NUCLEAR POWER – AN INEVITABLE OPTION

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A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
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CENTRE FOR CONTINUING EDUCATION
UNIVERSITY OF PETROLEUM & ENERGY STUDIES , DEHRADUN

APPENDIX – II

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Apart from efforts of the person doing the project, the success of any project depends largely on the encouragements and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of the project.

I would like to thank my Project Guide Mr..Ambrish Kumar Chaturvedi, Rtd. Chief Engineer, UPPCL who always assisted me in every possible manner.

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I also extend my thanks to all the faculties and my batch mates in University of Petroleum & Energy Studies (UPES), for their support and guidance throughout the course of project.

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APPENDIX – III

UTTAR PRADESH POWER CORPORATION LTD.

A Declaration by the Guide

This is to certify that the **Mr Saurabh Chaturvedi** , a student of **MBA (Power Management)**, Roll No. **500015208** of UPES has successfully completed this dissertation report on **"NUCLEAR POWER – AN INEVITABLE OPTION"** under my supervision.
Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of MBA.

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Date: 25/10/2015
Place LUCKNOW

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Hydroelectricity	169
Solar	45
Geothermal	38
Nuclear	66
Natural gas	443
Fuel Cell	664
Oil	1556
Coal	2010

Table 1

World Fossil Fuel Reserves and Projected Depletion

Global Fossil Fuel Reserves	World Petroleum (Billion Barrels)	Natural Gas (Trillion Cubic Feet)	Coal (Billion Short Tons)
World Reserves (Jan 1, 2000)	1,017	5,150	1089*
World Potential Reserve Growth	730	3,660	–
World Undiscovered Potential	939	5,196	–
TOTAL RESERVES	2,686	14,006	1,089
ANNUAL WORLD CONSUMPTION	27.340	84.196	4.740
YEARS OF RESERVES LEFT**	98	166	230

**World Estimated Recoverable Coal* ***Based on current levels of consumption and estimated total reserves*

World Fossil Fuel (Petroleum, Natural Gas, Coal) Assessment

Table 2

Technology	Power density W/sq. m.	Size for 35GW average output
Biofuel	~0.2-0.4	87,500-175,000 sq km
Wind power	~1-2	17,500-35,000 sq km
Solar power	~25	1400 sq km
Coal or nuclear power station	~4000	8.75 sq km

Table 3

LCOE in AUD per MWh (2006)

Technology	Cost
Coal	28–38
Coal: IGCC + CCS	53–98
Coal: supercritical pulverized + CCS	64–106
Open-cycle Gas Turbine	101
Hot fractured rocks	89
Gas: combined cycle	37–54
Gas: combined cycle + CCS	53–93
Small Hydro power	55
Wind power: high capacity factor	63
Solar thermal	85
Biomass	88
Photovoltaics	120

Table 4

French LCOE in €/MWh (2011)

Technology	Cost in 2011
Hydro power	20
Nuclear (with State-covered insurance costs)	50
Natural gas turbines without CO_2 capture	61
Onshore wind	69
Solar farms	293

Table 5

German LCOE in €/MWh (2013)

Technology	Cost range in 2013
Coal-fired power plants (brown coal)	38–53
Coal-fired power plant (hard coal)	63–80
CCGT power plants (cogeneration)	75–98
Onshore wind farms	45–107
Offshore wind power	119–194
PV systems	78–142
Biogas power plant	135–250
Source: Fraunhofer Institute- Levelized cost of electricity renewable energy technologies	

Table 6

UK LCOE in £/MWh (2010)

Technology	Cost range (£/MWh)[42]
Natural gas turbine, no CO_2 capture	55 – 110
Natural gas turbines with CO_2 capture	60 – 130
Biomass	60 – 120
New nuclear(a)	80 – 105
Onshore wind	80 – 110
Coal with CO_2 capture	100 – 155
Offshore wind	150 – 210
Tidal power	155 – 390
new nuclear power: guaranteed strike price of £92.50/MWh for Hinkley Point C in 2023	

Table 7

State-wise all India allocated power capacity as of July 2015[1]

(including allocated shares in joint and central sector utilities)

State/Union Territory	Thermal (in MW)				Nuclear (in MW)	Renewable (in MW)			Total (in MW)	% of Total
	Coal	Gas	Diesel	Sub-Total Thermal		Hydel	Other Renewable	Sub-Total Renewable		
Maharastra	24,669.27	3,475.93	-	28,145.20	690.14	3,331.84	6,205.65	9,537.49	38,372.83	13.91%
Gujarat	16,010.27	6,806.09	-	22,816.36	559.32	772.00	4,802.40	5,574.4	28,950.08	10.49%
Madhya Pradesh	11,126.39	257.18	-	11,383.57	273.24	3,223.66	1,670.34	4,894.00	16,550.81	6.00%
Chhattisgarh	13,193.49	-	-	13,193.49	47.52	120.00	327.18	447.18	13,688.19	4.96%
Goa	326.17	48.00	-	374.17	25.80	-	0.05	0.05	400.02	0.14%
Dadra & Nagar Haveli	44.37	27.10	-	71.47	8.46	-	-	-	79.93	0.03%
Daman & Diu	36.71	4.20	-	40.91	7.38	-	-	-	48.29	0.02%
Central - Unallocated	*1,622.35*	*196.91*	-	*1,819.26*	*228.14*	-	-	-	*2,047.40*	*0.74%*
Western Region	***67,029.01***	***10,815.41***	-	***77,844.42***	***1,840.00***	***7,447.50***	***13,005.62***	***20,453.12***	***100,137.54***	***36.29%***
Rajasthan	9,400.72	825.03	-	10,225.75	573.00	1,719.30	4,710.50	6,429.8	17,228.55	6.24%
Uttar Pradesh	11,677.95	549.97	-	12,227.92	335.72	2,168.30	989.86	3,158.16	15,721.80	5.70%
Punjab	6,444.88	288.92	-	6,733.80	208.04	3,145.13	503.42	3,648.55	10,590.38	3.84%
Haryana	6,527.53	560.29	-	7,087.82	109.16	1,456.83	138.60	1,595.43	8,792.41	3.19%
Delhi	5,001.87	2,366.01	-	7,367.88	122.08	822.05	34.71	856.76	8,346.72	3.03%
Himachal Pradesh	152.02	61.88	-	213.90	34.08	3,421.51	728.91	4,150.42	4,398.40	1.59%
Uttarakhand	399.50	69.35	-	468.85	22.28	2,441.82	244.32	2,686.14	3,177.27	1.15%
Jammu & Kashmir	329.32	304.14	-	633.46	77.00	1,805.21	156.53	1,961.74	2,672.20	0.97%
Chandigarh	32.54	15.32	-	47.86	8.84	62.32	5.04	67.36	124.06	0.04%
Central - Unallocated	*977.19*	*290.35*	-	*1,267.54*	*129.80*	*754.30*	-	*754.30*	*2,151.64*	*0.78%*
Northern Region	***40,943.50***	***5,331.26***	***12.99***	***46,274.76***	***1,620.00***	***17,796.77***	***7,511.89***	***25,308.66***	***73,203.42***	***26.53%***
Tamil Nadu	10,075.10	1026.30	411.66	11,513.06	986.50	2,182.20	8,423.15	10,605.35	23,104.91	8.37%
Karnataka	6,408.46	-	234.42	6,642.88	475.86	3,599.80	4552.48	8,152.28	15,271.02	5.53%
Andhra Pradesh	5,849.21	1,672.65	16.97	7,538.83	127.16	1,721.99	2,002.65	3,724.64	11,390.64	4.13%
Telangana	5,598.47	1,697.75	19.83	7,316.05	148.62	2012.54	62.75	2,075.29	9,539.96	3.46%
Kerala	1,038.69	533.58	234.60	1,806.87	228.60	1881.50	204.05	2,085.55	4,121.02	1.49%
Puducherry	249.32	32.50	-	281.82	52.78	-	0.03	0.03	334.63	0.12%
Central - NLC	100.17	-	-	100.17	-	-	-	-	100.17	0.04%
Central - Unallocated	*1,523.08*	-	-	*1,523.08*	*300.48*	-	-	-	*1,823.56*	*0.66%*
Southern Region	***30,842.50***	***4,962.78***	***917.48***	***36,722.76***	***2,320.00***	***11,398.03***	***15,245.11***	***26,643.14***	***65,685.90***	***23.81%***
West Bengal	8,083.83	100.00	-	8,183.83	-	1,248.30	131.45	1,379.75	9,563.84	3.47%
Odisha	6,753.04	-	-	6,753.04	-	2,166.93	116.55	2,283.48	9,036.52	3.28%
DVC	*7,160.66*	*90.00*	-	*7,250.66*	-	*193.26*	-	*193.26*	*7,443.92*	*2.70%*
Bihar	2,516.24	-	-	2,516.24	-	129.43	114.12	243.55	2,759.79	1.00%
Jharkhand	2,404.93	-	-	2,404.93	-	200.93	20.05	220.98	2,625.91	0.96%
Sikkim	92.10	-	-	92.10	-	174.27	52.11	226.38	318.48	0.12%
Central - Unallocated	*1,572.07*	-	-	*1,572.07*	-	-	-	-	*1,572.07*	*0.57%*
Eastern Region	***28,582.87***	***190.00***	-	***28,772.87***	-	***4,113.12***	***434.54***	***4,547.66***	***33,320.53***	***12.08%***
Assam	187.00	718.62	-	905.62	-	429.72	34.11	463.83	1,369.45	0.50%
Tripura	18.70	538.82	-	557.52	-	62.37	21.01	83.38	640.90	0.23%
Meghalaya	17.70	105.14	-	122.84	-	356.58	31.03	387.61	510.45	0.19%
Arunachal Pradesh	12.35	43.06	-	55.41	-	97.57	104.64	202.21	257.62	0.09%
Manipur	15.70	67.98	36.00	119.68	-	80.98	5.45	86.43	206.11	0.07%
Nagaland	10.70	46.35	-	57.05	-	53.32	29.67	82.99	140.04	0.05%
Mizoram	10.35	38.29	-	48.64	-	34.31	36.47	70.78	119.42	0.04%
Central - Unallocated	*37.50*	*104.44*	-	*141.94*	-	*127.15*	-	*127.15*	*269.09*	*0.10%*
North-Eastern Region	***310.00***	***1,662.70***	***36.00***	***2,008.70***	-	***1,242.00***	***262.38***	***1,504.38***	***3,513.08***	***1.27%***
Andaman & Nicobar	-	-	40.05	40.05	-	-	10.35	10.35	50.40	0.02%
Lakshadweep	-	-	-	-	-	-	0.75	0.75	0.75	0.00%
Islands	-	-	***40.05***	***40.05***	-	-	***11.10***	***11.10***	***51.15***	***0.02%***
Total	***167,707.88***	***22,962.15***	***993.53***	***191,663.56***	***5,780***	***41,997.42***	***36,470.64***	***78,468.06***	***275,911.62***	***100.00%***

