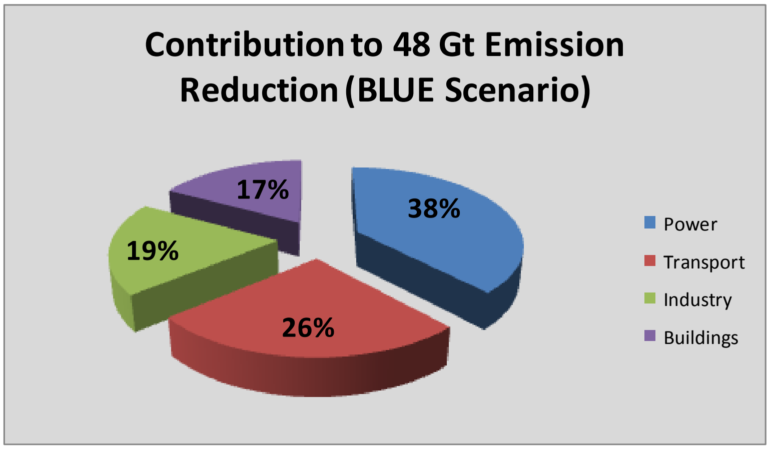
Figure 2.12: Per Capita CO_2 Emissions



Source: WEC, 2008-EE

The IEA projections show that, in the Baseline scenario, CO_2 emissions will increase from 27 giga tons (10^9 tons) in 2005 to 42 giga tons by 2030 reaching 62 giga tons in 2050 (a 130% increase compared with 2005 level). Most of the emissions come from the power sector, followed by the industrial and transport sectors. In the ACT scenario, CO_2 emissions can be brought back to 2005 level of 27 giga tons by 2050. However, the BLUE scenario, targets at least a 50% reduction in CO_2 emissions by 2050, bringing emissions down to about 12 giga tons. As shown in Figure 2.13, most of the contributions to emission reductions come from the power sector and the transport sector.

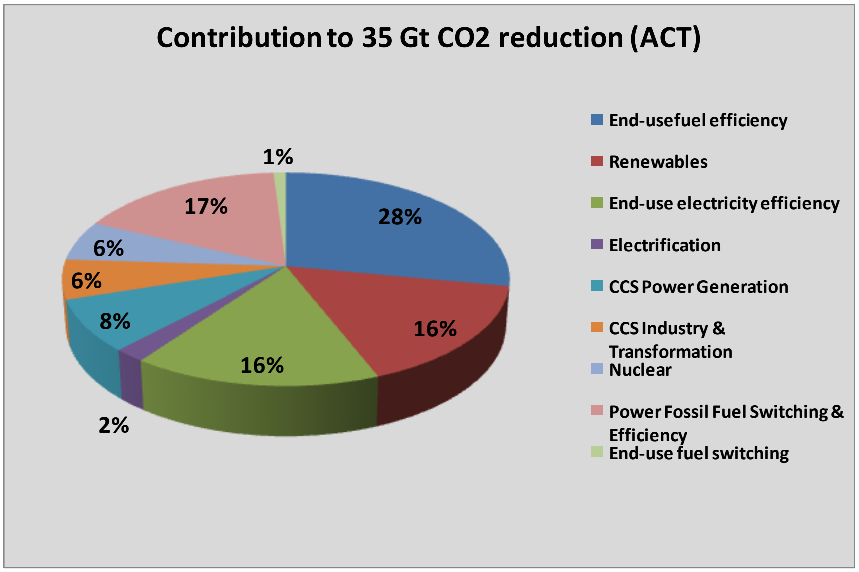
Figure 2.13: Contribution to 48 Gt Emission Reduction in the BLUE Scenario (by sector)



Source: IEA-ETP-2008

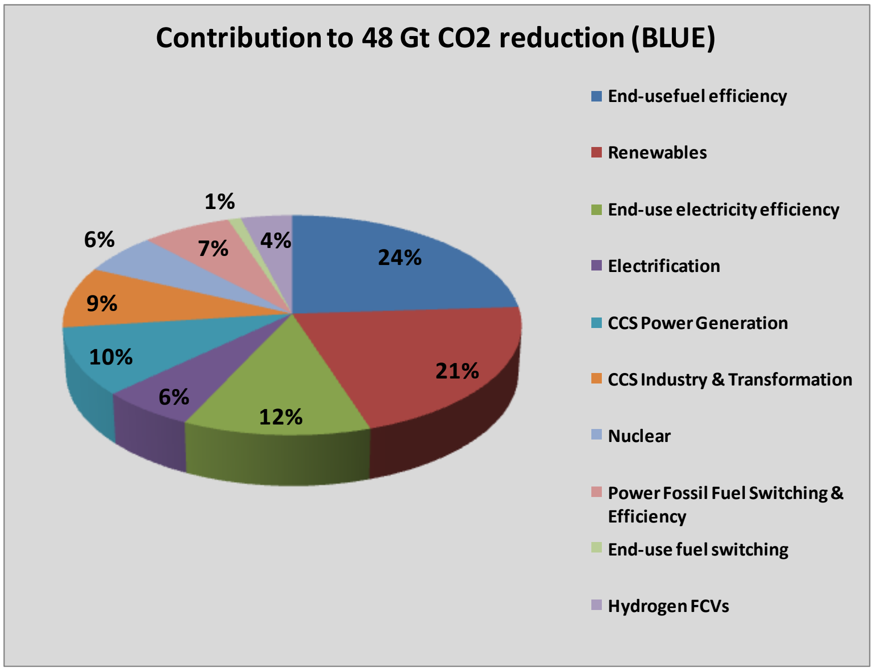
Technology contributions to emission reductions in ACT and BLUE scenarios are shown in Figures 2.14 – 2.15 and Table 2.8.

Figure 2.14: Technology Contribution to 35 Gt Emission Reductions in the ACT Scenario



Source: IEA-ETP-2008

Figure 2.15: Technology Contribution to 35 Gt Emission Reductions in the BLUE Scenario



Source: IEA-ETP-2008

Table 2.8: Technology Contribution to Emission Reductions in ACT and BLUE Scenarios

Technology	Contribution to 35 Gt CO2 reduction (ACT)	Contribution to 48 Gt CO2 reduction (BLUE)
End-usefuel efficiency	28%	24%
Renewables	16%	21%
End-use electricity efficiency	16%	12%
Electrification	2%	6%
CCS Power Generation	8%	10%
CCS Industry & Transformation	6%	9%
Nuclear	6%	6%
Power Fossil Fuel Switching & Efficiency	17%	7%
End-use fuel switching	1%	1%
Hydrogen FCVs	0%	4%

As shown in the above figures and table, in both ACT and BLUE scenarios, end-use efficiency provides the greatest opportunity for emission reductions followed by changes in power generation. Renewables account for 16% and 21% of emission reductions respectively. About 1/4th of the renewable contribution comes from biofuels.

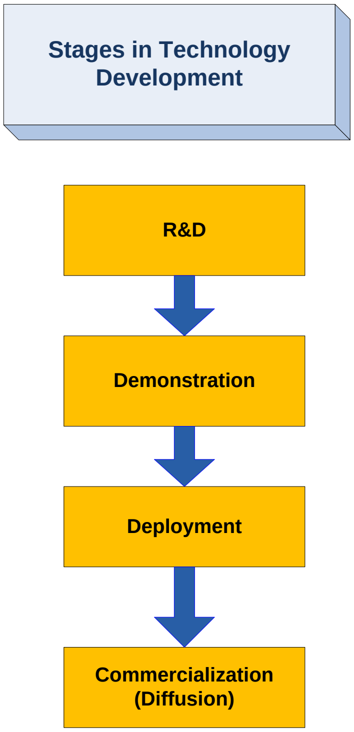
Carbon Capture and Storage (CCS) which account for 14% and 19% of emission reductions in ACT and BLUE scenarios, involves three main steps: 1) CO_2 capture from a large stationary source such as a power plant; 2) Transportation to an injection sink. Onshore or offshore pipelines, ships and trucks are the most common options; 3) Underground geological injection. CCS costs between $40 to $90/ton of CO_2 emissions avoided. Using CCS with new natural gas and coal-fired power plants would increase electricity production costs by 2 to 4 cents/KWh.

2.6 Technology Development & Innovation

Technology development and innovation contribute to energy solutions on both demand-side and supply-side. On the demand-side, it contributes to energy efficiency improvements in buildings, appliances, transportation, industry, and power equipments. On the supply-side, it contributes to the development of renewable resources, clean coal technologies, and advanced nuclear technologies. It also contributes to the development of energy-storage and cost-effective CO_2 capture and Storage (CCS).

Technology development is essential in reducing costs for existing and new technologies. Only through global R&D efforts and commercialization of these technologies, their costs could be reduced to the levels acceptable to energy producers and consumers. Figure 2.16 illustrates technology development process.

Figure 2.16: Technology Development Process



Source: IEA-ETP-2008

Legend:

R&D: *R&D seeks to overcome technical barriers and to reduce costs. Commercial outcomes are highly uncertain, especially in the early stages.*

Demonstration: *The technology is demonstrated in practice. Costs are high. External (including government) funding may be needed to finance part or all of the costs of the demonstration.*

Deployment*: Successful technical operation, but possibly in need of support to overcome cost or non-cost barriers. With increasing deployment, technology learning will progressively decrease costs.*

Commercialization*: The technology is cost competitive in some or all markets, either on its own terms or, where necessary, supported by government intervention (e.g. to value externalities such as the cost of pollution).*

Today, private sector spending on energy-related R&D is about $40-$60 billion per year compared to $10 billion per year in the public sector. The average R&D spending in OECD countries is less than 0.03% of GDP, except for Japan which is about 0.08% of its GDP.

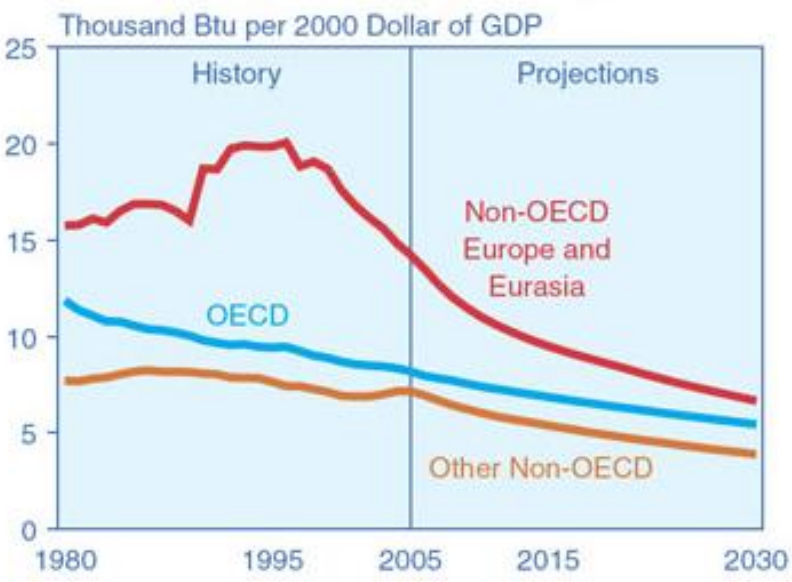
Governments have a crucial role to play in ensuring the technology development and innovation required by the ACT and BLUE scenarios. In addition to investment, governments have to establish processes to prioritize and evaluate national RD&D programs. They must develop policies that can stimulate private sector investment in energy RD&D technology.

International cooperation and public-private partnerships are needed to increase RD&D investments for the deployment of new energy technologies.

2.7 Global Energy Intensity

Energy intensity is measured as the energy required to produce a unit of economic activity. It is a measure of energy efficiency. Global energy intensity has declined at an average rate of 1.5% per year since 1973. Europe has the lowest energy intensity. European energy intensity is 30% lower than in North America and 40% lower than in China. The Commonwealth of Independent States (CIS) requires three times more energy per unit of GDP than Europe. High energy intensities are as a result of various factors such as lower energy efficiency, dominant role of the energy-intensive industries and low energy prices (WEC, 2008-EE). Figure 2.17 shows energy intensity trends by region from 1980 to 2030.

Figure 2.17: Energy Intensity by Region, 1980-2030



Source: Energy Information Administration. International Energy Outlook 2008 http://www.eia.doe.gov/oiaf/ieo/world.html

Industrial energy intensity has declined substantially over the last three decades. However, there are still ample opportunities for improving energy efficiency in this sector. For example, in energy-intensive industries such as pulp and paper, aluminum, chemicals, steel and cement manufacturing, there are commercially available, cost-effective technologies that would reduce energy usage by 10%-20%.

Steam supply system has large share of industrial energy use. The efficiency of steam boilers is low due to low load factors and poor maintenance. For example, average boiler efficiency in China is about 65% compared to 85% for efficient boilers that are available in the market. There are also opportunities in improving other parts of steam supply system such as pipes, ducts and control system.

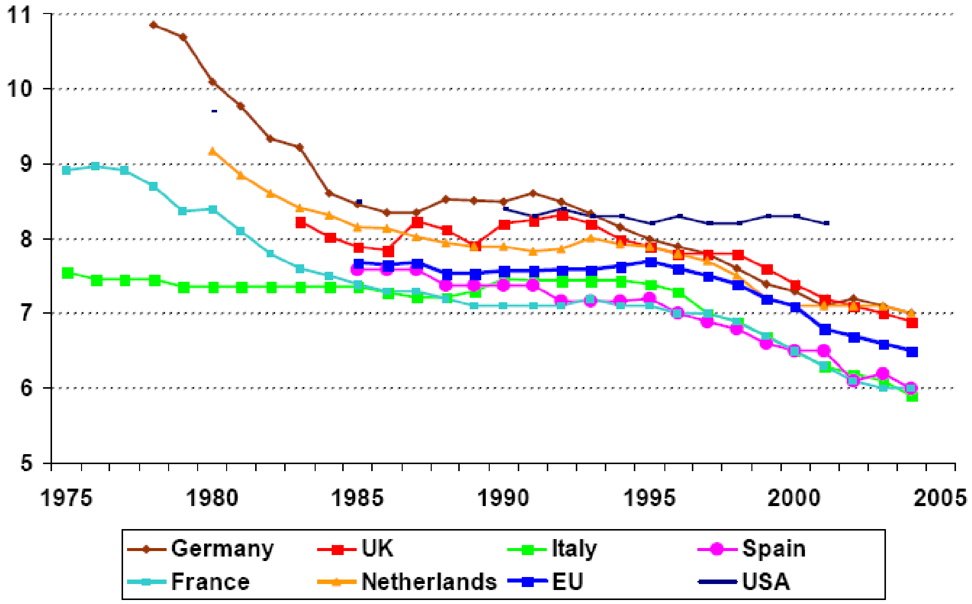
Motor system such as compressors, pumps or fans account for 60% of the electricity consumed in the industrial sector and for more than 30% of all electricity use. It is estimated that improving efficiency of motor system could reduce global electricity use by up to 7%.

Buildings are the largest consumer of electricity. In 2005, buildings consumed 57% of global electricity (ETP 2008). Economic growth, rising household incomes, particularly in developing countries, and urbanization will dramatically increase energy use in buildings. Although energy consumption in buildings is highly influenced by local climate and cultures, there are still many opportunities to reduce energy intensity in buildings. For example, better building envelops, energy efficient appliances, efficient lighting systems, improving efficiency of heating, ventilation and air conditioning (HVAC) systems, and use of heat pumps and solar heating.

Power plants are major consumers of energy. The average power plant efficiency is now 34% compared with 46% for the most efficient ones currently operating in Spain. If all world regions had the same performance as the best one in Spain, 770 Mtoe of fuel would have been saved in 2006, avoiding 2.4 Gt of CO_2 emissions.

Transportation sector is the largest consumer of oil. The opportunities to improve energy intensity in the transportation sector include expanded use of public transport and increased fuel efficiency for new cars. Figure 2.18 shows trends in automobile fuel efficiency improvements in several countries.

Figure 2.18: Automobile Fuel Efficiency for New Cars (liters/100km)



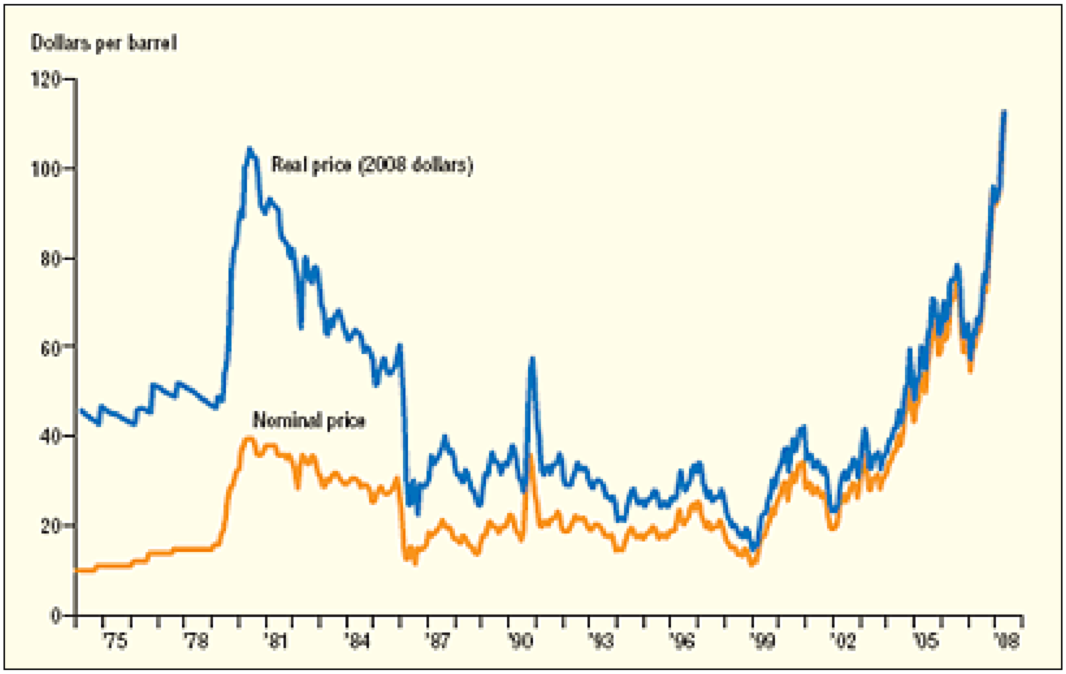
Source: WEC, 2008-EE

There is a strong need to decouple economic growth and energy consumption. The ACT scenario requires sustained global energy efficiency improvements of 1.4% per year and the BLUE Map scenario calls for 1.7% improvement per year.