Table 8

All India (Anticipated) Power Supply Position in FY2015-16[27]

Region	Energy			Peak Power		
	Requirement (MU)	Availability (MU)	Surplus(+)/Deficit(-)	Demand (MW)	Supply (MW)	Surplus(+)/Deficit(-)
Northern	355,794	354,540	-0.4%	54,329	54,137	-0.4%
Western	353,068	364,826	+3.3%	48,479	50,254	+3.7%
Southern	313,248	277,979	-11.3%	43,630	35,011	-19.8%
Eastern	124,610	127,066	+2.0%	18,507	19,358	+4.6%
North-Eastern	15,703	13,934	-11.3%	2,650	2,544	-4.0%
All India	*1,162,423*	*1,138,346*	*-2.1%*	*156,862*	*152,754*	*-2.6 %*

Table 9

Energy resource type	Amount (tonnes)	Power potential (TWe-year)
Coal	54 billion	11
Hydrocarbons	12 billion	6
Uranium (in PHWR)	61,000	0.3–0.42
Uranium (in FBR)	61,000	16–54
Thorium	~300,000	155–168 or 358

Table 10

Very high-grade ore (Canada) – 20% U	200,000 ppm U
High-grade ore – 2% U,	20,000 ppm U
Low-grade ore – 0.1% U,	1,000 ppm U
Very low-grade ore* (Namibia) – 0.01% U	100 ppm U
Granite	3-5 ppm U
Sedimentary rock	2-3 ppm U
Earth's continental crust (av)	2.8 ppm U
Seawater	0.003 ppm U

Table 11

Known Recoverable Resources of Uranium 2013

	tonnes U	percentage of world
Australia	1,706,100	29%
Kazakhstan	679,300	12%
Russian Fed	505,900	9%
Canada	493,900	8%
Niger	404,900	7%
Namibia	382,800	6%
South Africa	338,100	6%
Brazil	276,100	5%
USA	207,400	4%
China	199,100	4%
Mongolia	141,500	2%
Ukraine	117,700	2%
Uzbekistan	91,300	2%
Botswana	68,800	1%
Tanzania	58,500	1%
Jordan	33,800	1%
Other	191,500	3%
World total	5,902,500	

Table 12

APPENDIX – VI

LIST OF FIGURES

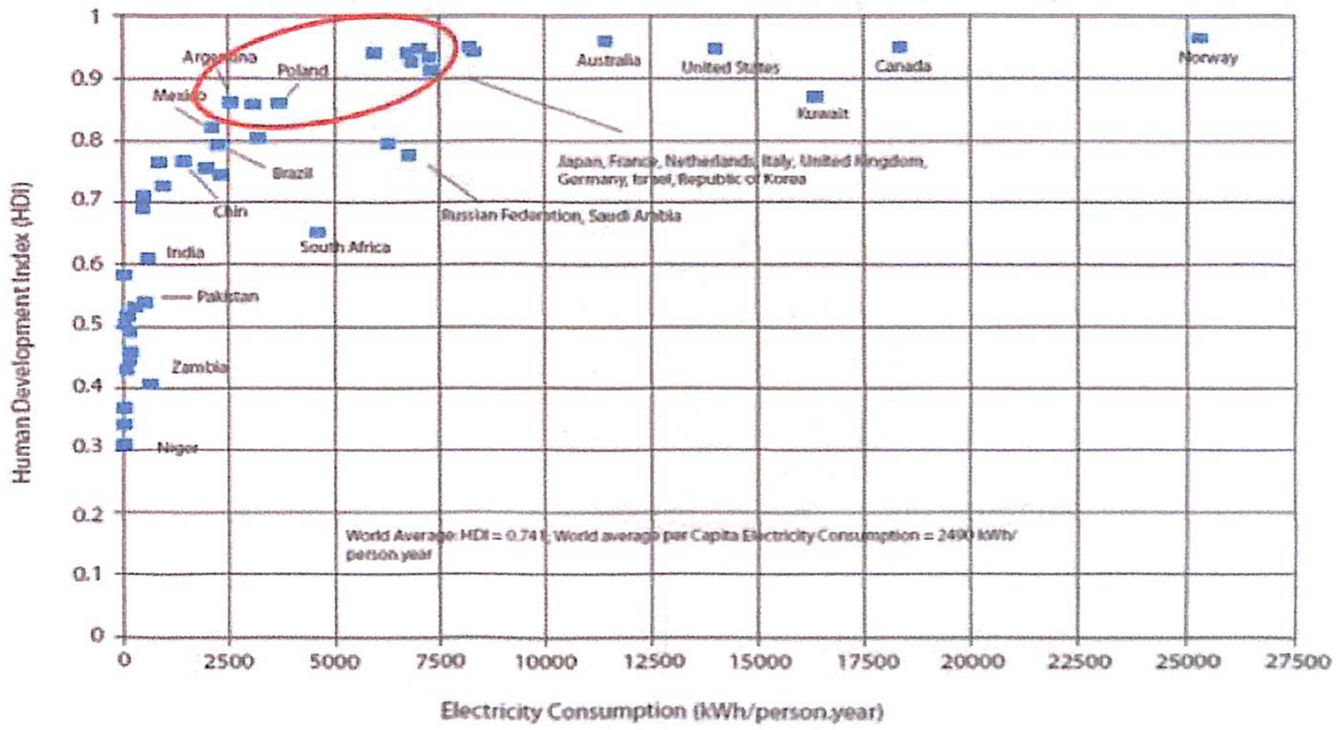
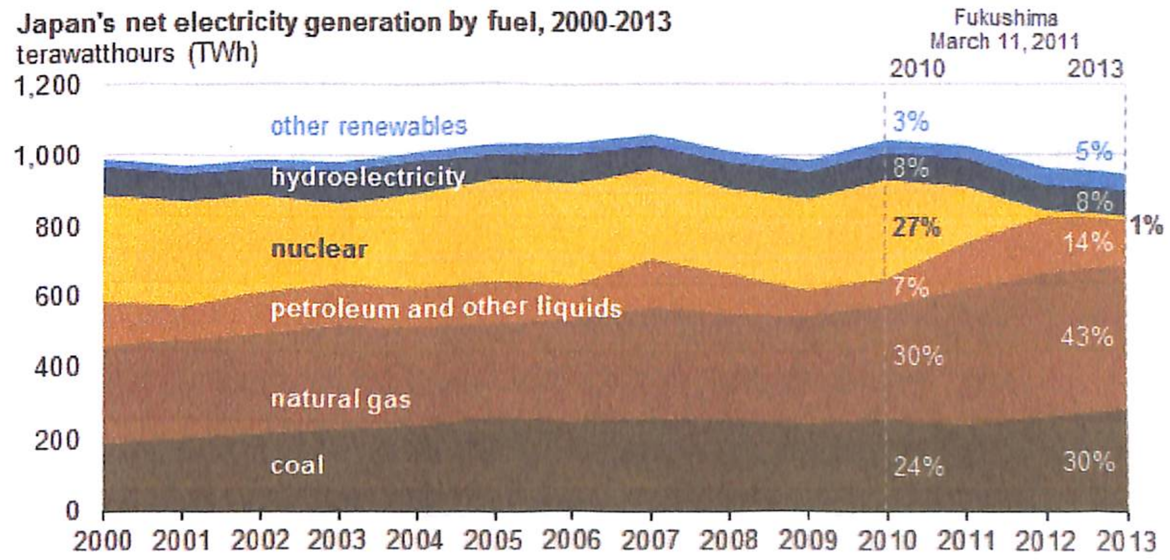


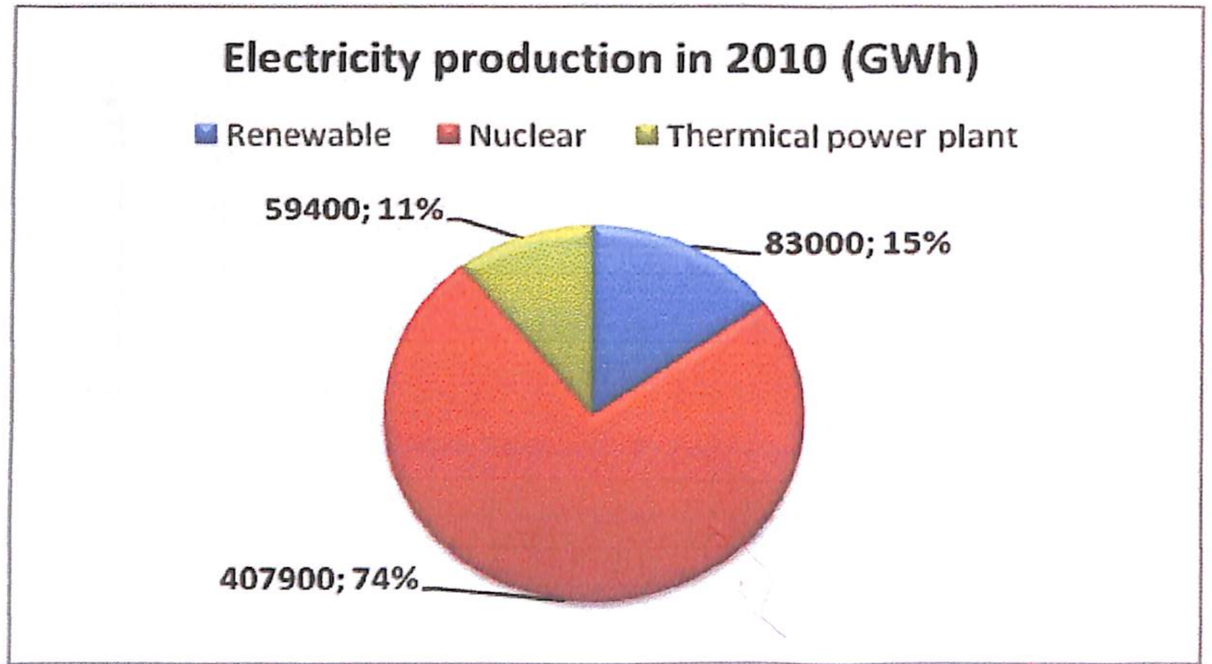
Figure 1.1



Source: US Energy Information Administration, International Energy Agency, METI

Figure 2.1

FRANCE (source : EDF)



	Electricity production in France, 2010	GWh	Σ (GWh)	Mtep	%	Σ (%)
NON renewelable	Nuclear power	407900	467300	33592	74,1	84,9
	Thermical power plants	59400		4892	10,8	
Renewelable	Hydraulic	68000	83000	5600	12,4	15,1
	Wind	9600		791	1,7	
	Biomass	4800		395	0,9	
	Photovoltaic	600		49	0,1	
	Net electricity	550300		45319	100,0	

Figure 2.2

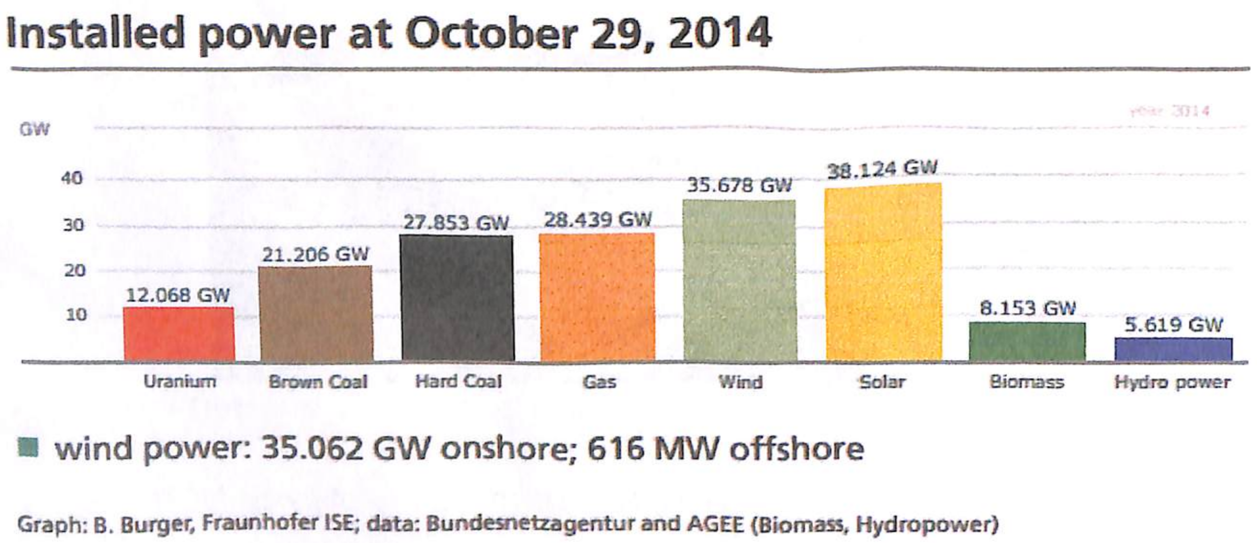
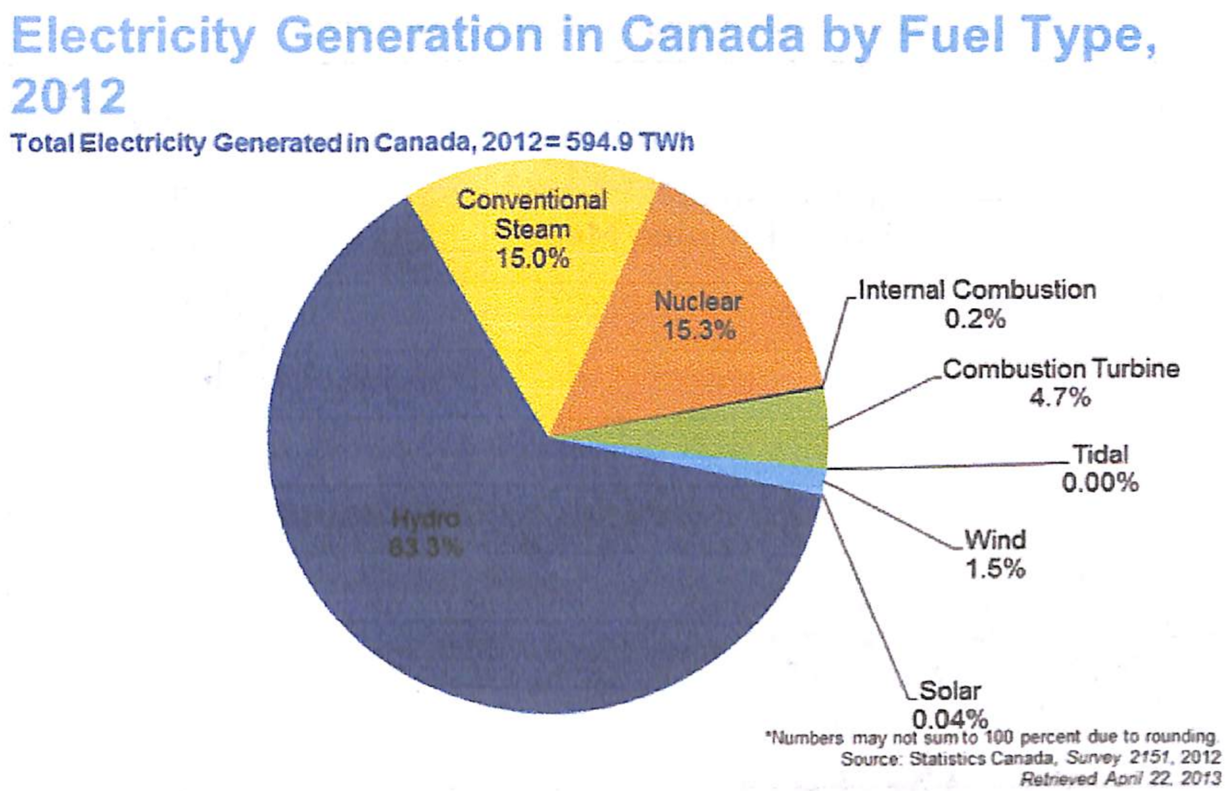


Figure 2.3



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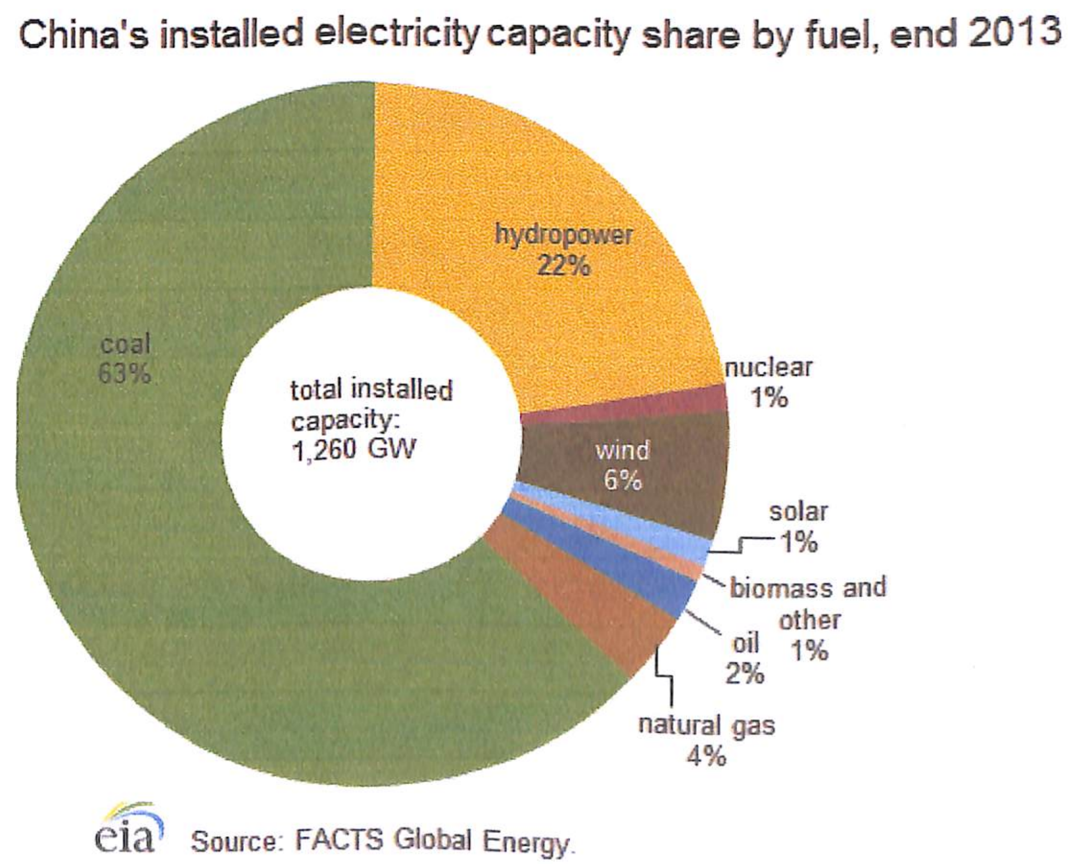