2.8 Oil Prices

Energy prices normally respond to changes in demand and supply. However, oil prices are affected not only by global demand for oil, but also on the uncertain future of oil supply, the value of U.S. dollar, as well as political factors which could lead to short term supply disruptions. Figure 2.19 shows historical trends in oil prices. Note that the 1979 sudden peak in oil prices was as a result of the Iranian revolution. Reducing dependence on oil has become a key policy in the United States and many other developed economies.

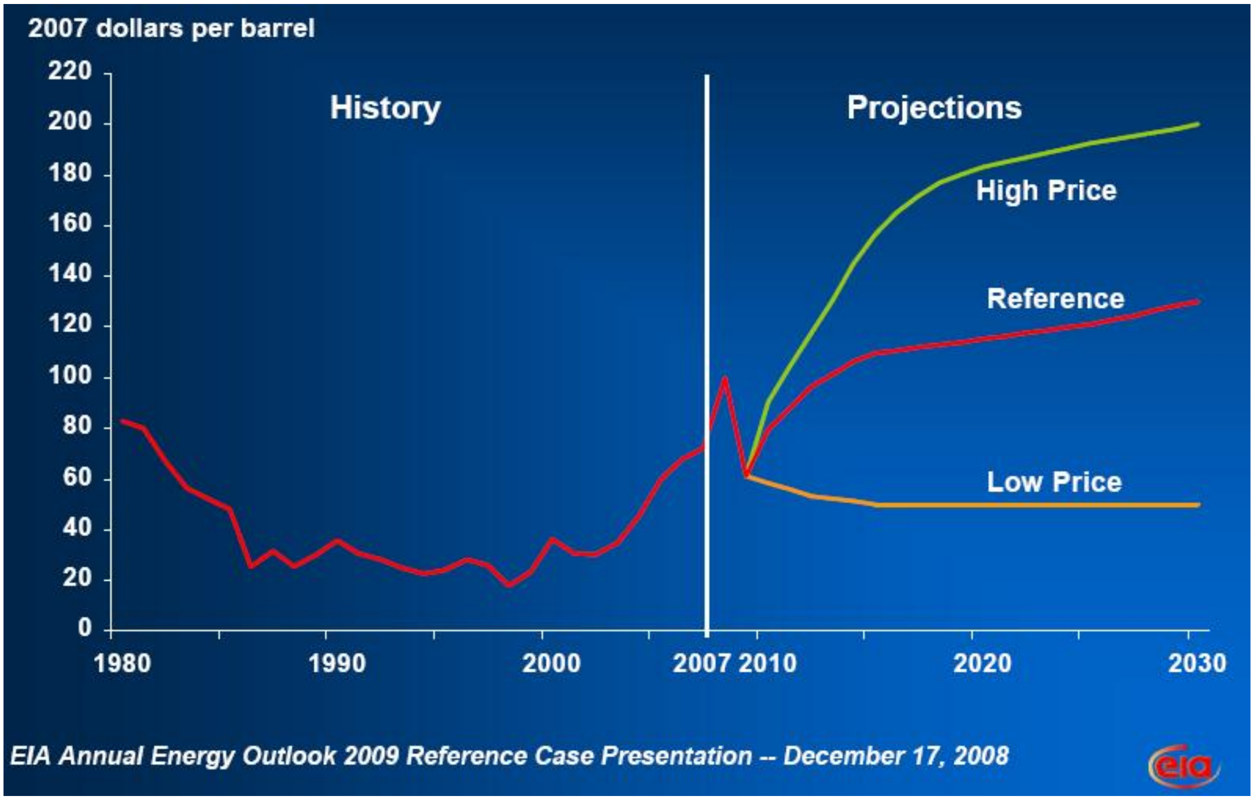
Figure 2.19: Historical trends in oil prices.



Source: Economic Letter—Insights from the Federal Reserve Bank of Dallas
Vol. 3, No. 5, May 2008.

Price of oil reached its peak of $147.27 per barrel on July 11, 2008 before dropping more than 70% to about $39 per barrel in December, 2008. This huge fluctuation in oil prices is unusual and it was primarily due to global financial crisis. The United States Energy Information Administration (EIA) provides periodic forecasts of oil prices. Figure 2.20 illustrates EIA's 2008 forecast. As this figure shows, there are three oil-price scenarios. In the "Reference" scenario, oil price will reach $130 per barrel (in 2007 dollars) by 2030. This rise is primarily due to decline in non-OPEC production beyond 2016. As this figure indicates, there is a wide gap between the "Low" and "High" scenarios. The price of a barrel of oil in 2030 could be as low as $50 to as high as $200 per barrel (in 2007 dollars). This wide range of prices is due to uncertainties on the availability and cost of non-OPEC oil, OPEC's production policies, and the supply of non-conventional liquids.

Figure 2.20: World oil prices, 1980-2030



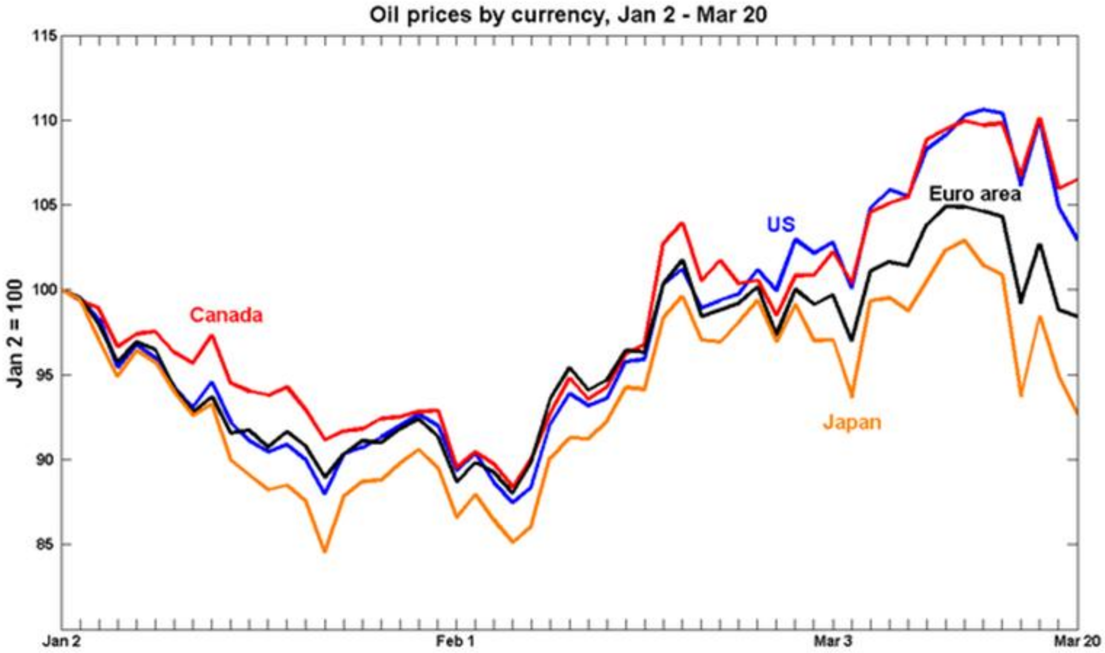
Source: Annual Energy Outlook 2009 with Projections to 2030. United States Energy Information Administration (EIA), June 2008

http://www.eia.doe.gov/

Many oil analysts believe that in the absence of long-term supply disruptions, it is unlikely that oil prices will remain above $100 per barrel (in 2007 dollars) for a long period of time.

Oil is traded in U.S. dollars. Since OPEC countries obtain 80-90% of their revenue from oil sales, any changes in the value of U.S. dollar would affect their purchasing power. In recent years, the value of dollar has declined dramatically against other major currencies, particularly the Euro. Weaker dollar makes oil cheaper for Europeans and other consumers, causing a rise in demand. Weak dollar puts upward pressure on oil prices. Between 2001 and 2008, the dollar fell 46% against the EURO. Figure 2.21 illustrates how changes in the value of U.S. dollar affects oil prices in other currencies.

Figure 2.21: Oil Prices in Different Major Currencies: January-March 2008



Source: Worthwhile Canadian Initiative

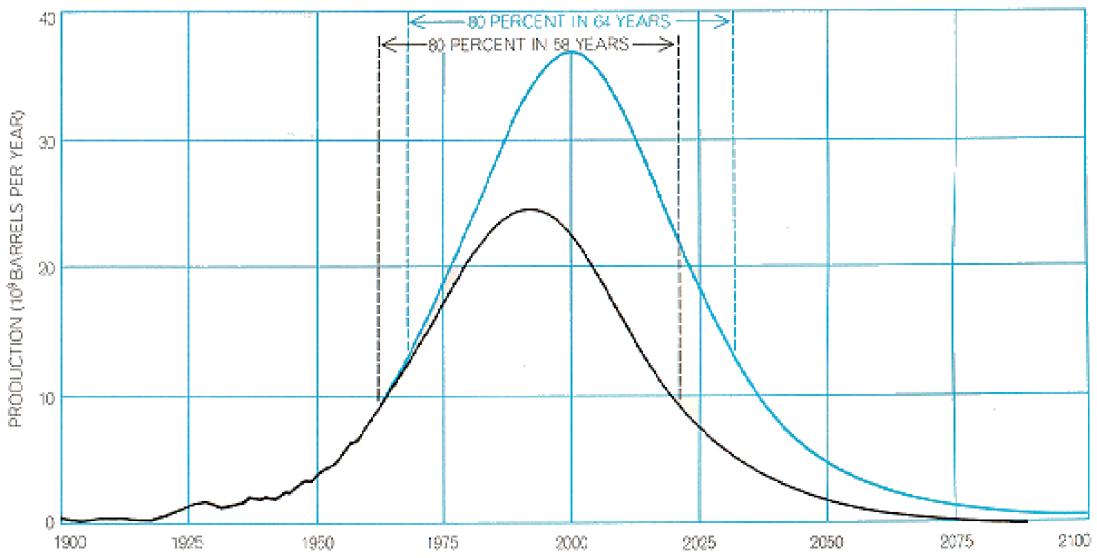
Oil demand in the IEA's Baseline scenario is projected to increase by 86% between 2005 and 2050, from 85 Mb/d (4,000 Mtoe) in 2005 to 135 Mb/d (6,287 Mtoe) in 2050. In 2007, oil consumption increased to 85.6 Mb/d supporting IEA's projection in the rising trend in consumption. It is unclear where the additional oil supply will come from. Very large investments, especially in OPEC-member countries and Russia will be required to meet the growth in demand and to create a stable oil market.

If investments in OPEC and Russia do not materialize in the coming decades, oil and gas prices will rise further, thus increasing demand for alternative energy sources, whether high-or low-carbon.

In the ACT scenario, oil demand is 30% lower than the Baseline scenario (94.5 Mb/d). In Blue scenario, oil demand will be 27% less than the 2005 level or 55% below the Baseline scenario in 2050 (62 Mb/d). Improving fuel efficiency of transportation system, use of hybrid and electric vehicles and expanded use of biofuels and synfuels from coal and gas are the major contributors to the reduction in oil demand in these two scenarios.

In 1949 a well-known geophysicist, M. King Hubbart, predicted that the fossil fuel era would be of very short duration and that the world will run out of oil by 2100 as shown in Figure 2.22. He predicted that the US will run out of oil by 2050.

Figure 2.22: M. King Hubbart's predictions on world oil production



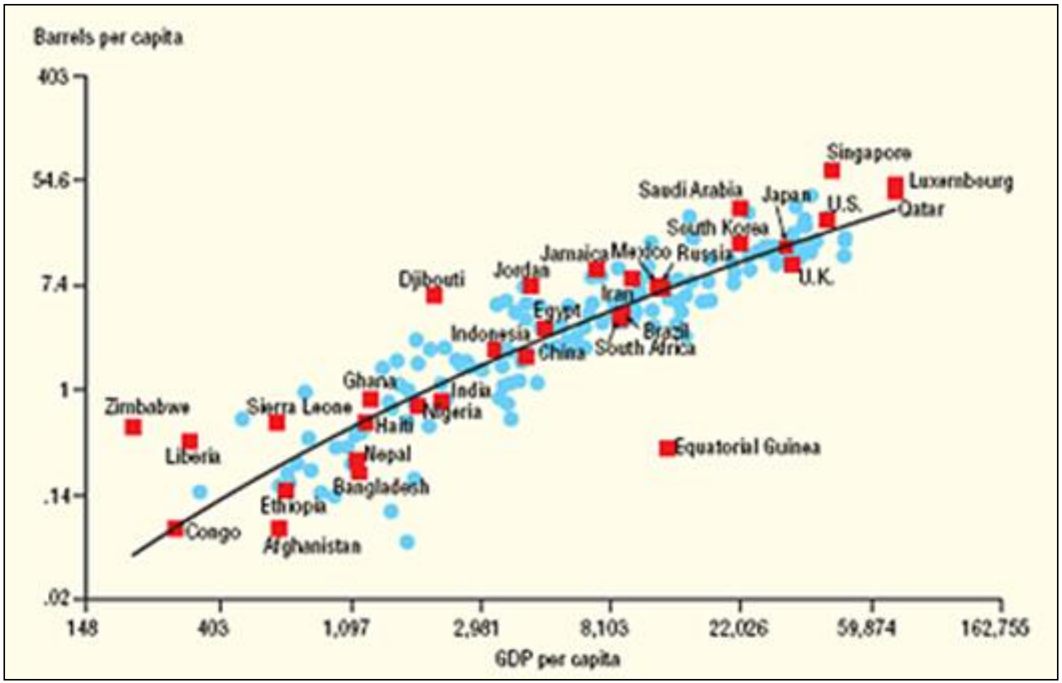
CYCLE OF WORLD OIL PRODUCTION is plotted on the basis of two estimates of the amount of oil that will ultimately be produced. The colored curve reflects Ryman's estimate of 2,100 × 10^9 barrels and the black curve represents an estimate of 1,350 × 10^9 barrels.

M. King Hubbert. "The Energy Resources of the Earth." Energy and Power. A Scientific American Book, 1971, pg 39

Most experts argue that the world is not running out of oil, even by 2050. But most of the remaining crude oil and natural gas resources will continue to be concentrated in a few countries. This raises concerns about the security of supply and uncertainties about oil-price fluctuations. Organization of Petroleum Exporting Countries (OPEC) which now controls about 40% of world oil supply is expected to maintain its oil production at least at today's level by 2050.

Oil demand is directly related to economic development. As people's incomes rise, they will use more energy for heating, cooling, lighting, appliances, and particularly transportation. They will also demand more goods and services. Figure 2.23 shows that, doubling per capita income will more than double per capita oil consumption. This is primarily due to increased use of transportation fuels.

Figure 2.23: Per-capita oil consumption as a function of per-capita GDP

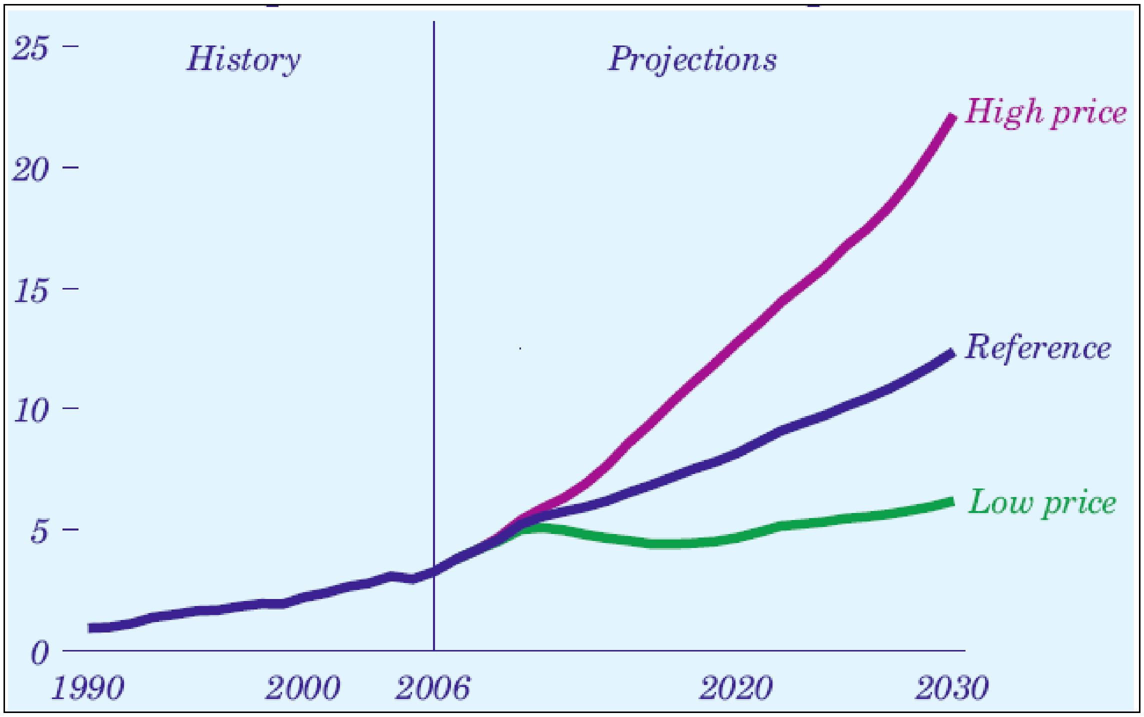


Source: Economic Letter—Insights from the Federal Reserve Bank of Dallas
Vol. 3, No. 5, May 2008.

Oil prices are also affected by increased supply of non-conventional oil. Non-conventional oil includes sources such as oil shale, tar sands, synfuel from coal and gas, and biofuels. Tar sands and oil shale are already in production. Biofuels are too limited in scale and currently too costly to make much difference to crude oil pricing.

In 2006, total world production of liquid fuels from unconventional resources was 2.8 million barrels per day, about 3% of total liquids production (IEA, 2008). It included 1.2 million barrels per day from oil sands in Canada, 600,000 barrels per day from heavy oils in Venezuela, and 320,000 barrels of ethanol per day in the United States. Figure 2.24 shows EIA's projections for non-conventional liquid fuel supply by 2030. Depending on oil-price assumptions, total production in 2030 could be between 8.2 and 21.7 million barrels per day, accounting for between 6% and 22% of the world's total production of liquids. Substantial increase in production of nonconventional oil will put downward pressure on the price of crude oil. Most analysts believe that when crude oil prices rise above $70 per barrel, nonconventional oil become cost competitive.

Figure 2.24: Unconventional resources as a share of the world liquids market, 1990-2030 (percent)



Source: International Energy Outlook 2008. United States Energy Information Administration (EIA)

http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf

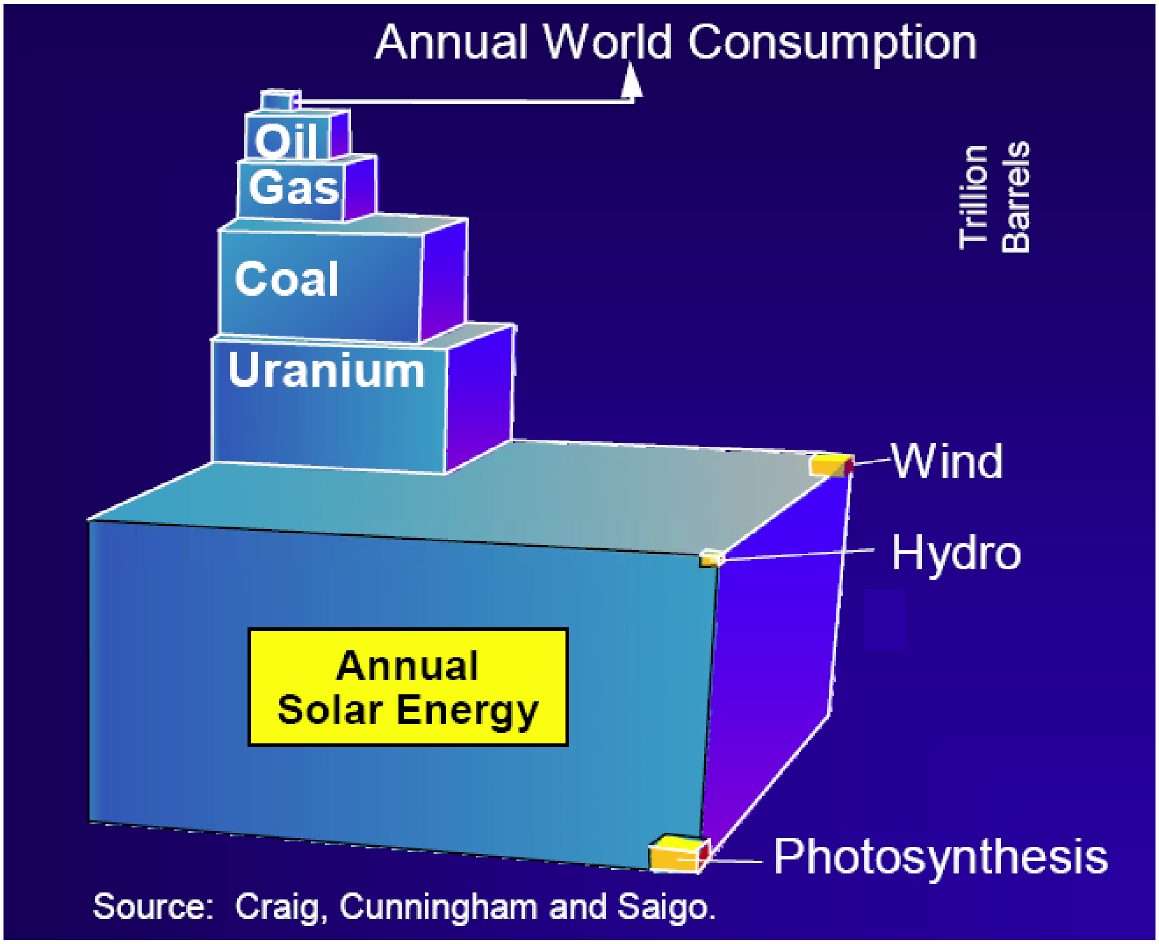
2.9 Alternative Energy Sources

Pace of development of alternative energy sources and clean technologies will have significant impact on world energy supply and demand and consequently on global climate change. The following sections provide a brief overview of alternative energy sources and technologies.

2.9.1 Solar Energy

Solar energy is the most abundant energy source on earth (See Figure 2.25). Currently, it provides less than 1% of the world’s total commercial energy.

Figure 2.25: Total Energy Resources



Source: National Petroleum Council (2007) Facing the Hard Truths about Energy: A Comprehensive View to 2030 of Global Oil and Natural Gas.

Solar energy can be captured in many ways. It can be used for space heating and water heating in residential and commercial sectors as well as process heat in the industrial sector. Solar energy can be used to produce electricity either directly using ***Photovoltaic*** (PV) cells, or indirectly by producing steam for a steam turbine using ***Concentrated Solar Power*** (CSP). It can also be used to produce hydrogen fuel. The potential for solar energy is significant in both developed and developing countries.

The IEA projections to 2050 indicate that solar power could provide 6% of global electricity production in the ACT Scenario (2,319 TWh/yr) and 11% in the BLUE Scenario (4,754 TWh/yr) from PV and CSP in roughly equal proportions. Figure 2.26 illustrates three solar technologies in use. Today, three countries (Germany, Japan and the US) account for approximately 70% of global cumulative PV capacity.

Figure 2.26: Solar Technologies

Solar PV System

Solar Water Heater

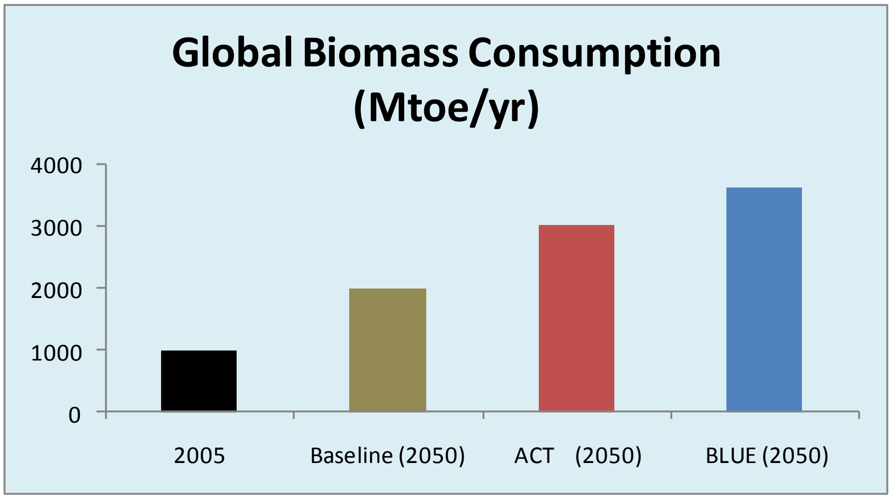
Concentrated Solar Power

2.9.2 Biomass

Plants and trees, through the photosynthesis process, use solar energy to convert CO_2 in the atmosphere into carbohydrates such as sugar and starch. Although biomass, when used releases CO_2, there is no net increase in carbon dioxide emissions to the atmosphere. Biomass is used either directly for cooking and heating or it is converted into liquid biofuels.

Biomass is the most important global renewable energy source today and well into the future. It contributes about 10% of the world´s total energy needs today, most of it in the form of heat for cooking and heating. There are about 2.5 billion people in the developing countries that rely on biomass for cooking and heating and this number is on the rise. According to IEA report (ETP 2008), bioenergy has the highest technical potential of all renewable energy sources and its contribution to global energy needs could quadruple to 3,604 Mtoe/yr in 2050 (see Figure 2.27). The IEA report indicates that about half of the primary bioenergy would be used for the production of liquid biofuels. The other half would be used for power generation, heating and industrial feedstock’s.

Figure 2.27: Global Biomass Consumption (2005 and 2050)



Source of Data: ETP 2008

The first generation of biofules is based on corn, sugarcane, soybeans, palm, and other crops that are also food sources. The second generation is biomass conversion to biofuels which is still in the early stages of development. The second generation biofuels are produced from the non-food vegetation (*energy crops)* such as plant waste, trees, and algae. Sustainable development of biofules require more efficient land and water management in both agriculture and forestry systems.

2.9.3 Wind Power

The global market for wind power has grown tremendously since its early deployment in the 1980s. Total world installed capacity has grown 50 times between 1990 and 2007 to about 94 GW. This amounts to about 1% of global electricity supply. Most of the world wind power capacity (72%) is located in five countries as shown in Figure 2.28 and Table 2.9.

Figure 2.28: Global Wind Power Capacity in 2007 (percent of world total)

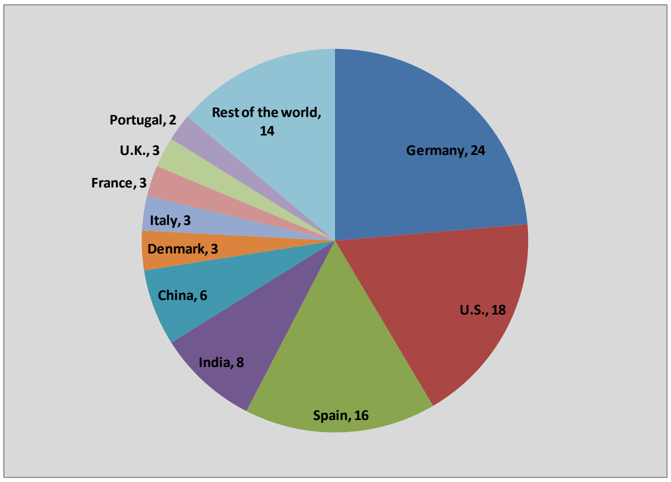


Table 2.9: Global Wind Power Capacity in 2007 (MW)

Country	Wind Power Capacity (MW)	Wind Power Capacity(% of total)
Germany	22,247	24
U.S.	16,818	18
Spain	15,145	16
India	8,000	8
China	6,050	6
Denmark	3,125	3
Italy	2,726	3
France	2,454	3
U.K.	2,389	3
Portugal	2,150	2
Rest of the world	13,018	14
World Total	94,122	100.0

Source of Data: IEA, ETP 2008

The IEA projections show that wind power could provide as much as 12 percent of global electricity generation in 2050 as shown in Figure 2.29 and Table 2.10. China is projected to have the largest wind power capacity in the world by 2050.

Figure 2.29: Global Wind Power Capacity in 2007 and 2050 (GW)

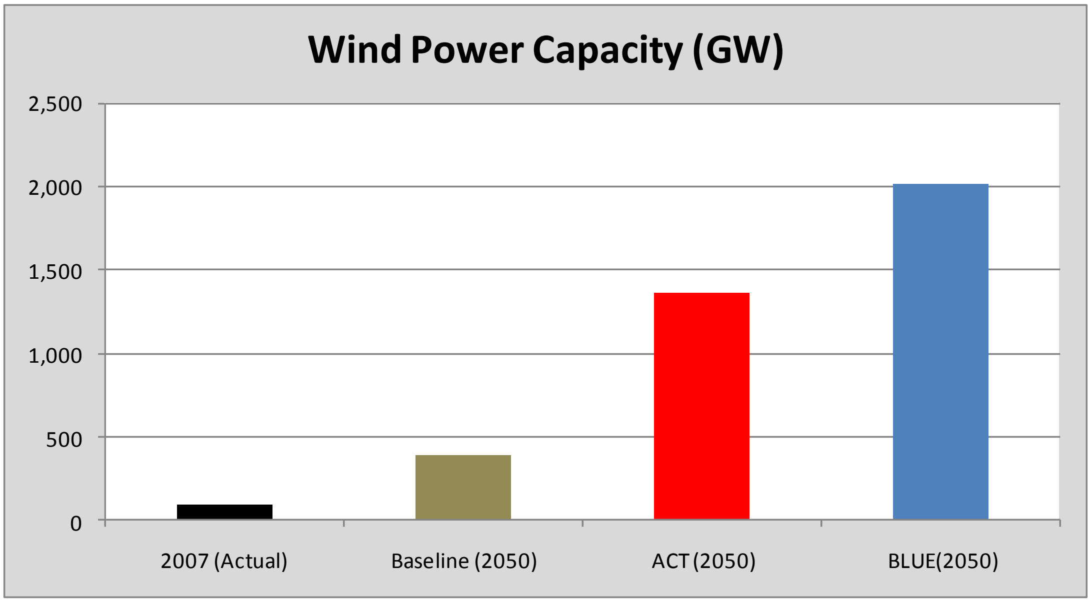


Table 2.10: Global Wind Power Capacity in 2007 and 2050

Scenarios	Wind Power Capacity (GW)	Percent of Global Electricity Production
2007 (Actual)	94	1
Baseline (2050)	391	2
ACT (2050)	1,360	9
BLUE(2050)	2,010	12

Source of Data: IEA, ETP 2008

Wind turbines need no fuel and have zero CO_2 emissions (except for production, delivery and installation of equipment) and they can be installed relatively quickly. Today, energy from the wind cost 25% of what it did in the early 1980s. According to IEA, three factors have contributed to the reduction in cost of wind energy:

1) wind turbines have become larger (turbine size has grown to as much as 6 MW);

2) turbine efficiency has increased significantly; and

3) capital cost per kW has declined significantly

In 2006, onshore wind power installed costs ranged from $1,224/kW in Denmark to $1,707/kW in Canada. In the same year, operation and maintenance costs ranged from 1.3 cents/kWh to 2.4 cents/kWh. Offshore capital costs were higher. They ranged from $2,226/kW to $2,969/kW.

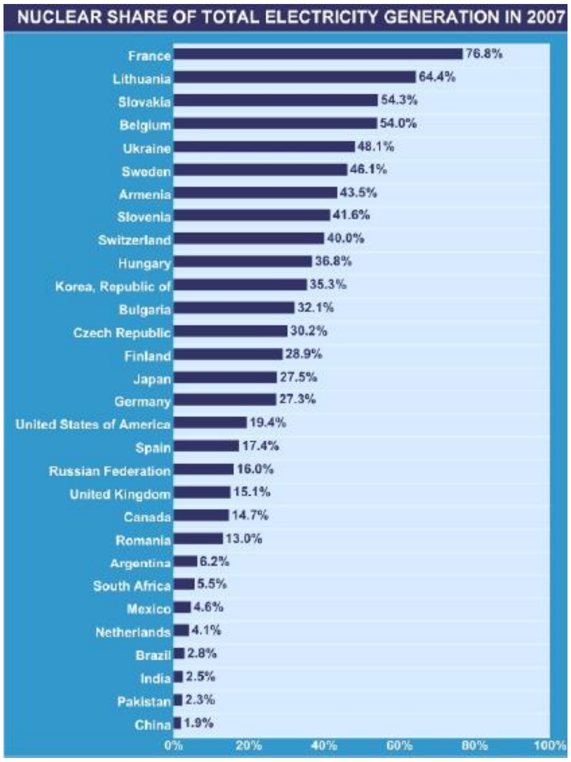
Total cost of wind power today ranges from 6.5 cents/kWh to 13.5 cents/kWh depending on the wind energy at the site. The IEA projections show that the costs will be reduced further to about 5.3 cents/kWh to 6.3 cents/kWh by 2015 making wind energy competitive with conventional sources of power. About 75%-80% of total wind power costs are capital costs. The average life of a wind turbine is about 20 years.

In the last two decades, government support for R&D has played a critical role in wind power development. This support must continue until wind energy reaches its full potential by 2050.

2.9.4 Nuclear Power

In 2007, there were 438 operating nuclear power plants in 30 countries with a total installed capacity of 372 GW (IAEA, 2008). This amounts to about 15% of the world's electricity generation. About half of these units are in three industrialized countries: U.S. 104, France 59 and Japan 55. Many industrialized countries generate substantial portions of their electricity from nuclear power, for example in 2007, nuclear energy provided 76.8%% of France's electricity. Figure 2.30 illustrates the share of nuclear energy in total electricity generation in 30 countries.

Figure 2.30: Nuclear Share of Total Electricity Generation in 2007



Source: International Atomic Energy Agency (IAEA).

Energy, Electricity and Nuclear Power: Developments and Projections - 25 Years Past and Future.

In the last three decades, the Three Mile Island (TMI) and Chernobyl accidents caused a considerable slowdown in nuclear power expansion. Despite the concerns about safety, nuclear weapon proliferation and radioactive waste management, nuclear power is becoming an attractive option for power generation in many countries. This is primarily due to increasing concerns about the cost and supply security of conventional energy sources and concerns about global climate change. For example, China, Russia, Japan, South Korea and Ukraine are planning to increase their total nuclear capacity by 116 GW over the next 25 years. In its 2008 edition of *Energy, Electricity and Nuclear Power Estimates for the Period to 2030*, IAEA expects global nuclear power capacity in 2030 to range from a low case scenario of 473 GW to a high case scenario of 748 GW.