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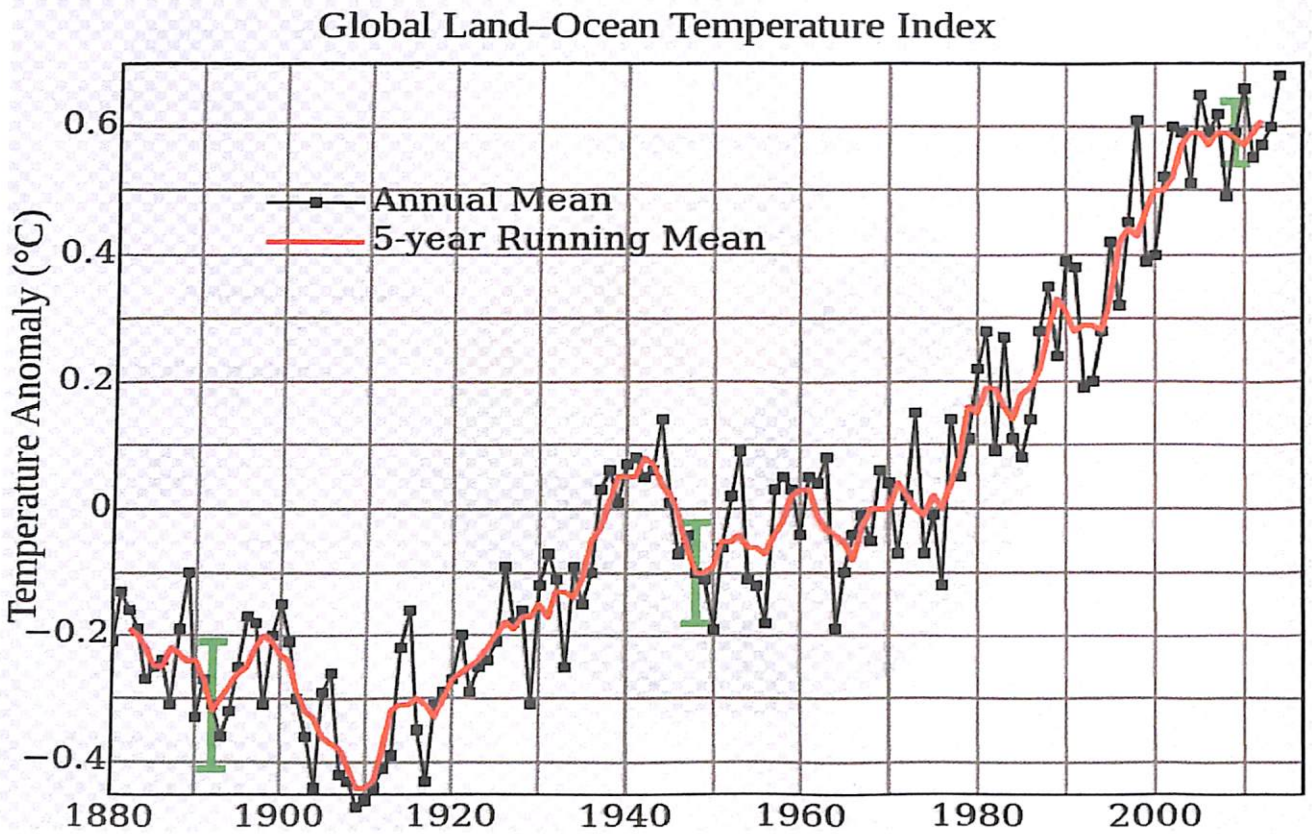
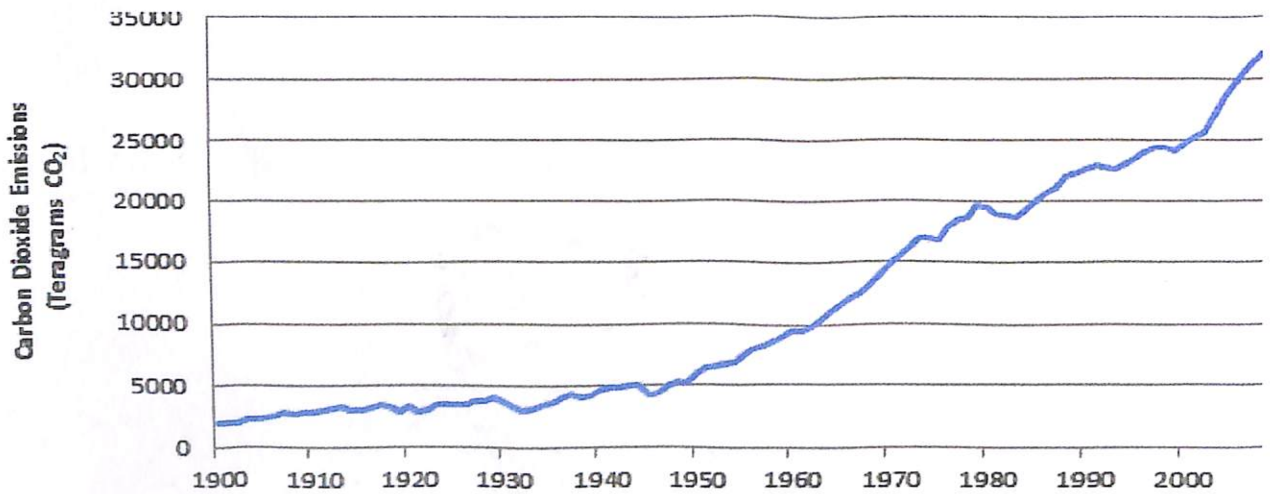
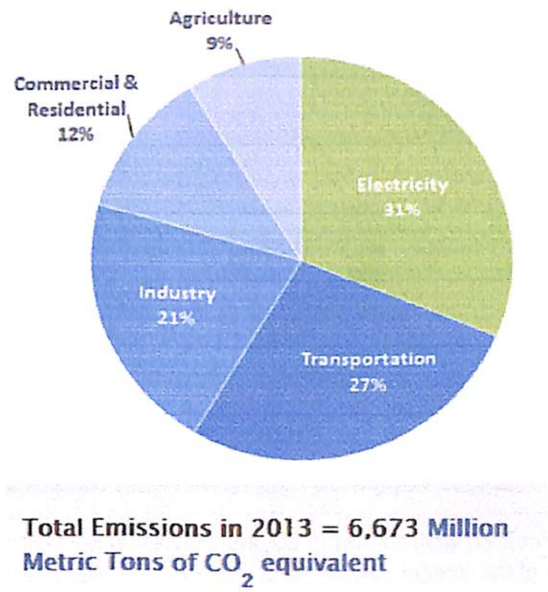


Figure 3.1



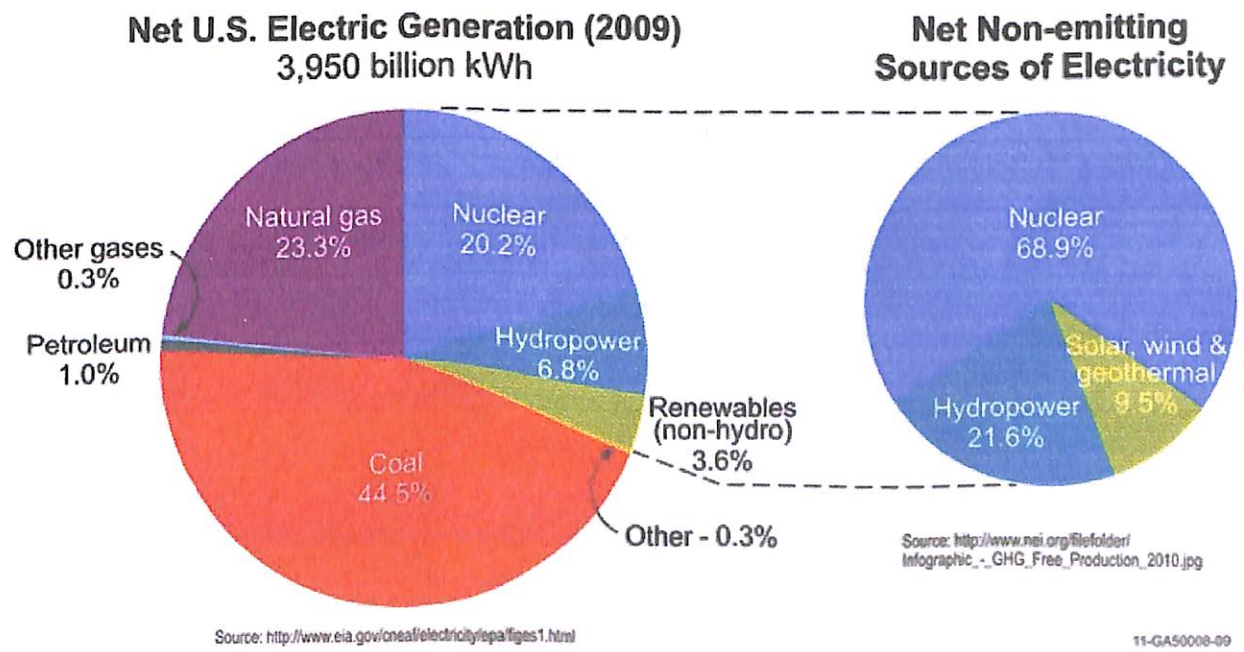
Fossil fuel related carbon dioxide (CO2) emissions over the 20th century

Figure 3.2



Total U.S. Greenhouse Gas Emissions by Economic Sector in 2013

Figure 3.3



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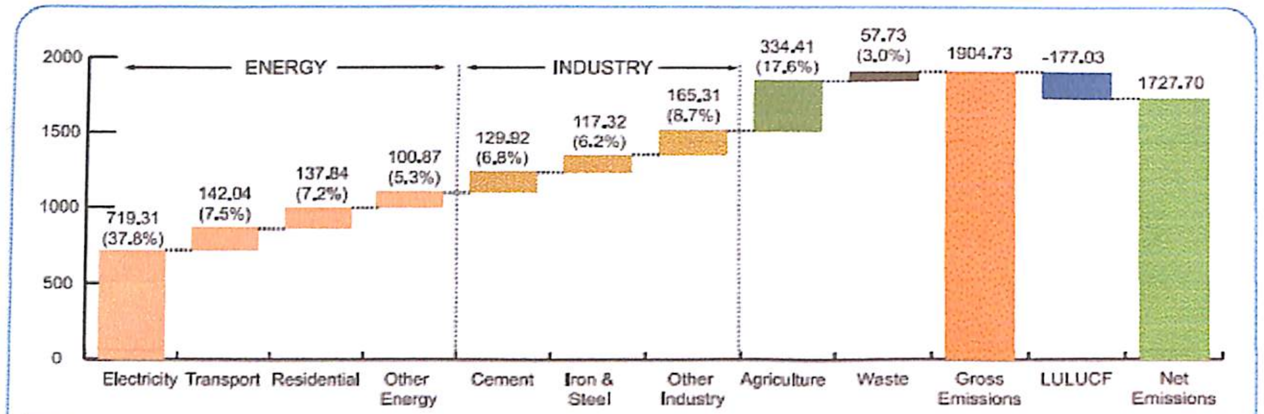


Note:

Other Energy: includes GHG emissions from petroleum refining, manufacturing of solid fuel, commercial & institutional sector, agriculture & fisheries and fugitive emissions from mining, transport and storage of coal, oil and natural gas.