In the IEA report (ETP 2008), under both ACT and BLUE Scenarios, nuclear power will make greater contribution to the electricity needs of both developed and developing countries. Under these scenarios, 30GW of nuclear capacity must be added each year between now and 2050.

To resolve their nuclear waste disposal problem, France plans to have a disposal facility working in 2025, Japan in about 2035 and UK in 2045. Currently, France, UK and Russia have commercial reprocessing plants in operation.

2.9.5 Hydro, Geothermal and Ocean Energy

Hydropower accounts for about 90% of all renewable power generation today. The main challenge for hydropower projects are competition for scarce water and land resources in most parts of the world, and social and environmental impact of hydro schemes. These challenges are likely to limit the potential of large schemes.

Existing hydropower is one the cheapest ways of producing power. Most plants were built many years ago and their initial costs have been fully amortized. For large plants, capital costs are about $2400/KW and generating costs around 3 to 4 cents/KWh. In developing countries, investment costs are routinely below $1000/KW

Hydropower production doubles in ACT and BLUE Map scenarios by 2050, reaching 5000 TWh to 5500 TWh per year from 1700 GW of capacity. Important technical potentials remain in Asia, Africa and South America.

Small hydro schemes still have considerable potential. Worldwide, the technical potential for small hydropower is estimated at 150 GW to 200 GW. Only 5% has been exploited.

The potential for geothermal energy is huge. High-quality resources are already economically viable today. Only 10 GW of geothermal electrical capacity are currently installed worldwide. Geothermal power production increases 20-fold to 200 GW in 2050 in the BLUE Map scenario. Capital costs are $1150/KW installed capacity for large, high quality resources to $5500/KW for small ones. Operating costs are about 1.5 to 2.5 cents/KWh.

Almost all ocean energy power generation today is based on harnessing tidal energy. There has been a lot of progress in wave energy. But capacity is still very small, at less than 1 GW installed capacity in total. Costs need to be reduced to a third or a quarter of their current levels, and reliability must be improved. Ocean power production will stay below 50 GW in the BLUE Map scenario in 2050.

2.9.6 Energy Storage

In the BLUE scenario, the storage capacity increases from 100 GW today to 500 GW in 2050. This storage consists of a combination of pumped hydro storage, underground compressed air energy storage systems, and other storage options to a lesser extent. About 1,000 GW of gas-fired capacity also operates as reserve for these variable renewables.

The penetration of a number of renewable energy sources is limited by their intermittency. Electricity storage usually involves 40% to 50% conversion losses, and is often limited by geographic factors. An alternative is to store heat for conversion to electricity at times when the intermittent renewable is unavailable. Thermal storage losses can normally be held to less than 7% per unit of energy stored.

3 Using System Dynamics to Analyze Interrelationships among the Driving Forces

Driving forces of the world energy markets are not *independent* variables. Most of these forces are interrelated resulting in a complex web of interactions and, as a result, greater complexity of energy-scenario analysis. In the initial stage of scenario analysis, we are interested in exploring the cause and effect relationships of the driving forces and determining key factors that require further investigation. To determine interrelationships and interactions of the driving forces in a more manageable way, we use system dynamics. The following is a brief description of system dynamics.

John Sterman, an MIT professor and one of the pioneers in popularizing applications of system dynamics, defines *system dynamics* as “a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems” (Sterman, 2000). System dynamics was developed by Jay Forrester at MIT in the late 1950s and is increasing in popularity. Today, system dynamics models are widely used in large-scale projects including defense, energy, construction, and information systems.

All dynamic systems are composed of several elements and their interrelationships. The complexity of a system is based on the dynamic interaction of its components, not the number of components. There are only two types of interactions between the elements of a dynamic system: positive (*reinforcing*) or negative (*counteracting*), or, as Sterman (2000) calls it, *self-correcting*. The following figures are simple examples of system dynamics models. In Figure 3.1, chickens and eggs are variables that form a positive *cycle*. More chickens lead to more eggs, and more eggs lead to more chickens, and so on. However, as shown in Figure 3.2, when a fox is introduced into this dynamic system, the outcomes become much more complex and uncertain, because the fox eats both chickens and eggs.

Figure 3.1: System Dynamics—A Positive Cycle

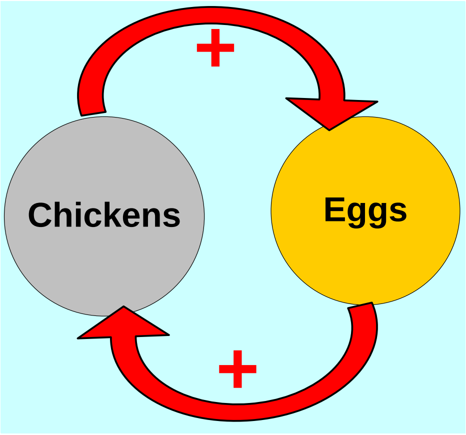
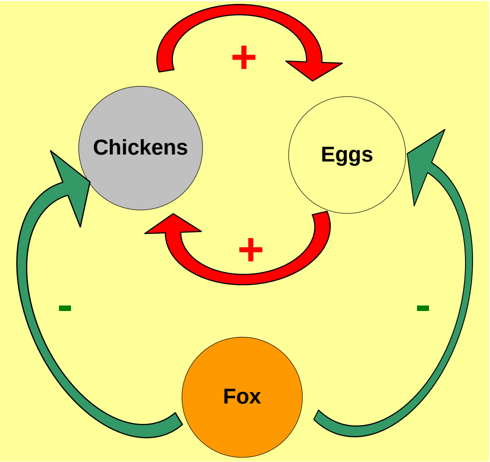


Figure 3.2: System Dynamics with Both Positive and Negative Cycles



To determine interrelationships among the driving forces systematically, we use Structure® software program developed by the author. Structure® uses *graph theory* in developing a dynamic system of the global energy markets' driving forces and their interactions. For a more detailed description of graph theory, read Roberts (1976). To use Structure® in scenario analysis, the following steps should be followed.

Step 1. Identify the key variables of the problem (the driving forces) and enter them randomly in a file specified by the program.

Step 2. Determine interrelationships among these variables (the driving forces) two-at-a-time, in an *adjacency matrix*. This simplifies the complex problem for the user by allowing him/her to look at the variables (driving forces) one pair at a time. There is a relationship between variable V_i and variable V_j if a change in V_i has a *significant, direct* effect on V_j.

The choices are as follows:

When V_i is increased:

V_j will not change (use 0)

V_j will also increase (use +1)

V_j will decrease (use –1)

Change in V_j is undefined (leave it as a ?)

If the first option is chosen, obviously, there is no relationship between the two variables. If the second option is chosen, the effect of V_i on V_j is *augmenting*. All other things being equal, an increase in V_i leads to an increase in V_j, and a decrease in V_i leads to a decrease in V_j. If the third option is chosen, the effect of V_i on V_j is *inhibiting*. All other things being equal, an increase in V_i leads to a decrease in V_j and vice versa. If you are uncertain about the relationship, you should choose the last option.

After completing Step 2, Structure® provides the following information:

Displays interrelationship of driving forces graphically

The program draws a *signed digraph* (directed graph) to display the interrelations of the driving forces. Nodes represent variables (driving forces), and arrows show relationships between variables. If a change in variable V_i has a *significant, direct* effect on $V_{j,}$ the program draws an arrow from V_i to V_j. If an increase in V_i causes an increase in V_j and vice versa, the program draws a red arrow from V_i to V_j (red represents a + sign). On the other hand, if an increase in V_i causes a decrease in V_j and vice versa, the program draws a green arrow from V_i to V_j (green represents a – sign).

Display interrelationships of driving forces in a matrix

An *adjacency matrix* displays the relationships among the variables numerically. If two variables are related, the user assigns "+1" or "–1" to the cell representing these two variables. Otherwise, "0" is assigned. In a case where the relationship is unknown, the program assigns a "?."

Display dependency level of each variable

Two bar graphs show the dependency levels of variables. One bar graph displays the ratings of *independent variables*, and the other displays the ratings of *dependent variables.*

Display independent variables

The user can view each node as an *independent* variable and determine how it influences other variables.

Display dependent variables

The user can view each node as a *dependent* variable and determine how other variables influence it.

Display cycles

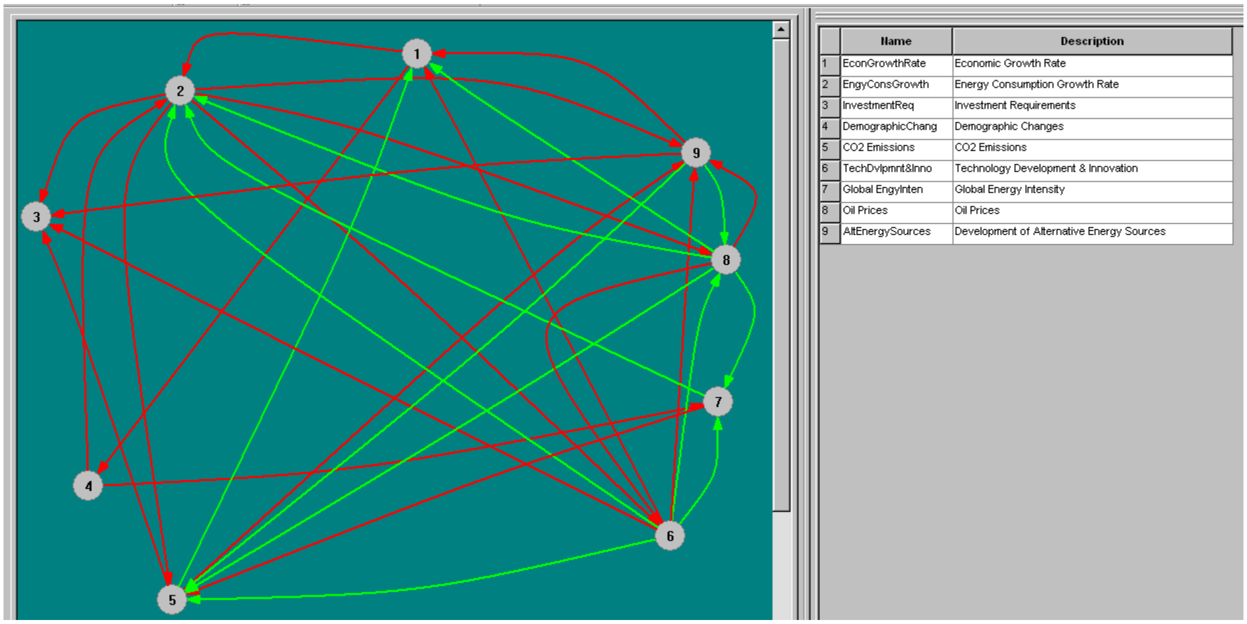
Structure® also displays all the possible cycles among variables. A cycle is a sequence of arrows that starts at a node, goes through other nodes following the arrows in the same direction and finally ends at the starting node. For example, in the chicken and egg problem, there is a positive cycle of chicken-egg-chicken. The sign of a cycle is positive, or *impact amplifying*, if it has no minus sign or even number of minus signs. Otherwise, its sign will be negative, or *impact counteracting*. Going through each cycle also improves the user's understanding of and reasoning for the relationships.

Structure® is an ideal tool for the analysis of the driving forces in scenario planning by allowing the analysts to display the main driving forces and determine their interactions. Once the analysis team completes this process, the problem is illuminated and structuring of the problem for further analysis is easier. The final outcome of this process is a model displaying a clear map of the driving forces and their key attributes. This map will help the analyst to design an effective scenario plan.

Structure® has been used to analyze utility deregulation issues in the United States; to analyze global energy and environmental issues; demand-side policy issues in China, India, Latvia, and Indonesia; as well as for specific issues such as risk assessment for international investment, drilling for oil, and ash disposal from a power plant.

Using Structure® software, the interrelationships of the driving forces in the global energy markets are determined, as shown in Figures 3.3 and 3.4.

Figure 3.3: Interrelationships of the Driving Forces of Global Energy Markets

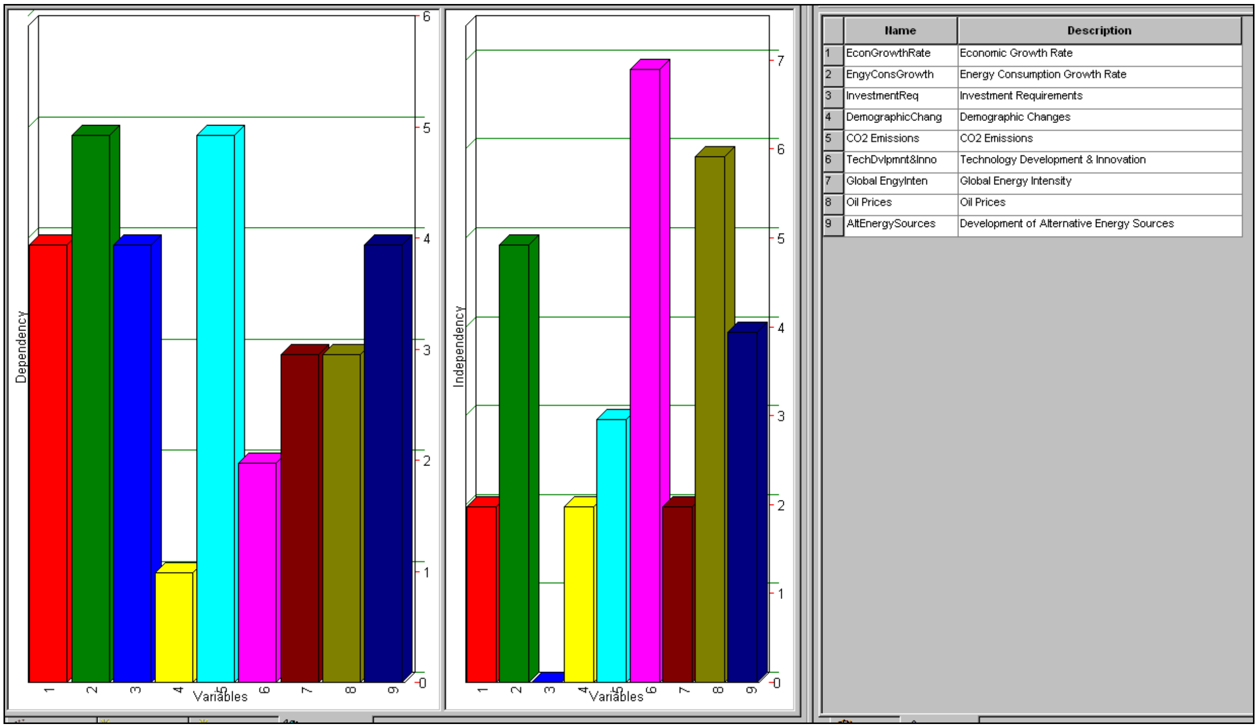


	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources

Note: Green lines represent negative relationships and red lines represent positive relationships among variables.

Figure 3.4 shows how each driving force (variable) depends on other driving forces (dependency level) and how each driving force affects other driving forces (independency level).

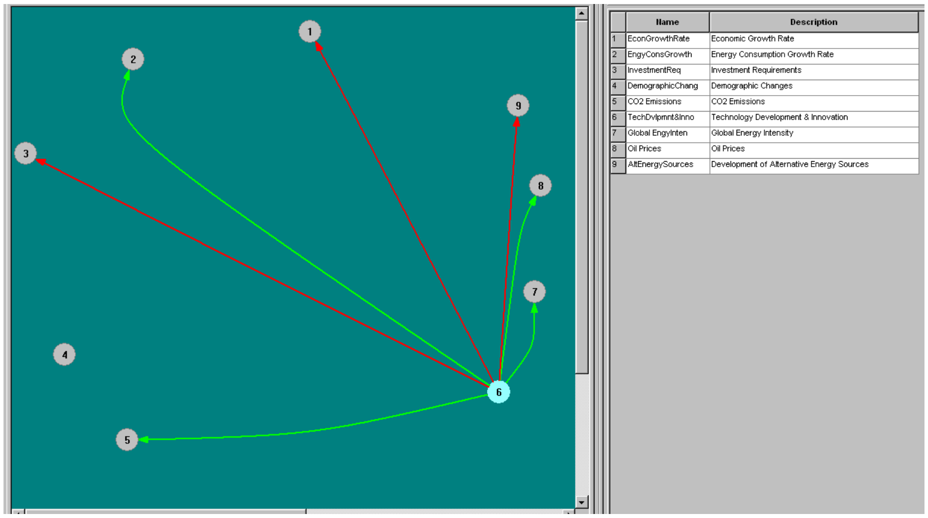
Figure 3.4: Dependency Level of Each Driving Force on Other Driving Forces



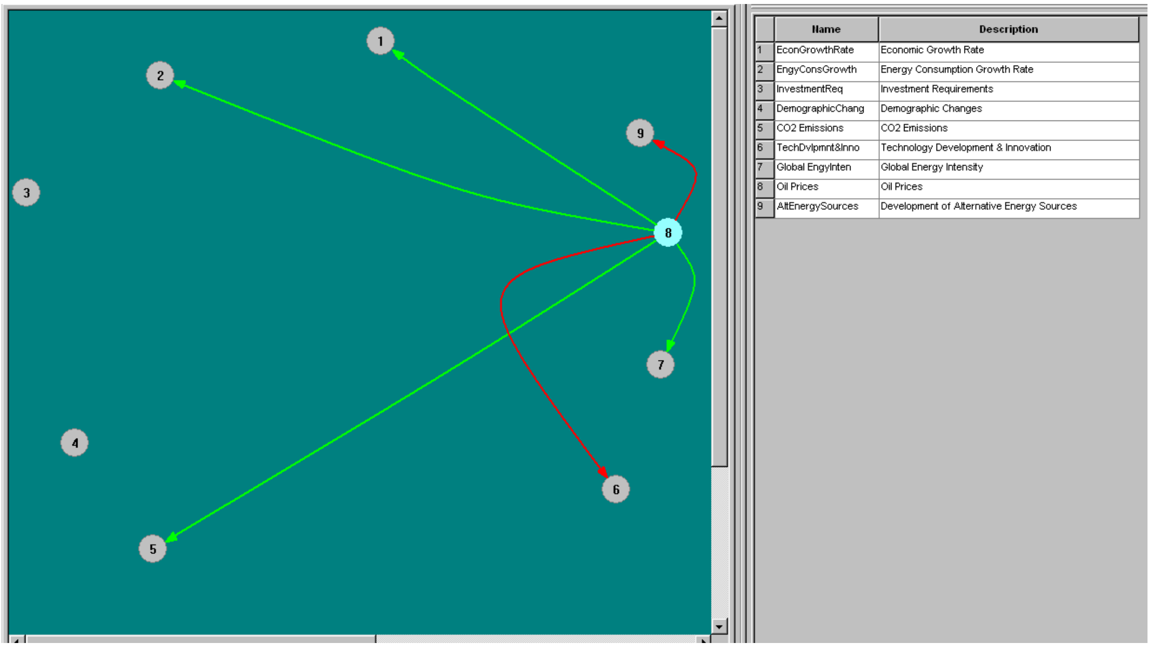
	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources

The ***most independent driving force*** is the ***Technology Development & Innovation*** (variable 6) followed by *Oil Prices* (variable 8), and the *Energy Consumption Growth Rate* (variable2). Figure 3.5 shows how these three forces affect other driving forces**.**

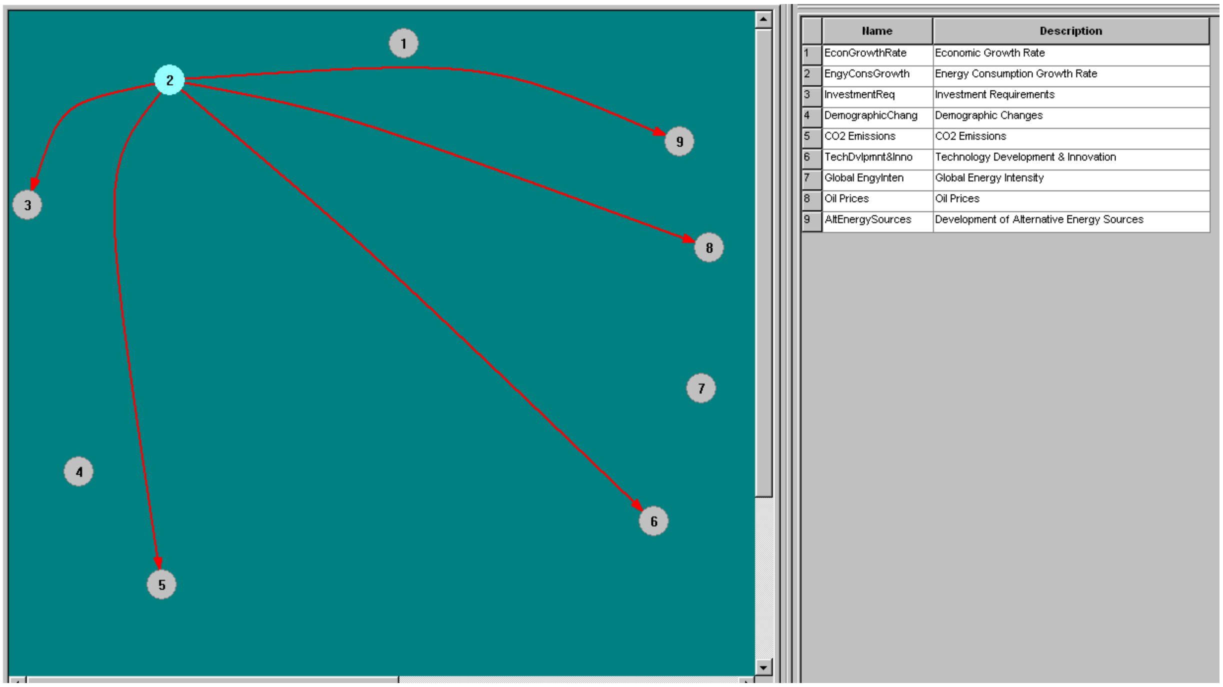
Figure 3.5: The most independent Driving Forces and their Impacts on other forces



	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources



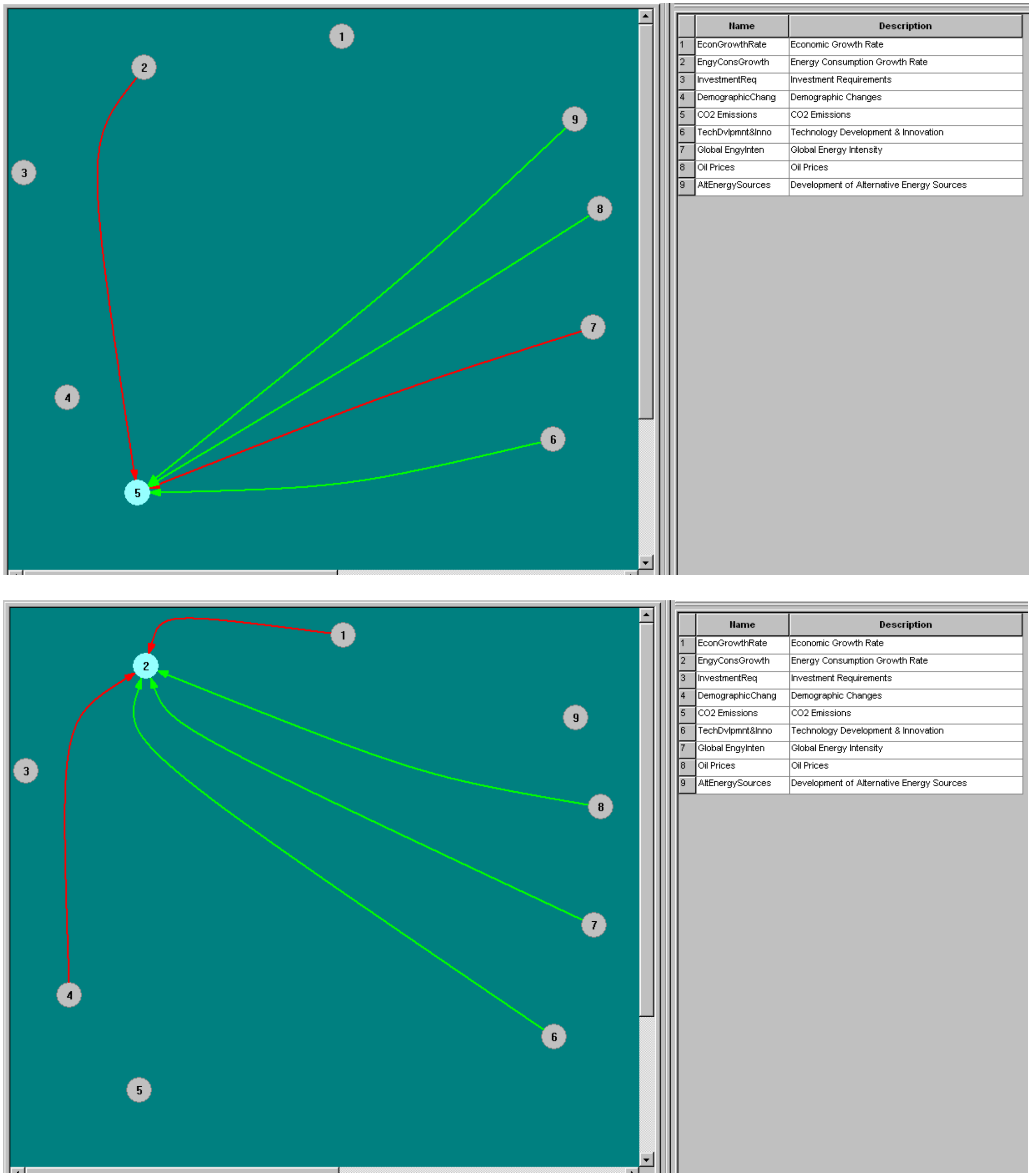
	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources



	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources

The ***most dependent driving forces*** are the ***CO_2 Emissions*** (variable 5) and the *Energy Consumption Growth Rate* (variable 2). Since CO_2 Emissions are affected by the energy consumption, it is the most dependent driving force as shown in Figure 3.6.

Figure 3.6: The most dependent driving forces

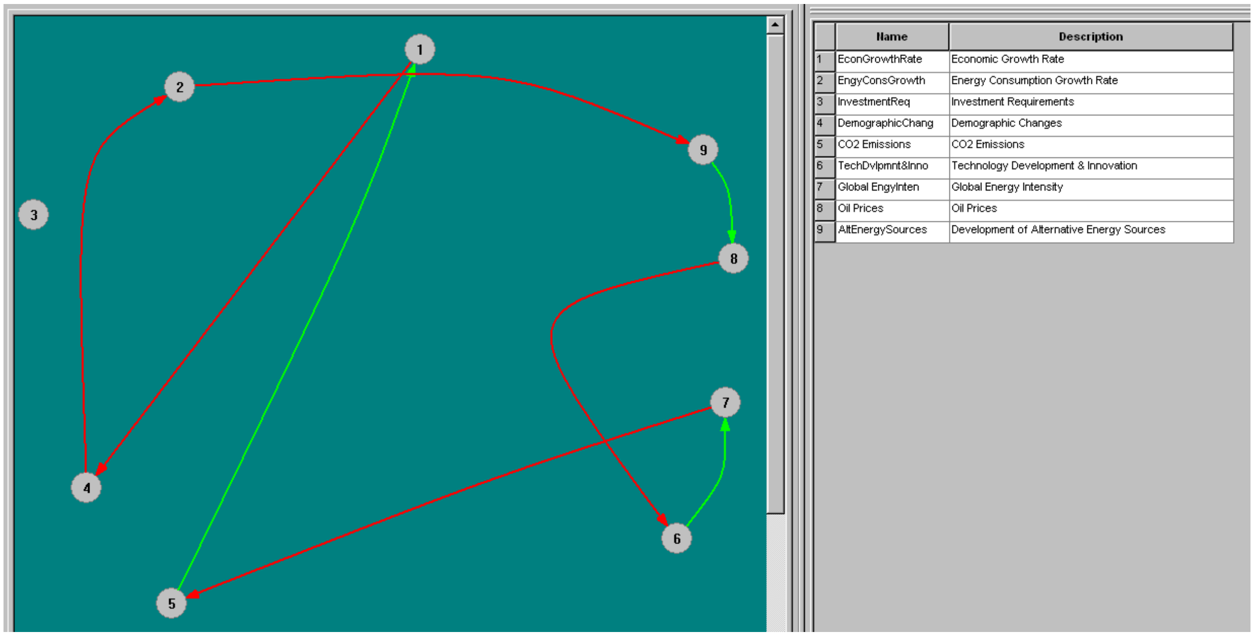


	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources

	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources

STRUCTURE® also allows the user to view cycles among the variables. There are numerous cycles among the driving forces. Figure 3.7 illustrates an example. This cycle is negative, or *impact counteracting*. Higher *economic growth rate* (1) will lead to more *demographic changes* (4); higher *demographic changes* will lead to higher *energy consumption growth rate* (2); Higher *energy consumption growth rate* will encourage further *development of alternative energy* *sources* (9); more rapid *development of alternative energy sources* will cause a drop in *oil prices* (8); lower *oil prices* will slow down *technology development and innovation* (6); when *technology development and innovation* is slowed down, *global energy intensity* will continue to rise (7); a rise in *global energy intensity* will increase CO_2 *emissions* (5); and finally, higher CO_2 *emissions* and its global environmental impacts will lower *economic growth rate* (1).

Figure 3.7: A Cycle among the Driving Forces



	Name	Description
1	EconGrowthRate	Economic Growth Rate
2	EngyConsGrowth	Energy Consumption Growth Rate
3	InvestmentReq	Investment Requirements
4	DemographicChang	Demographic Changes
5	CO2 Emissions	CO2 Emissions
6	TechDvlpmnt&Inno	Technology Development & Innovation
7	Global EngyInten	Global Energy Intensity
8	Oil Prices	Oil Prices
9	AltEnergySources	Development of Alternative Energy Sources

As shown in this example, each cycle provides an opportunity to discuss the driving forces and how they affect each other. The results of this analysis would be a better understanding of the dynamics of these forces.

To conclude this analysis, a sustainable energy future requires greater investment in ***energy technology development and innovation*** (variable 6). This will lead to lower CO_2 emission (variable 5), and, at the same time, meet global energy needs for projected economic growth.

4 World Energy Scenarios to 2050: A Decide2000® Model

Decide 2000®, is a decision support system using the Analytic Hierarchy Process (AHP). It is a valuable tool for structuring and solving complex decision problems, and is particularly effective when dealing with semi-structured decision problems. In a semi-structured problem, some elements are well known, while others may be partially known or totally unknown. In cases where the information on the elements is not available, the decision maker must rely on his expertise or the expertise of others to make judgments. By encouraging people to work together in solving a particular problem, Decide 2000® improves communication among the parties. Also, by documenting the judgmental process, Decide 2000® helps leaders and policy makers defend their plans logically to their stakeholders.

Decide 2000® has been used to solve variety of problems in decision making, prediction, scenario planning, resource allocation, conflict resolution, and strategic planning. Specific applications include risk assessment in drilling for oil, oil price scenarios in the international oil market, risk assessment for international investment, project proposal selection, risk prioritization in projects, world energy scenarios for the year 2010, conflict resolution in the international oil market, formulating energy strategies and policies for China, integrated resource planning (IRP) screening for utilities, demand-side management (DSM) program design and evaluation, site selection, and risk assessment for nuclear waste disposal. The following steps explain this hierarchical process:

Step 1: Constructing the hierarchy

Step 2: Entering the decision objective

Step 3: Entering the elements

Step 4: Relating the elements

Step 5: Rephrasing the question

Step 6: Making judgments and entering numeric values

Step 7: Computing relative weights of the elements

Step 8: Computing composite weights of the elements

Step 9: Checking consistency of judgments

Figure 4.1 is a hierarchical representation of the scenario model. This hierarchy consists of four levels. Level one is the objective of the model (World Energy Scenarios to 2050). Level two consists of the nine driving forces of the world energy future as were explained earlier in the paper. Level three shows the ranges for each driving force. Level four includes the three scenarios proposed by the IEA- Baseline, ACT Map, and BLUE-Map scenarios. The elements of the hierarchical model are explained below.

Level 1: Objective: World Energy Scenarios to 2050

Level 2: Criteria
Driving forces of the global energy markets as follows:

F1: Economic Growth Rate;

F2: Energy Consumption Growth Rate;

F3: Investment Requirements;

F4: Demographic Changes;

F5: CO_2 Emissions;

F6: Technology Development & Innovation;

F7: Global Energy Intensity;

F8: Oil Prices; and

F9: Development of Alternative Energy Sources

Level 3: Sub-Criteria
F1: Economic Growth Rate (average annual rate to 2050)

F1.1: High (4% per year)

F1.2: Moderate (3% per year)

F1.3: Low (2% per year)

F2: Energy Consumption Growth Rate (average annual rate to 2050)

F2.1: High (1.6% per year)

F2.2: Moderate (1% per year)

F2.3: Low (0.7% per year)

F3: Investment Requirements as a percent of Global GDP (average annual rate to 2050)

F3.1: High (7.1% per year)

F3.2: Moderate (6.4% per year)

F3.3: Low (6% per year)

F4: Demographic Changes

F4.1: High (Population grows to 10 billion and there is high per capita energy consumption)

F4.2: Moderate (Population grows to 9 billion and there is moderate per capita energy consumption)

F4.3: Low (Population grows to 8 billion and there is low per capita energy consumption)

F5: CO_2 Emissions

F5.1: High (62 Gt/year by 2050)

F5.2: Moderate (27 Gt/year by 2050)

F5.3: Low (12 Gt/year by 2050

F6: Technology Development & Innovation

F6.1: High

F6.2: Moderate

F6.3: Low

F7: Global Energy Intensity (global average by 2050)

F7.1: High-6000 BTU/year of US dollar of GDP (2000 dollar value)

F7.2: Moderate- 5000 BTU/year of US dollar of GDP (2000 dollar value)

F7.3: Low- 4000 BTU/year of US dollar of GDP (2000 dollar value)

F8: Oil Prices (2008 dollar value)

F8.1: High ($120/bbl by 2050)

F8.2: Moderate ($80/bbl)

F8.3: Low ($50/bbl)

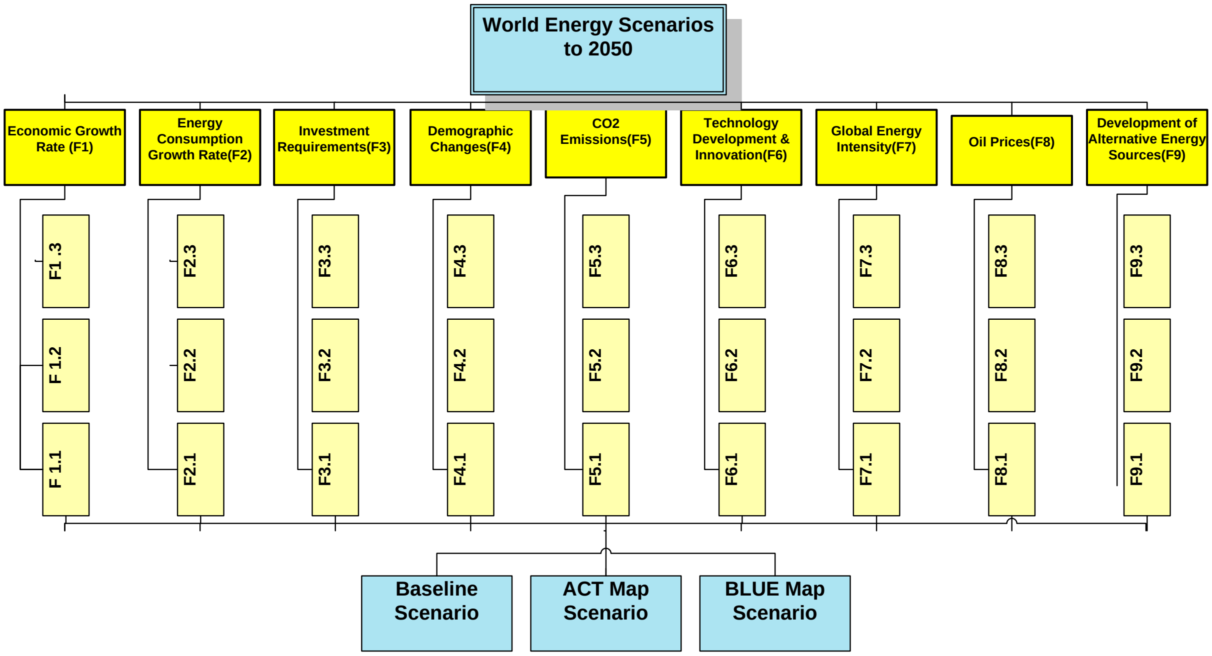
F9: Development of Alternative Energy Sources

F7.1: High

F7.2: Moderate

F7.3: Low

Figure 4.1: World Energy Scenarios to 2050: A Hierarchical Model



Figures 4.2 and 4.3 show priorities of the driving forces for the World Energy Scenarios to 2050. According to these figures, investments in the energy sector (0.17), the rate of technology development (0.17), and oil prices (0.16) will have greater influence in shaping world energy future than the other six forces such -global energy intensity (0.11), the rate of development of alternative energy sources (0.11), energy consumption growth rate (0.09), economic growth rate (0.08), CO_2 emissions (0.07), and demographic changes (0.05).