Other Industry: includes GHG emissions from production of glass and ceramics, soda ash, ammonia, nitric acid, carbides, titanium dioxide, methanol, ethylene oxide, acrylonitrile, carbon black, caprolactam, ferro alloys, aluminium, lead, zinc, copper, pulp and paper, food processing, textile, leather, mining and quarrying, non specific industries and use of lubricants and paraffin wax.

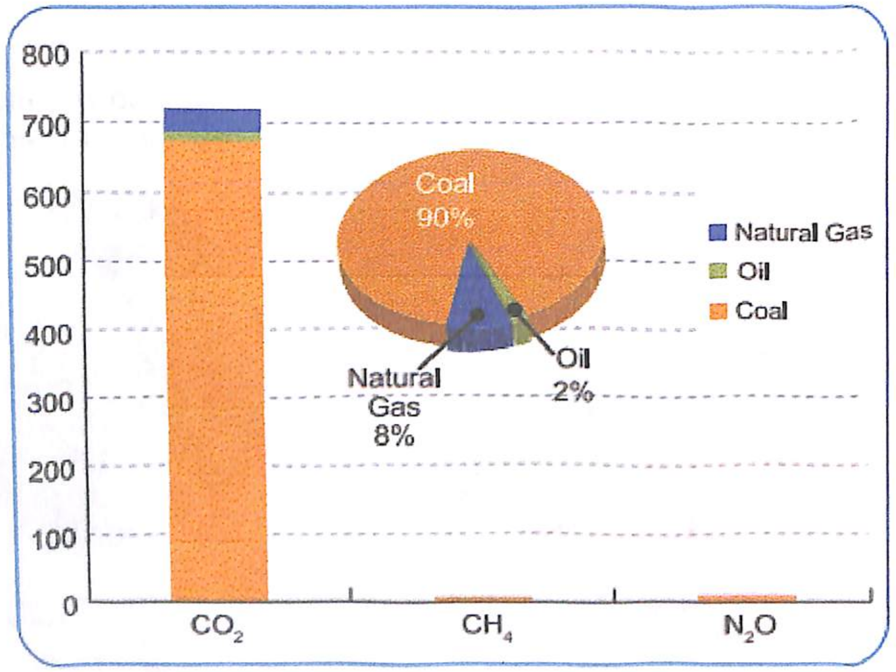
Agriculture: includes GHG emissions from livestock, rice cultivation, agricultural soils and burning of crop residue.

Waste: includes GHG emissions from municipal solid waste (MSW), industrial and domestic waste water.

LULUCF: includes GHG emissions and removals from changes in forest land, crop land, grass land, wet land, settlements and combustion of fuel wood in forests.

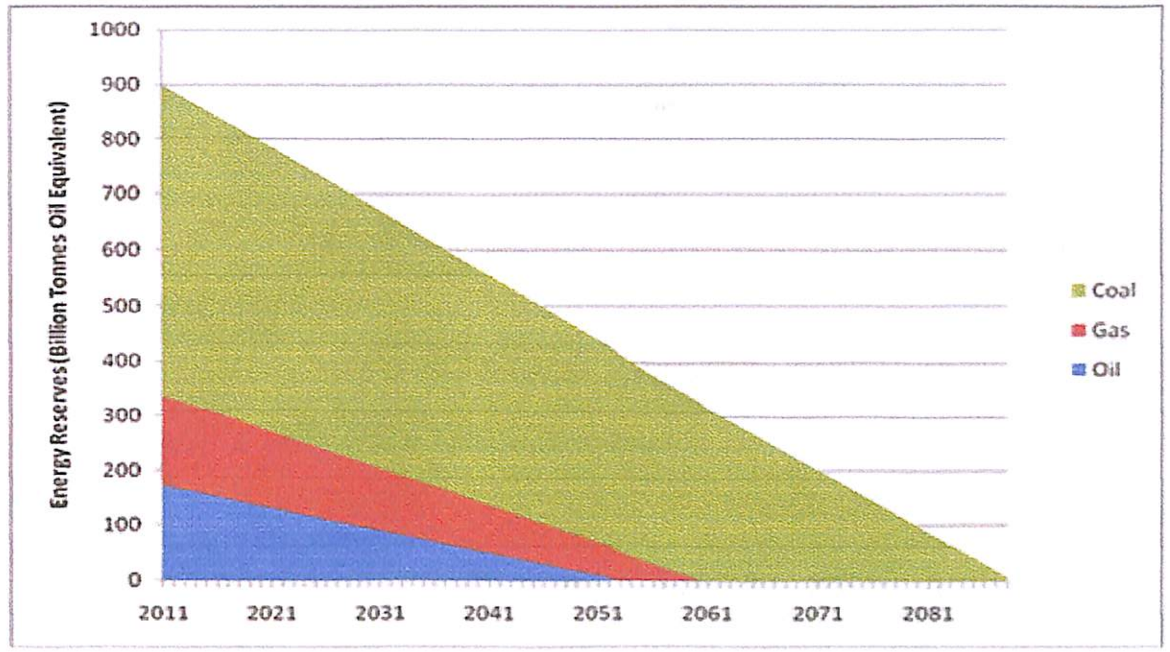
GHG emissions by sector in 2007 (million tons of CO_2 eq). Figures on top indicate the emissions by sectors and in brackets indicate % of emission of the category with respect to the net CO_2 equivalent emissions.

Figure 3.5



Fuel mix and GHG emissions in million tons from electricity generation

Figure 3.6



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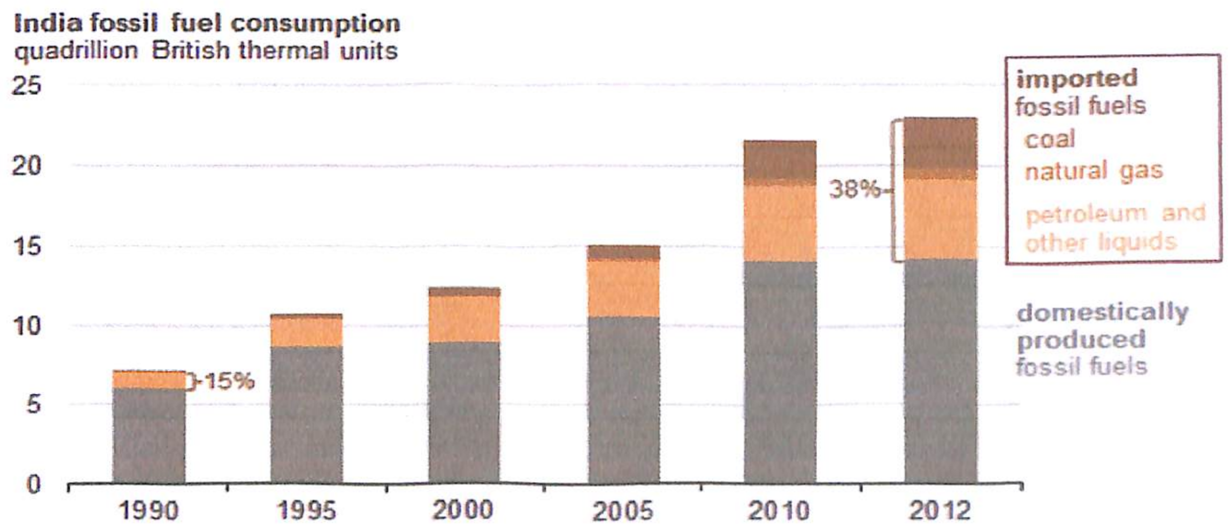
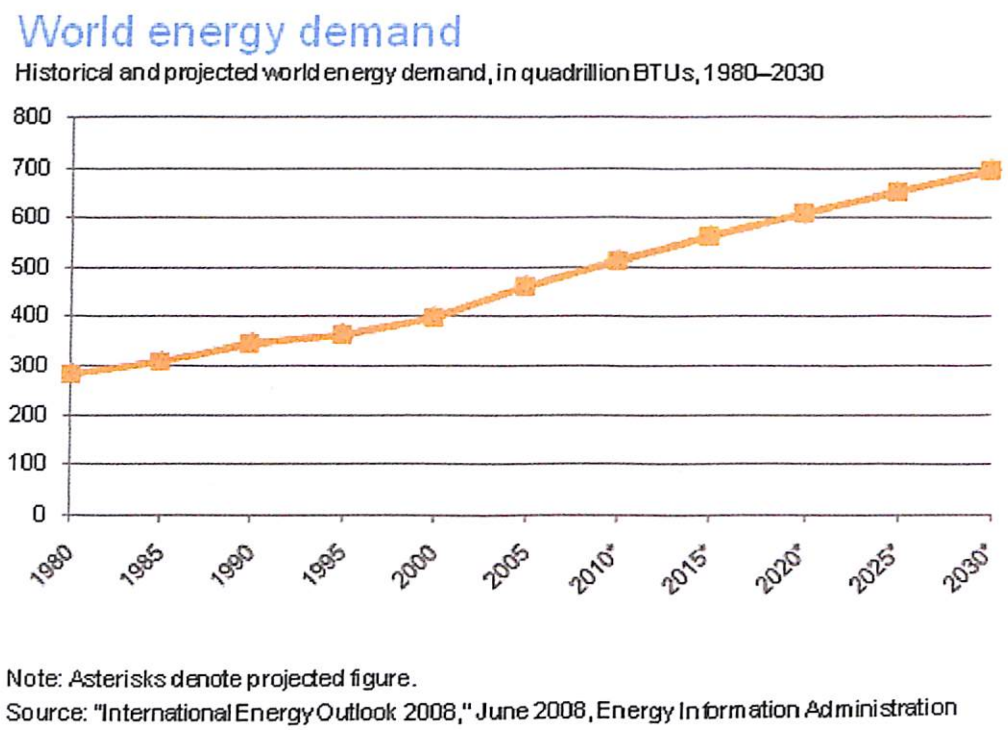


Figure 3.8



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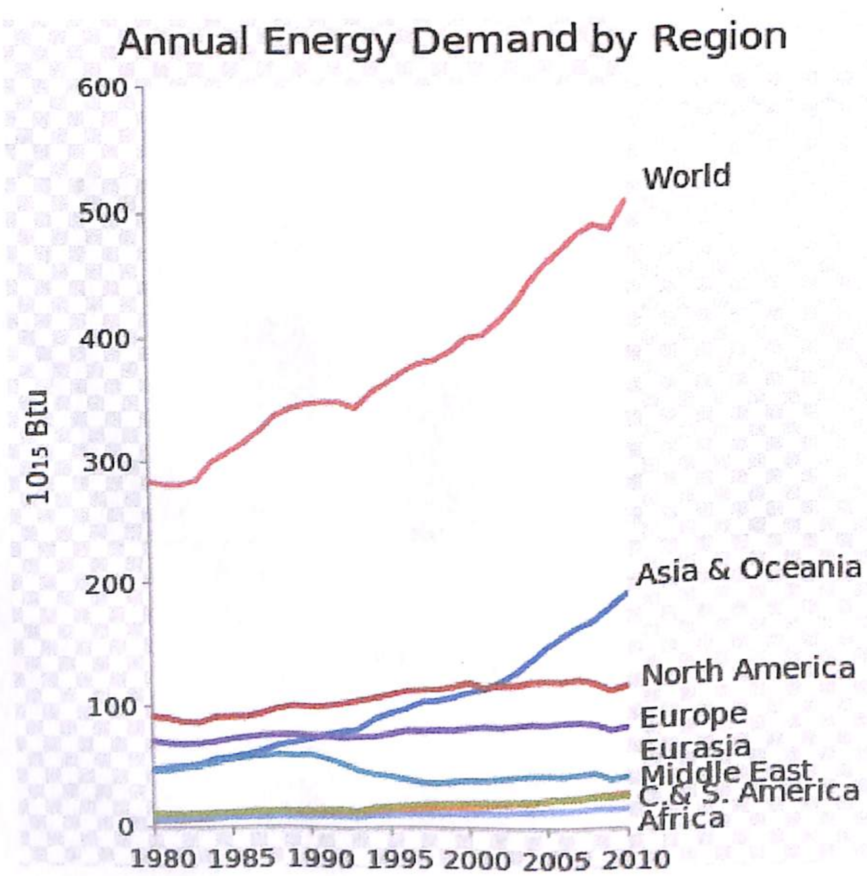
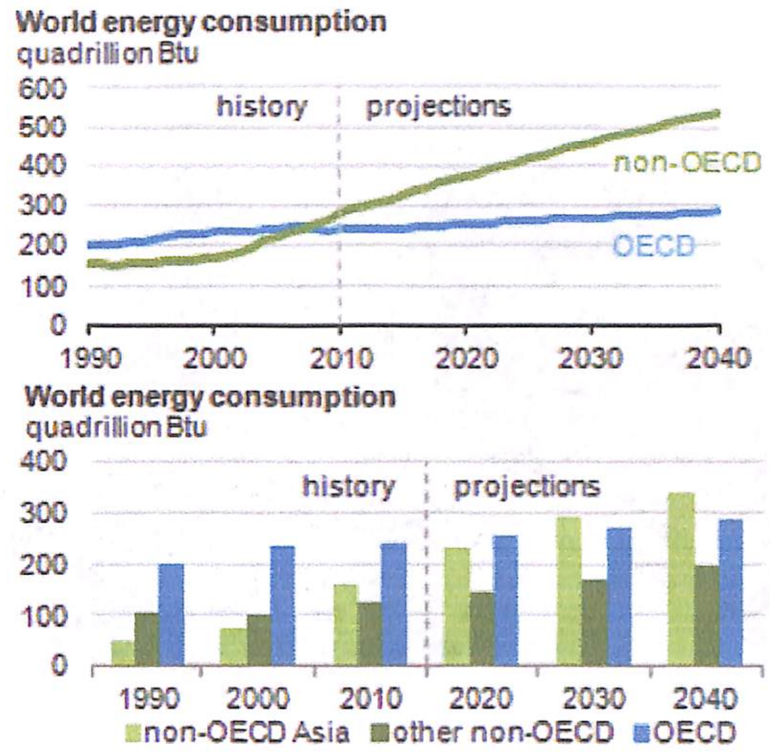


Figure 3.10



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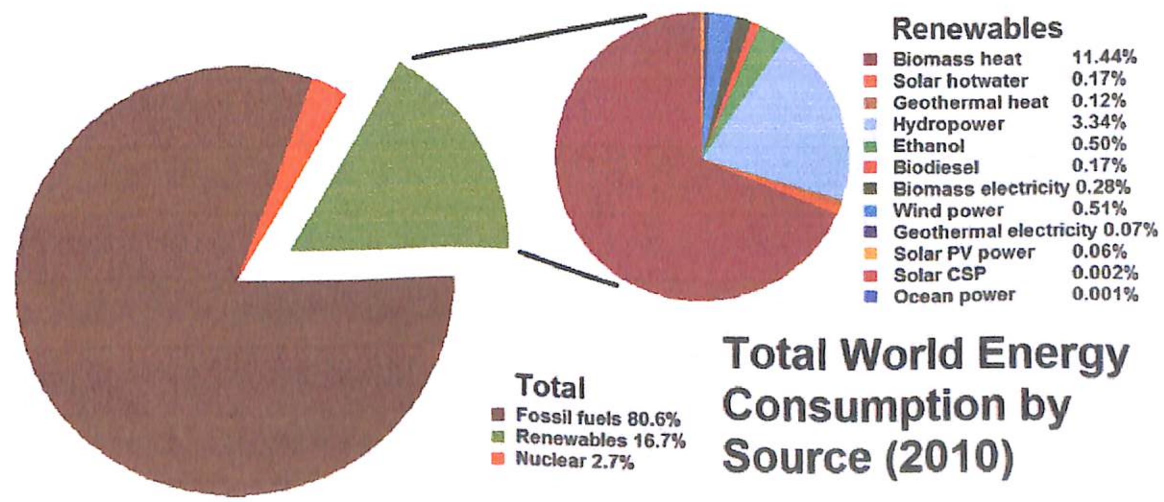