Figure 4.2: Priorities of the Driving Forces of the World Energy Markets

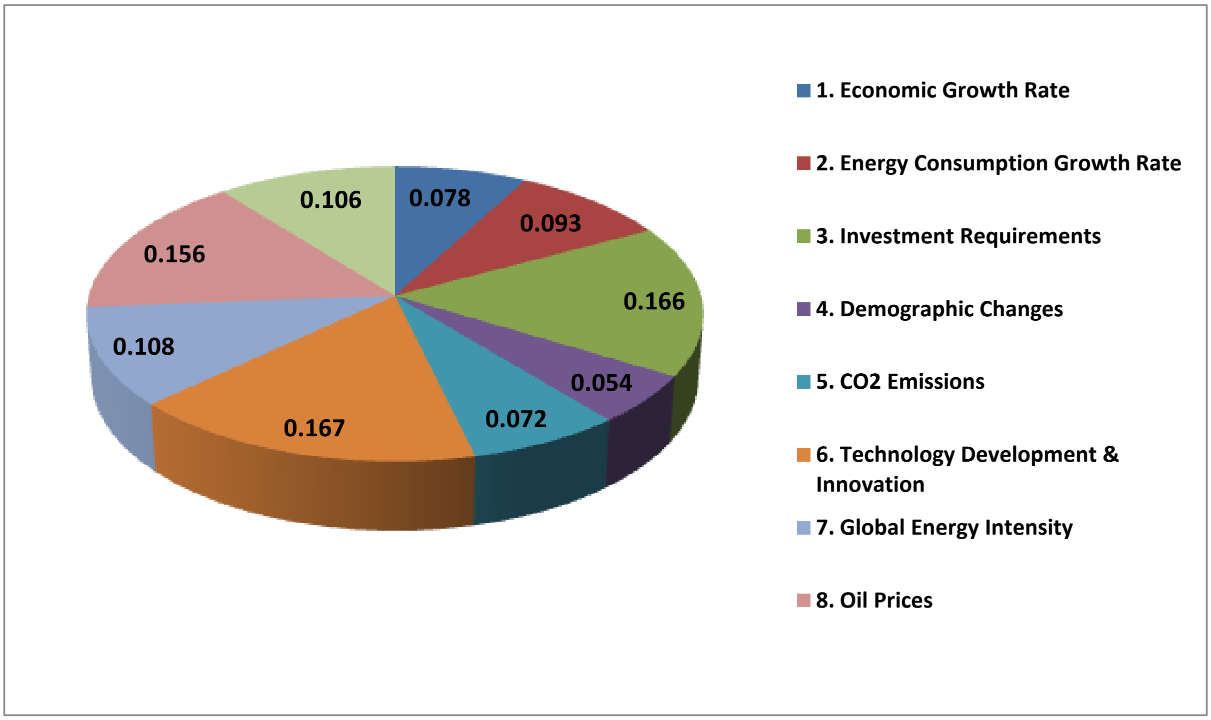


Figure 4.3: Probabilities of Ranges of the Driving Forces

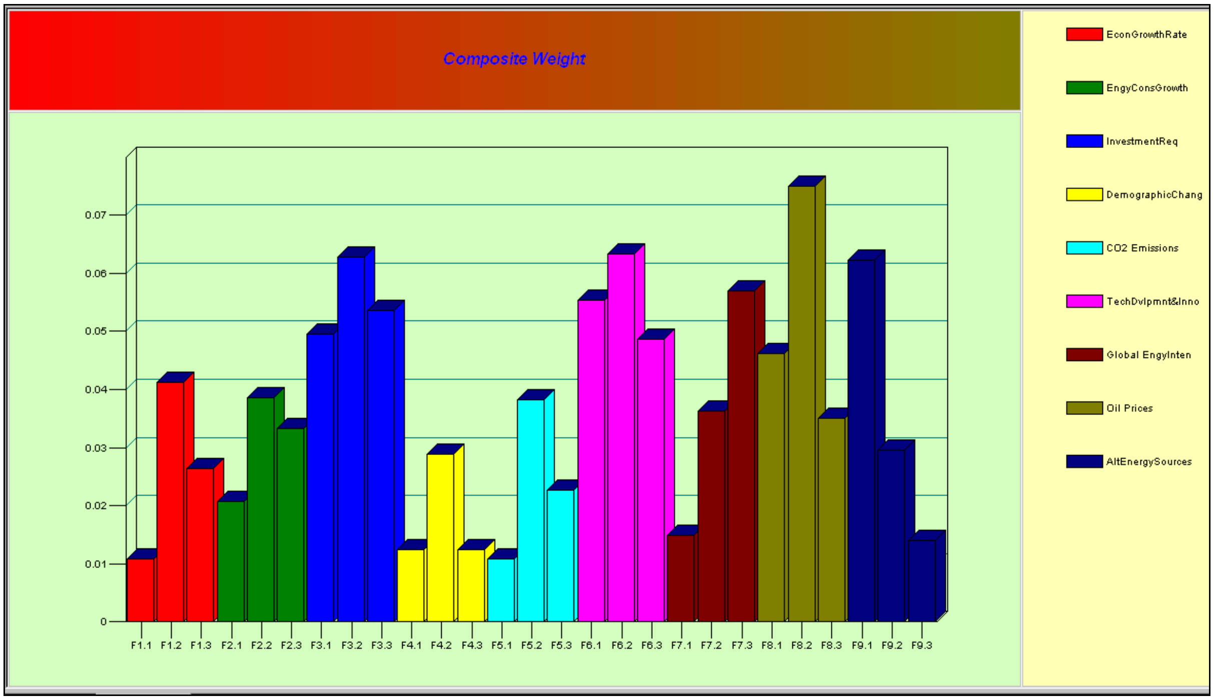
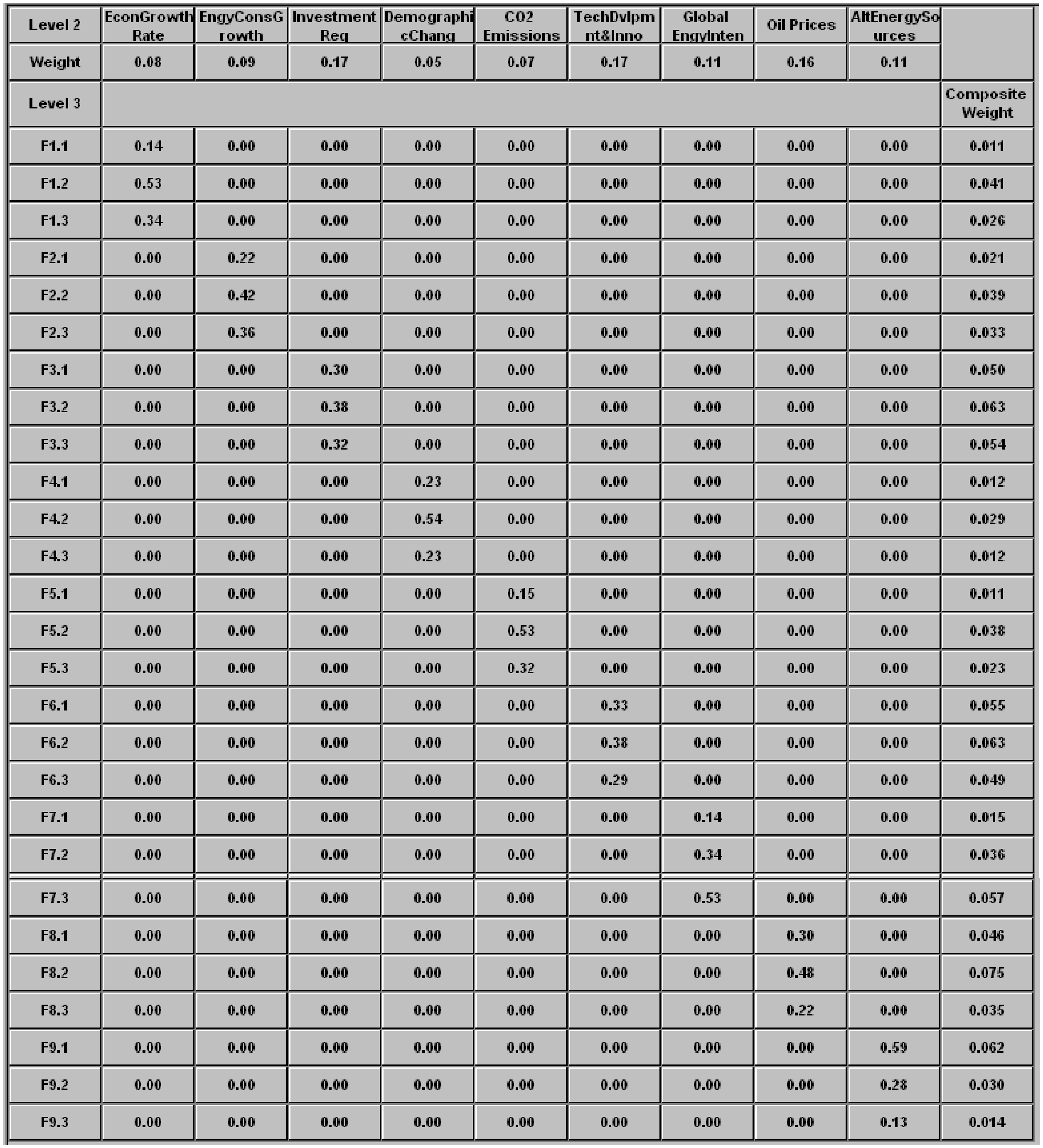


Table 4.1 is the payoff table showing priorities of the driving forces and their ranges

Table 4.1: Payoff Table Showing Priorities of the Driving Forces and their ranges



Level 2	EconGrowth Rate	EngyConsGrowth	Investment Req	DemographicChang	CO2 Emissions	TechDvlpmnt&Inno	Global EngyInten	Oil Prices	AltEnergySources	
Weight	0.08	0.09	0.17	0.05	0.07	0.17	0.11	0.16	0.11	
Level 3										Composite Weight
F1.1	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.011
F1.2	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.041
F1.3	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.026
F2.1	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.021
F2.2	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.039
F2.3	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.033
F3.1	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.050
F3.2	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.063
F3.3	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.054
F4.1	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.012
F4.2	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.029
F4.3	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.012
F5.1	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.011
F5.2	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.038
F5.3	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.023
F6.1	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.055
F6.2	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.063
F6.3	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.049
F7.1	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.015
F7.2	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.036
F7.3	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.057
F8.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.046
F8.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.075
F8.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.035
F9.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.062
F9.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.030
F9.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.014

Figure 4.5 and Table 4.2 show probabilities of world energy scenarios to 2050. According to this figure, the ACT Map scenario with a probability of 37.8% is the most likely one, followed very closely by the BLUE scenario (37.2%). The least likely scenario is the Baseline scenario with a probability of 25%.

Figure 4.5: Probabilities of World Energy Scenarios to 2050

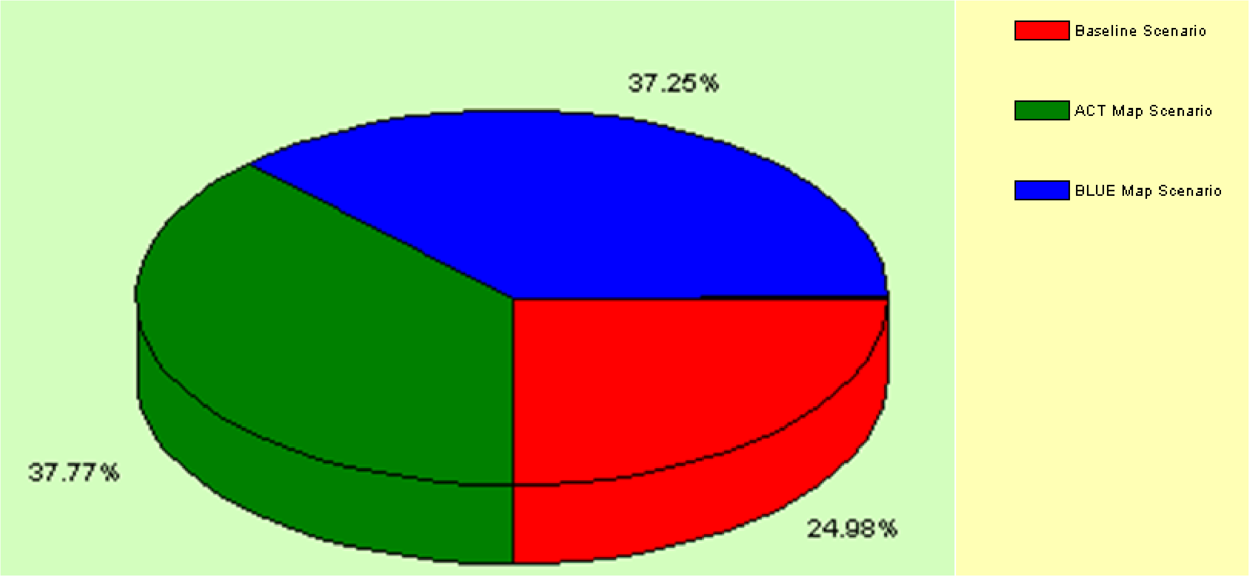
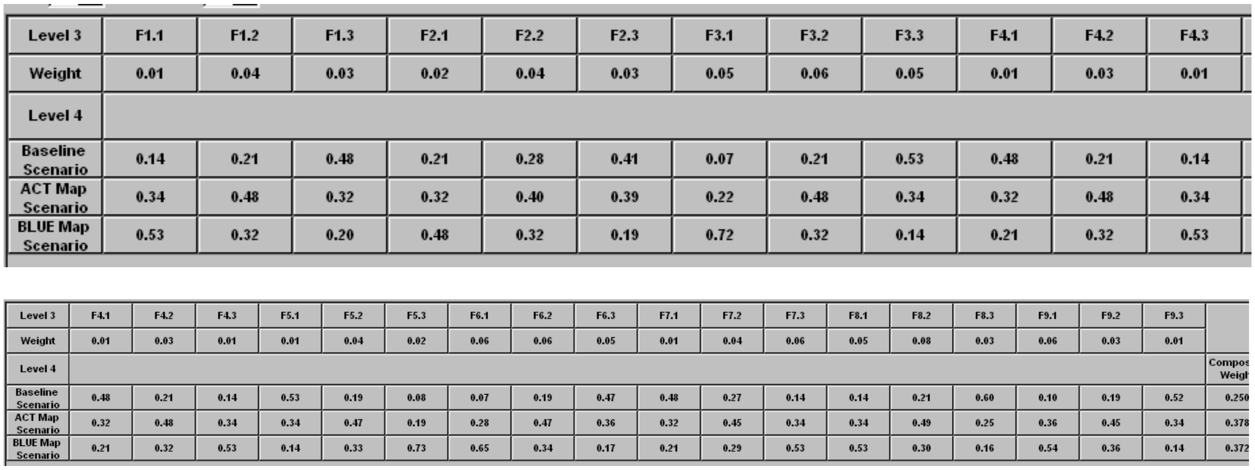
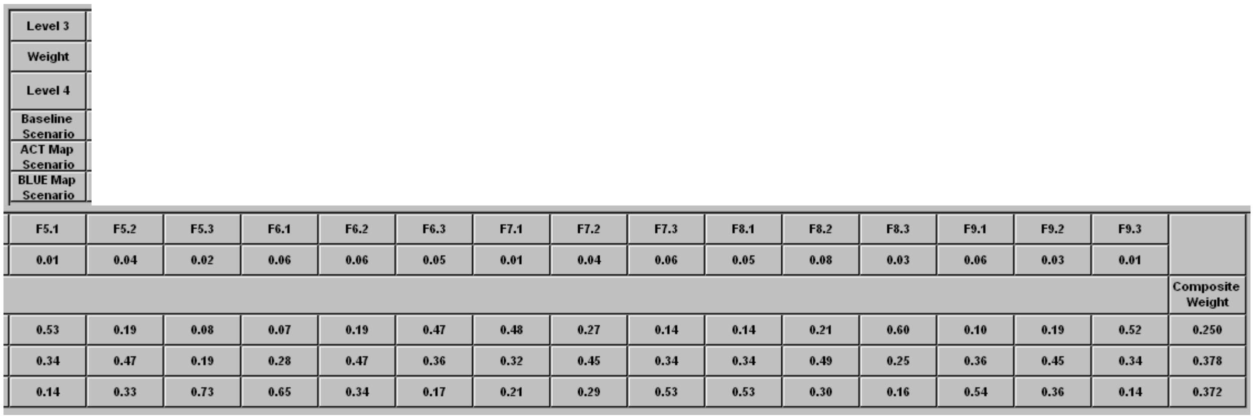