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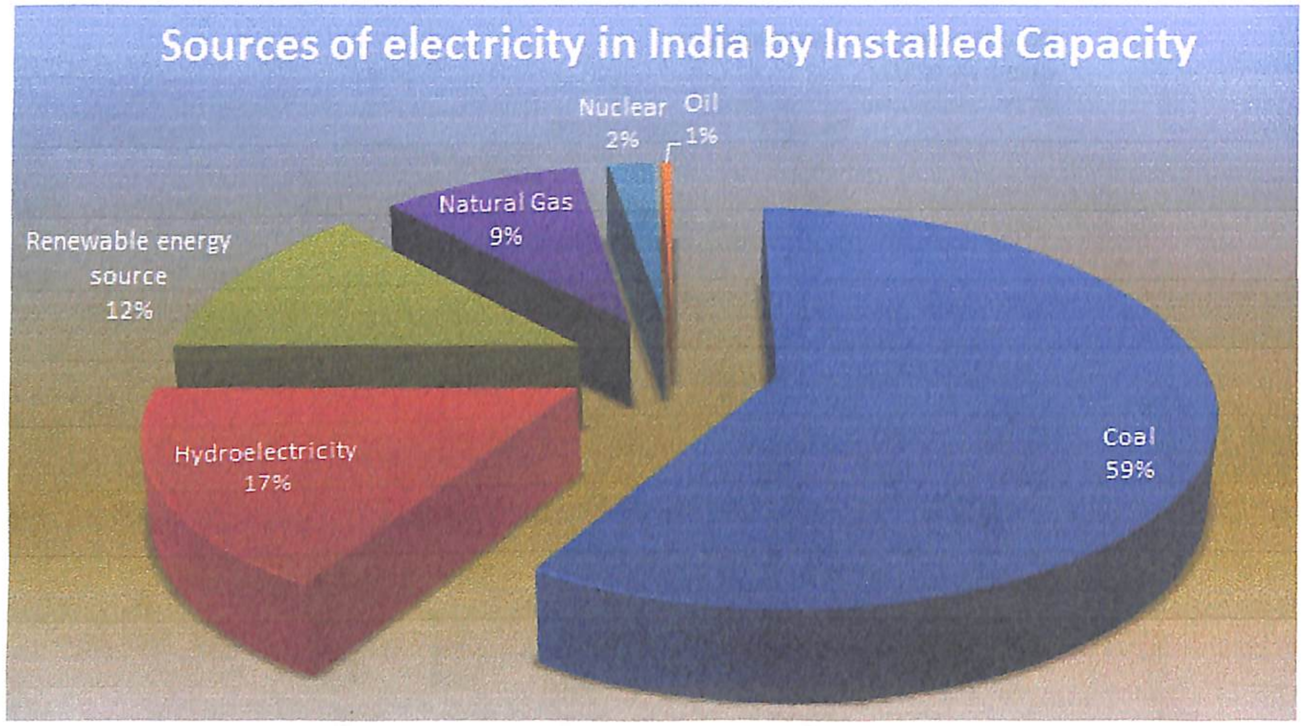
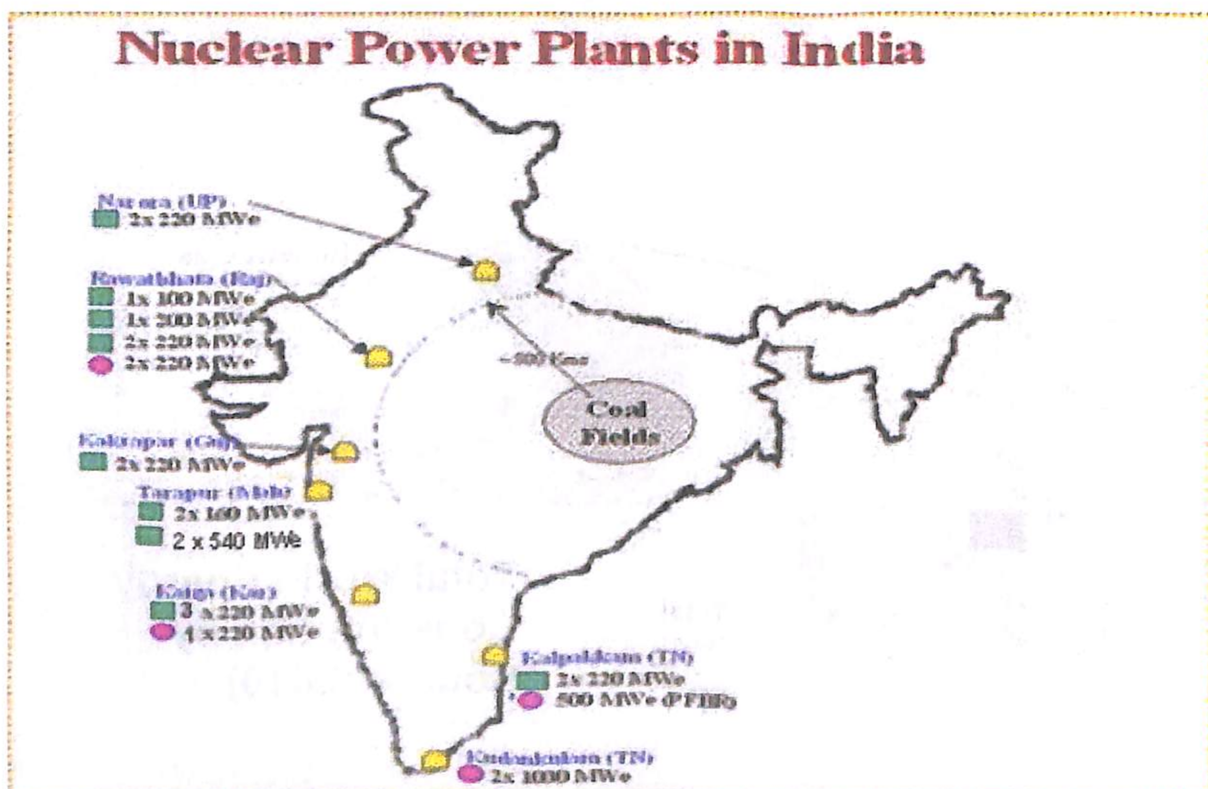
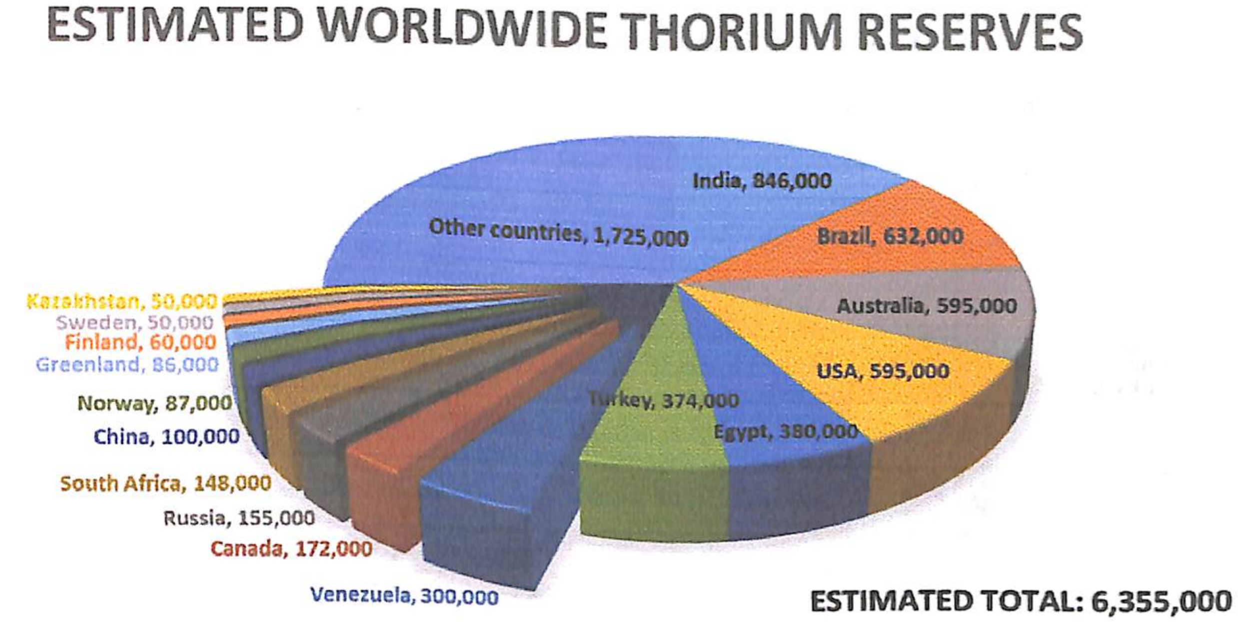


Figure 3.13



Source: Government of India, Department of Atomic Energy

Figure 4.1



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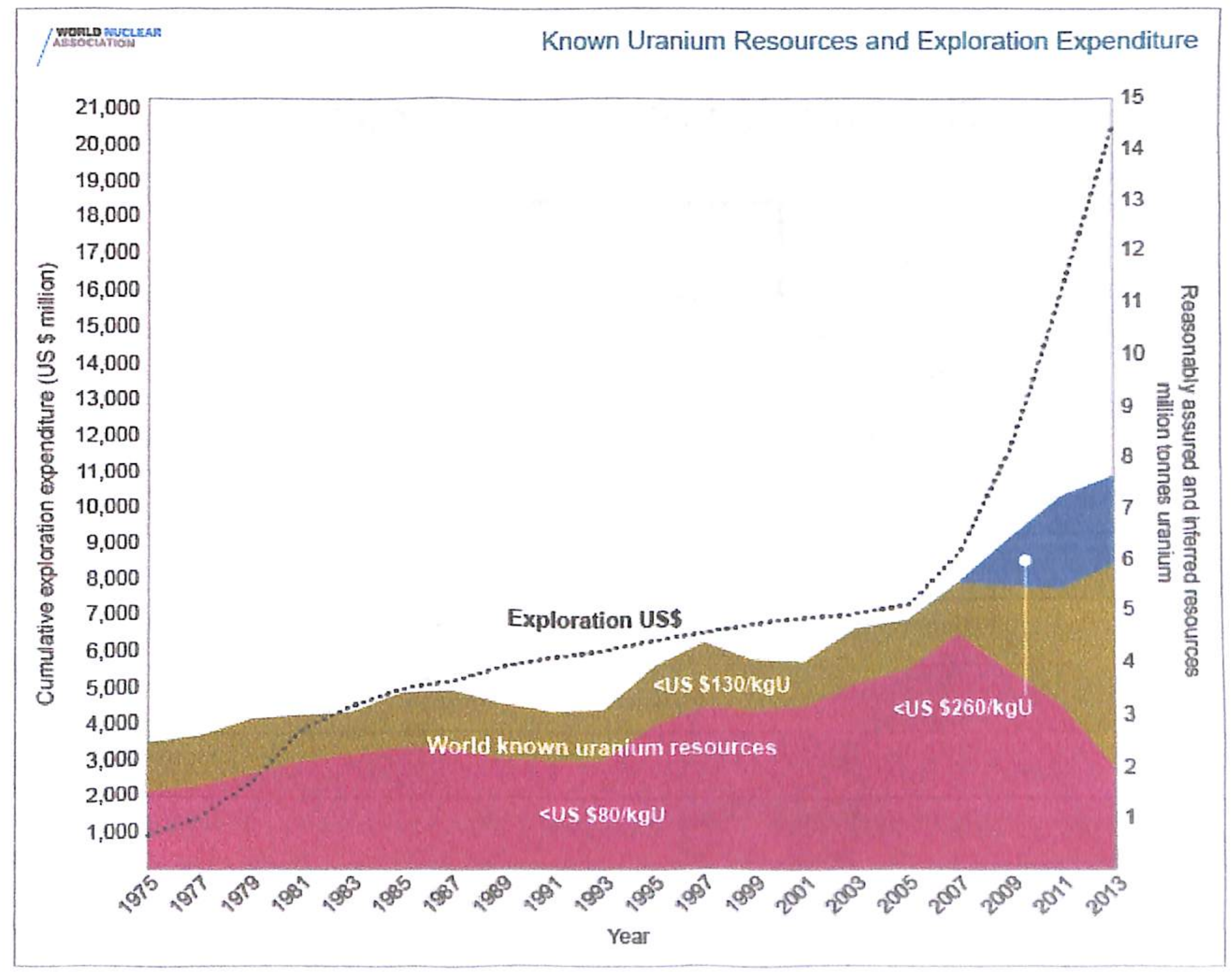
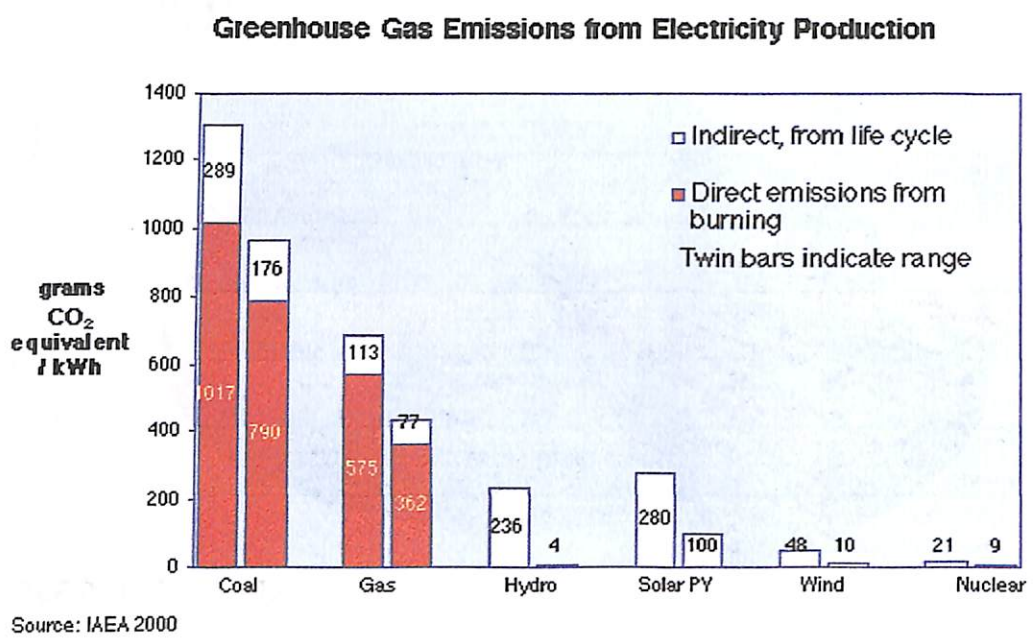