Table 4.2: Payoff Table Showing Probabilities of World Energy Scenarios to 2050 for Each Driving Force



Level 3	F1.1	F1.2	F1.3	F2.1	F2.2	F2.3	F3.1	F3.2	F3.3	F4.1	F4.2	F4.3
Weight	0.01	0.04	0.03	0.02	0.04	0.03	0.05	0.06	0.05	0.01	0.03	0.01
Level 4												
Baseline Scenario	0.14	0.21	0.48	0.21	0.28	0.41	0.07	0.21	0.53	0.48	0.21	0.14
ACT Map Scenario	0.34	0.48	0.32	0.32	0.40	0.39	0.22	0.48	0.34	0.32	0.48	0.34
BLUE Map Scenario	0.53	0.32	0.20	0.48	0.32	0.19	0.72	0.32	0.14	0.21	0.32	0.53

Level 3	F4.1	F4.2	F4.3	F5.1	F5.2	F5.3	F6.1	F6.2	F6.3	F7.1	F7.2	F7.3	F8.1	F8.2	F8.3	F9.1	F9.2	F9.3	
Weight	0.01	0.03	0.01	0.01	0.04	0.02	0.06	0.06	0.05	0.01	0.04	0.06	0.05	0.08	0.03	0.06	0.03	0.01	
Level 4																			Compos Weigh
Baseline Scenario	0.48	0.21	0.14	0.53	0.19	0.08	0.07	0.19	0.47	0.48	0.27	0.14	0.14	0.21	0.60	0.10	0.19	0.52	0.250
ACT Map Scenario	0.32	0.48	0.34	0.34	0.47	0.19	0.28	0.47	0.36	0.32	0.45	0.34	0.34	0.49	0.25	0.36	0.45	0.34	0.378
BLUE Map Scenario	0.21	0.32	0.53	0.14	0.33	0.73	0.65	0.34	0.17	0.21	0.29	0.53	0.53	0.30	0.16	0.54	0.36	0.14	0.372



Level 3	F5.1	F5.2	F5.3	F6.1	F6.2	F6.3	F7.1	F7.2	F7.3	F8.1	F8.2	F8.3	F9.1	F9.2	F9.3	
Weight	0.01	0.04	0.02	0.06	0.06	0.05	0.01	0.04	0.06	0.05	0.08	0.03	0.06	0.03	0.01	
Level 4																Composite Weight
Baseline Scenario	0.53	0.19	0.08	0.07	0.19	0.47	0.48	0.27	0.14	0.14	0.21	0.60	0.10	0.19	0.52	0.250
ACT Map Scenario	0.34	0.47	0.19	0.28	0.47	0.36	0.32	0.45	0.34	0.34	0.49	0.25	0.36	0.45	0.34	0.378
BLUE Map Scenario	0.14	0.33	0.73	0.65	0.34	0.17	0.21	0.29	0.53	0.53	0.30	0.16	0.54	0.36	0.14	0.372

Using the values suggested by the IEA for the three scenarios and the probabilities of these scenarios as shown in the above table, an expected value for the proposed scenarios for energy consumption and CO_2 emissions could be calculated as follows:

$EV = \Sigma P_i * D_i$

Where,

EV = Expected Value

P_i = Probability of scenario i

D_i = Estimated value for scenario i

EV (Energy consumption in 2050) = 0.2498 * 15,683 + 0.3777 * 12,076 + 0.3725 * 10,553
EV (Energy Consumption in 2050) = 12,410 Mtoe/yr

EV (CO2 emissions in 2050) = 0.2498 * 62 + 0.3777 * 27 + 0.3725 * 14
EV (CO2 emissions in 2050) = 31 Giga tons

According to these estimates, the expected values are closer to the ACT Map scenario than any other scenarios proposed by IEA.

It must be emphasized that although the numbers assigned to scenarios are useful for quantitative analysis, ***the value of this method is in the process*** that the analysts go through. At the end of this process, the energy analysts can tell a consistent and plausible “story” about the energy future.

5 Strategies to achieve the Desired Energy Scenario

Based on the previous analysis, the most realistic scenario would require expanded use of more efficient and cleaner technologies and expanded use of electric vehicles and biofules. Under this desired scenario, the energy consumption would be about ***12,410 Mtoe/yr*** (compared with 7,748 Mtoe/yr in 2005) and CO_2 emissions would be about ***31 Giga tons/yr*** by 2050 (compared with 27 Giga tons/yr in 2005). Achieving this scenario requires comprehensive and consistent strategies that must be implemented worldwide between now and 2050.

No single strategy will be sufficient to reach the desired levels of energy production, consumption and CO_2 emission reduction, rather a portfolio of reinforcing strategies will be required to make the transition to cleaner and more efficient energy future.

The purpose of this section is to identify, define, and prioritize a set of consistent strategies that their implementation will be essential in achieving the desired world energy scenario by 2050. Suggested strategies include the following:

Strategy 1: RDD&D Strategies

Strategy 2: Investment Strategies

Strategy 3: CO_2 Emission Reduction Strategies

Strategy 4: Energy Intensity Reduction Strategies

Strategy 5: International Collaboration Strategies

Strategy 6: Government Engagement Strategies

5.1 Strategy 1: RDD&D Strategies

A substantial increase and more continuous investments in research, development, demonstration and deployment (RDD&D) of energy technologies are needed in achieving the desired energy scenario by 2050. International cooperation and public-private partnerships are essential in reaching the desired level of RDD&D investment. According to IEA (ETP 2008), "*All countries have an important role to play in bringing these clean energy technologies to market. Developed countries will play the largest role in terms of RD&D, but many of these technologies will only be viable if they are deployed and commercialized in developing as well as in developed countries.*"

In 2005, private sector spending on energy-related R&D was about $40-$60 billion per year compared to $10 billion per year in the public sector. The average R&D spending in OECD countries was less than 0.03% of GDP, except for Japan which was about 0.08% of its GDP.

According to Jones and Williams (1997), the average return on RD&D to firms is estimated to be around 20% to 30%. This is high compared to the 10% rate of return typically required by the private sector on capital investment.

Moving from publicly-funded demonstration to commercial viability is often the most difficult phase for many technologies, resulting in what Murphy an Edwards (2003) have called a “valley of death”. It is at this point where investment costs can be very high and where risks also remain significant, that projects can easily fail. Frequently, neither the public nor the private sector considers it their duty to finance commercialization. This is where neither “technology-push” force nor “market-pull” force has sufficient strength to fill the gap. This gap is particularly problematic for technologies with long lead times and a need for considerable applied research and testing between invention and commercialization, as it is the case for many energy technologies (Norberg-Bohm, 2002).

The following list includes some of the important areas for RDD&D investments:

- Continued increase in R&D investments in energy efficiency and clean energy technologies. Government-funded RD&D can play a critical role in solving difficult technical problems that markets may fail to address.
- Development programs for energy technologies that are not yet cost-competitive, but whose costs could be reduced through learning-by-doing.
- Demonstration programs for energy technologies that need to prove they can work on a commercial scale under relevant opening conditions.
- Further R&D to develop more energy-efficient, sustainable and cost-effective heat pump technologies.
- Increased RDD&D in biofuels to reduce cost and to solve sustainability problems. Bioenergy is the largest renewable energy contributor to global energy today and has the highest technical potential of all renewable energy sources according to both the ACT Map and BLUE Map scenarios for 2050. Biomass used inefficiently for traditional domestic cooking and space heating accounts for around two-thirds of total current demand. Bioenergy costs are expected to reduce over time due to both technology learning and economies of scale in larger commercial plants. Current bio-electricity generation costs of around $62 to $185/MWh could reduce by 2050 to $49-123/MWh.
- The main constraint on the use of biofuels will be the amount of land that could be brought into production in a sustainable way, without compromising food security and environmental constraints.
- Increase RDD&D on PV systems. One promising area is PV-technology shift from crystalline silicon (c-Si) to thin-film technology.
- Increased RDD&D on fuel cells to reduce costs. Fuel cells are electrochemical devices that generate electricity and heat using hydrogen (H_2) or H_2-rich fuels, together with Oxygen from air. Several thousand fuel cell systems are produced each year. Most are for small stationary units. The cost of 200 kW to 300 kW units is between $12000/kW to $15000/kW compared to about $1400-$2000/kW for coal-fired plants or about $700/kW for gas-fired plants.

- Fossil fuels are at the core of energy demand in the transport and electricity generation sectors and will be for many years to come. Finding ways to make the best use of existing resources is critical.
- R&D on low-cost, long-range DC transmission systems.
- Development of Gen IV nuclear power plants will help to reduce costs, minimize nuclear waste, enhance safety and hence improve public acceptance of nuclear.
- Development of Small and Medium Reactor would minimize capital requirements and ease financing.
- Development of proliferation-resistant fuel systems.
- Uranium exploration and mine development should be further increased.
- Fusion power has great potential for power generation, but research in this area is area is costly.

5.2 Strategy 2: Investment Strategies

Governments must create the economic environment that is required for successful deployment and commercialization of energy efficiency and clean energy technologies. The main challenge for policy makers will be to ensure that the required investment in energy will actually occur, and in a timely fashion.

The investment needs of the energy sector are huge. According to the IEA, to meet global energy needs by 2050, total cumulative investment of at least $254 trillion is needed between 2005 and 2050 (in 2005 dollar value). This figure represents only 6% of cumulative global GDP over this period. The followings are some suggestions for implementing this strategy.

- Implement stable, consistent and predictable policy support to encourage investment in energy efficiency and clean energy technologies. One such measure would be to implement tax policies that favor energy efficiency and clean technologies despite the fact that clean energy technologies are more capital-intensive. But government financial incentives would minimize up-front capital costs. Policy initiatives are particularly necessary for the development of transportation systems, planning towns and cities, modernization of communication systems, and work practices.
- Develop clear, long-term incentives to help establish investor confidence in innovative technologies.
- Industry leaders have to ensure that corporate policy, investment criteria, and business practices are all geared to deliver the goods and services that support the government's policy intent.

5.3 Strategy 3: CO_2 Emission Reduction Strategies

In the absence of new initiatives, global energy demand and CO_2 emissions will more than double by 2050. According to IEA a "*50% reduction in CO_2 emissions by 2050 is technically feasible*". However, the technologies that are capable of reducing CO_2 emissions to this level

are not cost effective under the current policy environment. This level of reduction in worldwide emissions by 2050 would require a cost of up to $200/ton of CO_2.
The following are some suggestions for implementing this strategy.

- Provide financial incentives for CO_2 reduction to encourage the adoption of low-carbon technologies.
- Provide financial incentives for CO_2 Capture and Storage (CCS) to reduce emissions even further.
- On the supply side, encourage implementation of clean coal technologies to minimize the growth of CO_2 emissions from power generation.
- On the demand side, improving energy efficiency should be high priority in reducing CO_2 emissions.

5.4 Strategy 4: Energy Intensity Reduction Strategies

Energy Efficiency means using less energy to provide the same, if not higher, quality energy services. For example, an energy-efficient building is more comfortable to live in, yet, it uses less energy to heat, cool, and it will even provide more pleasant lighting. Greater energy efficiency can reduce energy costs to consumers, enhance environmental quality, improve people's standard of living, increase energy security, and promote a strong economy. Improving energy efficiency makes sense economically and it certainly makes sense from the environmental point of view.

According to IEA, energy efficiency offers the highest potential for reducing future CO_2 emissions. The majority of the technologies needed are already available today at low or negative costs. End-use energy efficiency accounts for 36% to 44% of emissions reductions in the ACT Map and the BLUE Map scenarios compared to the Baseline scenario. In comparison, CCS represents 14% to 19% of reductions, nuclear 6% and renewables 21%. End-use efficiency improvements in the transportation, industry, commercial and residential sectors reduce the need for investment in upstream energy supply, but these clean energy investment requirements shift the balance of investment from the supply-side to the demand-side.
The following are some suggestions for implementing this strategy.

- Collect reliable and comprehensive data on end-use consumption and energy efficiency worldwide.
- Encourage innovative solutions for energy efficiency on the supply and demand side through national and regional programs.
- Develop and implement energy efficiency standards for buildings, lighting systems, appliances, and motors. There is a need for better international harmonization of codes, standards and labeling schemes, together with the continuous development of international standards is also needed.
- Encourage construction of "zero" energy buildings which is part of the BLUE scenario.
- Improve power plant efficiency. Because of the long lifespan (up to 60 years) of power plants, the average efficiency of currently operating power plants that are not

implementing appropriate plant operation and maintenance is substantially lower than which could be achieved by the best available technology. Power producers primarily aim to minimize their production costs, not to maximize efficiency-and those two objectives do not always coincide. The efficiency of hard coal-fired power plants averaged about 35% from 1992 to 2005 globally. The best available coal-fired plants can achieve 47%. The efficiency of brown coal-fired power plants increased from 33% in 1992 to 35% in 2005. Power generation using natural gas is competitive with coal at today's price for natural gas and coal in many regions of the world. The average efficiency of natural gas-fired power plants increased from 35% in 1992 to 43% in 2005. Most of the improvement in efficiency was a result of the introduction of large combined-cycle units, which now accounts for 38% of global gas-fired capacity. Today, natural gas combined-cycle (NGCC) power plants are often preferred over conventional coal-fired plants due to: 1) efficiency achievements topping 60%; 2) lower capital costs of $600 to $750 per KW, compared with $1400 to $2000 per KW for a typical coal-fired plant; 3) shorter construction times; and 4) lower emissions: NGCC plants emit less than half the CO_2 emissions of similarly rated coal-fired plants.

- Encourage cogeneration. Cogeneration, or combined heat and power (CHP), is the simultaneous utilization of useful heat and power from a single fuel source. CHP plants can convert 75% to 80% of the fuel resource into useful energy, with some plants reaching overall efficiencies of 90% or more. Almost any fuel is suitable for CHP.
- Introduce advanced fuel economy technologies, such as hybrid and plug-in hybrids globally.
- Increased investments in advanced public transit systems such as "bus rapid transit" can help cities ensure that their residents have low cost, high quality mobility options.

5.5 Strategy 5: International Collaboration Strategies

International collaboration is essential to minimize the costs and accelerate the rate of development and deployment of energy efficiency and clean energy technologies. There are a number of international network organizations operating today, including the International Energy Agency (IEA), Organization of the Carbon Sequestration Leadership Forum (CSLF), Intergovernmental Panel on Climate Change (IPCC), and the United Nations Environmental Program (UNEP). The international Collaboration strategies include:

- International collaboration in RD&D. This collaboration would reduce redundancy of RD&D activities simultaneously under way in several countries, improving cost effectiveness of global RD&D investment. It will also create a common pool of knowledge that would benefit both developed and developing nations.
- Global dialogue on security of supply and demand and strengthening regional partnerships for energy security through broader cooperation in resource exploitation, installations of trans-border power grids and natural gas networks, and stockpiles for emergencies.
- Development of global energy information network and energy education and awareness programs.
- Sharing best practices and lessons learnt from the innovative energy projects.

- Development of international energy efficiency standards for end-use equipment.
- Development, deployment and sharing of legal and regulatory frameworks.
- Development and deployment of international and regional instruments for CO_2 pricing.

5.6 Strategy 6: Government Engagement Strategies

The role of government in technology development has been proven in many countries. The most effective role of government is using a dual strategy of "***supply push***" and "***demand pull***." The *supply push* strategies include developing and implementing energy efficiency standards and RDD&D support for innovative technologies. The *demand pull* strategies include market pull through financial incentives, guaranteed purchase agreements, and public awareness of the benefits of new technologies.

Governments must create a stable and predictable policy environment in the energy markets that minimizes regulatory uncertainties and reduces risks to energy technology investors. Industry looks to governments to share the political, and in some cases financial, risks linked with bringing many of these clean energy technologies to market.

In addition to investment, governments have to establish processes to prioritize and evaluate national RD&D programs. They must develop policies that can stimulate private sector investment in energy RD&D technology.

To achieve the large-scale technological change required for the desired scenario by 2050, a portfolio of policies is needed. The government engagement strategies include:

- Developing consistent national, regional and international energy strategies.
- Developing a clear strategy for international RD&D collaboration.
- Create market and financial incentives to encourage the development and deployment of clean energy technologies.
- Develop well-defined and transparent RD&D prioritization and evaluation processes.
- Develop effective public-private partnerships.
- Develop "least-cost" policy solutions which consider externality costs. Current pricing policies do not reflect the full cost of energy technologies to society.
- Increase access to modern energy services, particularly in developing countries.
- Promote partnerships between regions and countries, public and private sectors, and among consumers in terms of energy savings, etc.
- Facilitate technology transfer, particularly to developing countries.
- Reduce lead times for planning and construction of new generation and transmission facilities.
- Reduce or eliminate fossil fuel subsidies.
- Develop tough efficiency regulations for buildings, appliances and vehicles.
- Create training and educational programs and viable career paths that are necessary to ensure that skilled professionals are available worldwide for the transition to more efficient and cleaner energy technologies.

6 Prioritization of Energy Strategies using Decide2000®

The recommended energy strategies are prioritized using the driving forces analyzed earlier in this paper as criteria. Figure 6.1 illustrates the hierarchical model of energy strategies. Figures 6.2 and 6.3 and Table 6.1 show priorities of the driving forces and strategies.

Figure 6.1: Hierarchical Model of Energy Strategies

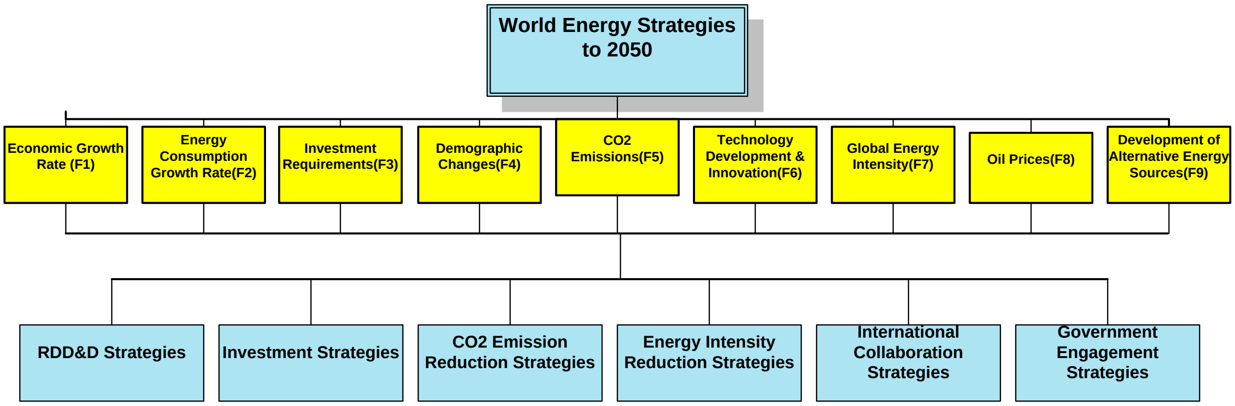


Figure 6.2: Priorities of the Driving forces vis-a-vis Strategies

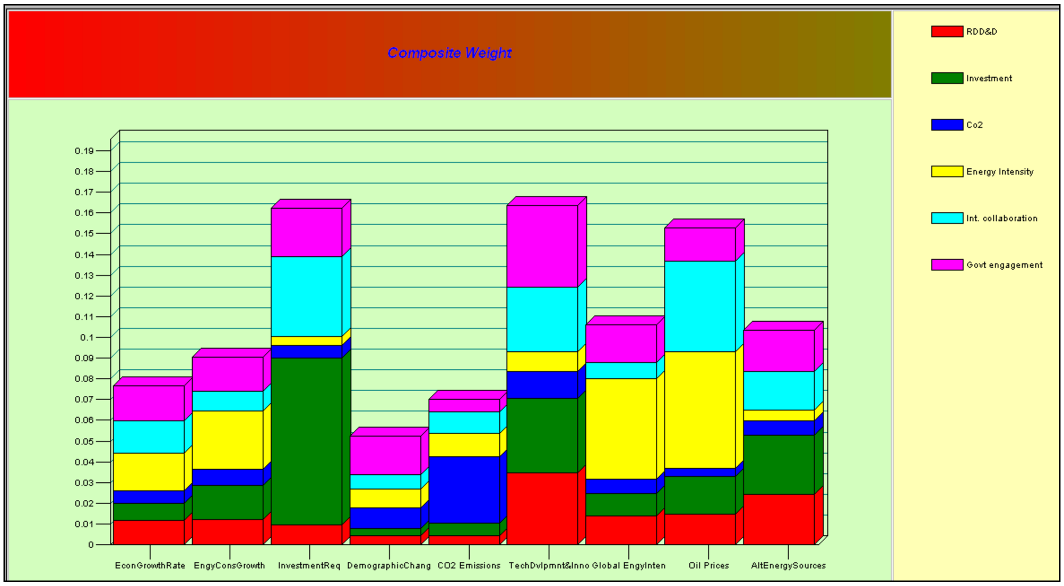


Figure 6.3: Priorities of the Strategies vis-à-vis the Driving forces

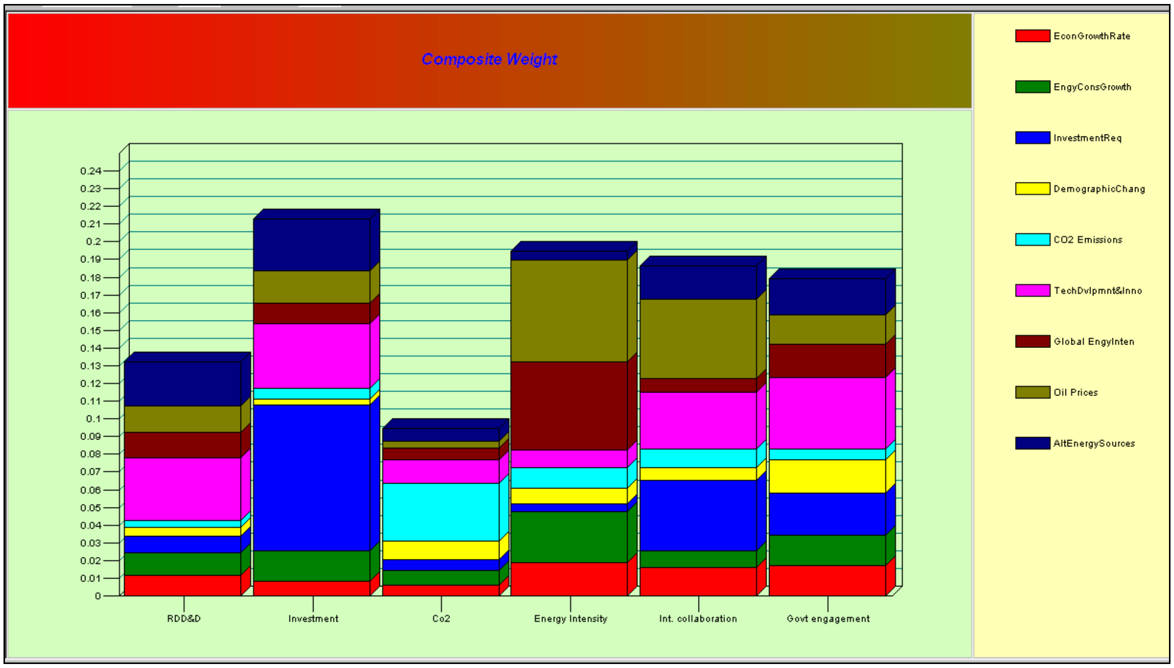
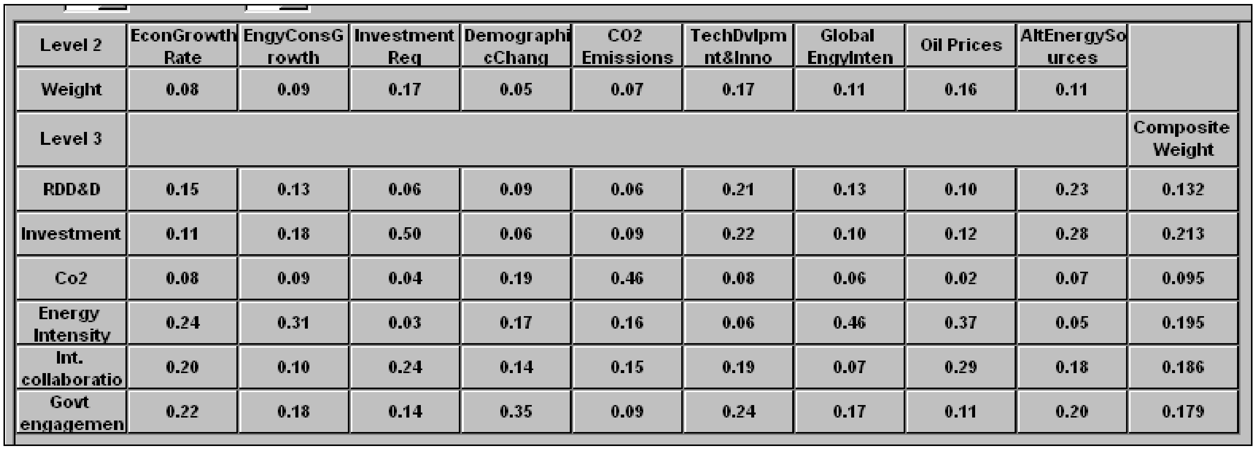


Table 6.1: Payoff Table of the driving forces and strategies



Level 2	EconGrowth Rate	EngyConsG rowth	Investment Req	Demographi cChang	CO2 Emissions	TechDvlpm nt&Inno	Global EngyInten	Oil Prices	AltEnergySo urces	
Weight	0.08	0.09	0.17	0.05	0.07	0.17	0.11	0.16	0.11	
Level 3										Composite Weight
RDD&D	0.15	0.13	0.06	0.09	0.06	0.21	0.13	0.10	0.23	0.132
Investment	0.11	0.18	0.50	0.06	0.09	0.22	0.10	0.12	0.28	0.213
Co2	0.08	0.09	0.04	0.19	0.46	0.08	0.06	0.02	0.07	0.095
Energy Intensity	0.24	0.31	0.03	0.17	0.16	0.06	0.46	0.37	0.05	0.195
Int. collaboratio	0.20	0.10	0.24	0.14	0.15	0.19	0.07	0.29	0.18	0.186
Govt engagemen	0.22	0.18	0.14	0.35	0.09	0.24	0.17	0.11	0.20	0.179

Conclusions

Effective implementation of all the recommended strategies is necessary to reach the desired energy scenario by 2050. According to the above figures, the ***investment strategy*** must be given the highest priority. Without the necessary investments in RDD&D, we will not reach the level of technological advancement needed to achieve the desired scenario. This strategy is followed closely by the ***energy intensity reduction strategy***, ***international collaboration*** and ***government engagement*** strategies. The RDD&D and CO_2 emissions reduction strategies are rated lower because their success depends on the implementation of the previously-mentioned strategies.

Bibliography

1. Brown, S.P.A., R. Virmani and R. Alm. Crude Awakening: Behind the Surge in Oil Prices.
Source: Worthwhile Canadian Initiative

2. Chevron (biofuel section). Biofuels: Turning Trash into Treasure.
Source:
http://www.fsela.com/main/inside.php?page=boilers&section=products_services&gclid=COvE9IDSx5YCFRg6awodqmM9xw

3. DeMis, W. D. (2007). Historical Analysis of Real Global Price of Oil: Implications for Future Prices. Search and Discovery Article #70037 (2007). Posted December 3, 2007
Source: www.eia.doe.gov/oiaf/aeo/

4. Energy Information Administration (2008). International Energy Outlook 2008
Office of Integrated Analysis and Forecasting
U.S. Department of Energy, Washington, DC 20585
Source: http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2008).pdf

5. Energy Information Administration (2008). Annual Energy Outlook 2008 with Projections to 2030.Office of Integrated Analysis and Forecasting
U.S. Department of Energy, Washington, DC 20585
Source: http://mplic.wordpress.com/2008/06/26/annual-energy-outlook-2008-with-projections-to-2030/

6. Energy Information Administration (2008). Electricity Basics 101.
U.S. Department of Energy, Washington, DC 20585
Source: http://www.eia.doe.gov/basics/electricity_basics.html

7. Energy Information Administration (2009). Annual Energy Outlook 2009 Early Release. Office of Integrated Analysis and Forecasting
U.S. Department of Energy, Washington, DC 20585
Source: http://www.eia.doe.gov/oiaf/aeo/

8. Federal Reserve Bank of Dallas, (2008). Economic Letter—Insights from the Federal Reserve Bank of Dallas, Vol. 3, No. 5.
Source: http://www.dallasfed.org/research/eclett/2008/el0805.html

9. Hubbert, M.K. “The Energy Resources of the Earth.” Energy and Power. A Scientific American Book. From Energy and Power, A Scientific American Book, 1971, pg 39

10. International Atomic Energy Agency (2008). **Energy, Electricity and Nuclear Power: Developments and Projections - 25 Years Past and Future**.
Source: http://www.iaea.org/OurWork/ST/NE/Pess/publications.shtml

11. International Energy Agency (2008). ***Energy Technology Perspectives 2008-Scenarios and Strategies to 2050.*** Paris, France

12. International Energy Agency (2008). ***World Energy Outlook 2008***. Paris, France

13. Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., D. Qin, M. Manning, Z. Chen, M,. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge United Kingdom and New York, NY, USA.

14. International Monetary Fund (IMF). World Economic Outlook Update
Global Economic Slump Challenges Policies. January 28, 2009
Source: http://www.imf.org/external/pubs/ft/weo/2009/update/01/index.htm

15. Jones, C. and J. Williams (1997), "Measuring the Social Return to R&D", Finance and Economics Discussion Series, 1997-12, Federal Reserve Board, Washington, DC.

16. National Petroleum Council (2007) Facing the Hard Truths about Energy: A Comprehensive View to 2030 Of Global Oil And Natural Gas.
Source: ***http://www.npc.org***

17. Nezhad, H. *Software Tools for Managing Project Risk*. Vienna, VA: Management Concepts, 2007.

18. Nezhad, H.G. "World Energy Scenarios for the Year 2010." *Journal of Strategic Planning for Energy and the Environment* 9, no. 4 (1990): 26–44.

19. Nezhad, H.G. *How to Make Decisions in a Complex World*. Lexington, MA: Ginn and Co., 1st ed. 1986; 2nd ed. 1989.

20. Nezhad, H.G. "Oil Price Scenarios: 1989 and 1995." *Journal of Strategic Planning and Energy Management* 7, no. 1 (1987): 19–31.

21. Nezhad, H.G., and S.R. Xia. "Formulating Energy Strategies and Policies for China: A Systematic Approach." *Journal of Environment and Planning B: Planning and Design* 11, no. 2 (1984): 213–228.

22. Nezhad, H.G., and T.L. Saaty. "High-Level Nuclear Waste Management: Analysis of Options." *Journal of Environment and Planning B: Planning and Design* 9 (1982): 181–196.

23. Nezhad, H.G., and T.L. Saaty. "A Desired Energy Mix for the United States in the Year 2000: An Analytic Hierarchy Approach." *International Journal of Policy Analysis and Information Systems* 6, no. 1 (1982): 47–64.

24. Nezhad, H.G."Critical Choices for OPEC Members and the U.S." *Journal of Conflict*

Resolution 25, no. 1 (1981): 115–143.

25. Roberts, F.S. *Discrete Mathematical Models with Applications to Social, Biological, and Environmental Problems*. Prentice-Hall, Inc., 1976.

26. Saaty, T.L. *The Analytic Hierarchy Process*. New York: McGraw-Hill, 1980.

27. Saffo, Paul (2007). Six Rules for Effective Forecasting. Harvard Business Review, 00178012, Jul/Aug2007, Vol. 85, Issue 7/8.

28. Schwartz, P. *The Art of the Long View*. New York: Doubleday, 1991.

29. Sterman, J.D. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill/Irwin, 2000.

30. U.S. Census Bureau (2008). International Data Base (IDB). Worl Population Information. Source: http://www.census.gov/ipc/www/idb/worldpopinfo.html

31. U.S. Department of Commerce. National Oceanic and Atmospheric Administration
Earth System Research Laboratory. Global Monitoring Division.
Source: http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html

32. World Business Council for Sustainable Development (WBCSD-2009). Transforming the Market: Energy Efficiency in Buildings.

33. World Energy Council (2008). Energy Efficiency Policies around the World: Review and Evaluation. Source: *www.worldenergy.org*.

LIST OF ACRONYMS

ACT	*The Accelerated Technology (ACT) Scenario*
AHP	*Analytic Hierarchy Process*
Baseline Scenario	*Business-as-usual scenario*
BLUE	*BLUE Map Scenario*
CSLF	*Carbon Sequestration Leadership Forum*
CDM	*Clean Development Mechanism*
CHP	*Combined Heat and Power*
CERT	*IEA Committee on Energy Research and Technology*
CCS	*Carbon (CO_2) Capture and Storage*
CIS	*Commonwealth of Independent States*
C-Si	*Crystalline Silicon*
CSP	*Concentrated Solar Power*
DSM	*Demand-Side Management*
EIA	*United States Energy Information Administration*
ETP	*Energy Technology Perspective Report by IEA*
EV	*Electric Vehicle*
GEF	*Global Environment Facility*
GHG	*Green House Gas Emissions*
Giga tons	*One Billion Tons*
GW	*Giga Watt (One Billion Watt)*
HVAC	*Heating, Ventilation and Air Conditioning Systems*
HFC	*Hydrogen Fuel Cell*

HSR	*High Speed Rail*
IAEA	*International Atomic Energy Agency*
IEA	*International Energy Agency*
IMF	*International Monetary Fund*
IGCC	*Integrated Gasification Combined-Cycle Technologies*
IPCC	*Intergovernmental Panel on Climate Change*
LPG	*Liquefied Petroleum Gas*
Mtoe/yr	*Million Tons of Oil Equivalent Per Year*
NIS	*Newly Independent States*
OECD	*Organization for Economic Cooperation and Development*
OPEC	*Organization of Petroleum Exporting Countries*
PPM	*Parts Per Million*
PV	*Photovoltaic Cells*
RDD&D	*Research, Development, Demonstration and Deployment*
T&D	*Transmission and Distribution Systems*
TMI	*Three Mile Island*
TWh/yr	*One Billion KWh Per Year*
UNDP	*United Nations Development Program*
UNEP	*United Nations Environmental Program*
WBCSD	*World Business Council for Sustainable Development*
WEC	*World Energy Council*