Figure 4.3



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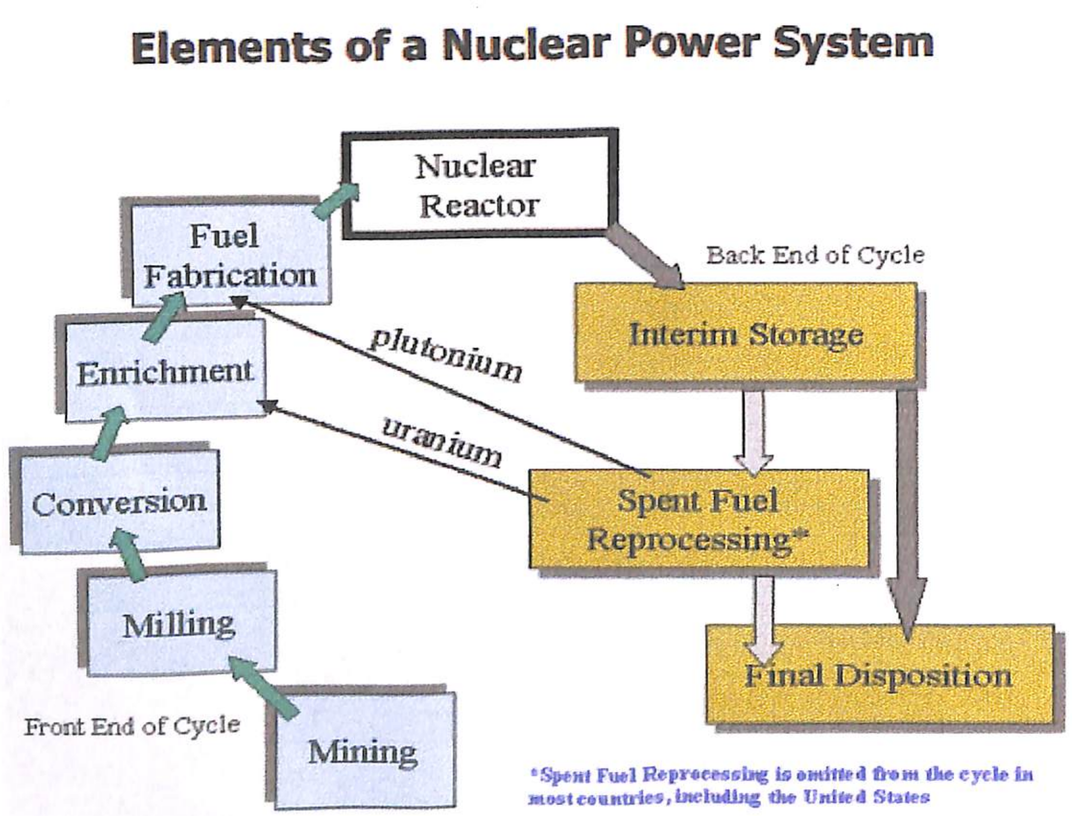


Figure 4.5

APPENDIX – VII

Executive summary

Until about 30 years ago, energy sustainability was thought of simply in terms of availability relative to the rate of use. Today, in the context of the ethical framework of sustainable development, including particularly concerns about global warming, other aspects are also very important. These include environmental effects and the question of wastes, even if they have no environmental effect. Safety is also an issue, as well as the broad and indefinite aspect of maximising the options available to future generations. Geopolitical questions of energy security are central to the assessment of sustainability for individual countries, along with the affordability of the electricity produced.

Sustainable development criteria have been pushed into the front line of energy policy. In the light of concerns about climate change due to apparent human enhancement of the greenhouse effect, there is growing concern about how we address energy needs on a sustainable basis. The following major concerns regarding meeting our energy requirements of present and future are discussed in the dissertation :

1. Global Warming :
   Increased energy demand and extensive use of fossil fuels might lead to global warming of around 4 °C.
2. Electricity sector Emissions :
   In 2007, the total GHG emissions from electricity generation in India was 719.31 million tons CO2 eq. In 2013, the electricity sector was the largest source of U.S. greenhouse gas emissions, accounting for about 31% of the U.S. total.
3. Depleting Fossil fuels
   Fossil fuel reserves are finite - it's only a matter of when they run out. India's dependence on imported fossil fuels rose to 38 per cent in 2012
4. Growing Electricity demand
   World energy consumption is projected to expand by 50 percent from 2005 to 2030
5. Renewable resources limitations
   The issue of intermittency & Energy and power density
6. Cost of electricity
   Nuclear power attractive as compared to other sources of power.
7. Electricity sector in India
   Growing population, Low fossil fuel reserves and High Thorium reserves.

All of the various means of generating electricity have a role to play in meeting the rapidly increasing demand for this form of energy. Fossil fuels, particularly coal and gas, will remain important. Since reliability is the most important attribute of electricity supply, the role of non-hydro renewables is limited. Nuclear electricity is one part of the solution of the energy equation for today and tomorrow, particularly in the light of concerns about carbon dioxide emissions. Without nuclear power the world would have to rely almost entirely on fossil fuels, especially coal, to meet demand for base-load electricity production. This has significant environmental, and particularly greenhouse gas, implications. Nuclear power plants do not emit any carbon dioxide, nor any sulphur dioxide or nitrogen oxides. Their wastes end up as solids and, though requiring careful handling, are very much less than the wastes from burning coal and are easily managed. Whenever new electricity generating capacity is required, or old fossil-fuelled plants need to be replaced, it is therefore sensible to consider nuclear as a serious option. Nuclear electricity has accumulated over 14,000 reactor-years of operating experience. The continued and expanded use of nuclear power is one among a range of measures which will effectively limit future global carbon dioxide emissions. Some 50 countries have chosen nuclear power as part of their energy mix. They have over 430 power station reactors in operation and more under construction.

Chapter 1: Introduction

The energy is the strategic input for sustainable development and the issue of energy security is considered like the individual security, social security and territorial security. Per capita consumption of energy and electricity are now widely accepted as important index of the state of development of a country. Nearly every aspect of development from reducing poverty and raising living standards to improving health care, and industrial and agricultural productivity requires reliable access to modern energy sources. In this context, it is important to consider the global energy imbalance: today, 1.6 billion people are without access to electricity, and 2.4 billion rely on traditional biomass for cooking and heating because they have no access to modern fuels. Current forecasts suggest the world will see an increase in global energy consumption of over 50% by 2030, with 70% of this growth in demand expected to come from developing countries.

In the past, especially during the period up to the global energy crises in the last quarter of the 20th century, the abundance of energy was never in any serious doubts. It was often thought that the economics of energy generation and supply was sufficient for decision making in energy planning. The harsh realities of the events of the energy crisis had compelled the mankind to introduce a series of structural changes and technological and administrative interventions at the national, regional and international levels in order to help mitigating the effects of such situations if and when they appear in the future. Thus, the availability of reliable and quality energy on a long term perspective of any country now assumes the same importance as any other form of security. The scenario has been further compounded with the almost coincidental with the advent of the global concern on environment. Today, environmental dimension of energy has to be considered with as serious issue as any other technological, economic or financial factors of the overall matrix of its demand-supply balancing of any country. Energy planning of countries is, therefore, a challenge of enormous proportions, especially if a target is set to ensure the sustainability of development.

Global warming has become the greatest problem of the world in the last few decades. Many efforts have already been made in some international treaties, but due to many limitations the success achieved so far is very minimal. The whole civilization depends on industrialization, which is making the environmental scenario worse day by day because of unavailability of green technology. Industrialization is important but Trading off between the carbon emission reduction and industrialization is more challenging task in hand.

Nuclear energy will play a vital role in providing increased access to affordable energy in many parts of the world. The first point to be made in any discussion of a coming nuclear renaissance is that peak oil is real. In other words, oil production will continue to decline over the next couple decades, at a time when population and energy demand are rising. This creates a situation in which the energy market is being hit on both ends: on the supply side, oil is in decline, and on the demand side, more people results in a greater demand for energy. It is this basic economic situation that sets the stage for nuclear power to be an outstanding investment opportunity.

This Dissertation proposes that the developing country needs to introduce nuclear power programme on a urgent basis and the developed countries should continue with their nuclear power programme so that long-term it may have in place environmentally friendly, dependable, fast growing, reliable, economically viable, secure and sustainable supply of energy. Advantages of nuclear power in terms of environment, economics, reliability, long-term energy security, base load power supply, etc make it an appropriate and indispensable option of electricity generation mix for the mid to long-term future for developing nations.

Indian scenario :

A quick look at figure 1.1 would suggest that we need around 5000 kWh/capita of electricity annually to reach a respectable human development index in our country. Being based on global statistics, in today's highly interconnected and interdependent world, we can surely depend on this number as a bench mark that we must achieve. Our current per capita electricity use is however a factor of seven lower. Unfortunately our population is also growing. Indications are that, we are likely to stabilize around 1.6 to 1.8 billion people. We thus need to secure energy resources and technologies to harness them at a level ten times larger than what we have at present.

Thus both on global level and for India, in this dissertation, the present energy scenario and future energy demand have been discussed. Also to meet this growing energy demand various energy options present are discussed. The challenges presented by green house gases emitted by thermal power stations, the scarcity of fossil fuels and the economics of renewable and nuclear sources of energy are also discussed in detail along with the ongoing debate in various countries about nuclear power post Fukushima disaster in Japan. Considering all the facts and figures and also the challenges posed by nuclear power plants such as Capital cost and electricity generation cost of nuclear power stations, Safety, waste disposal and proliferation suspicion in the end of the dissertation it has been concluded that ***Nuclear power – Is Inevitable Option.***

Chapter 2: The Debate *"Nuclear power or No Nuclear power"*

1) **"Japan plans for post-Fukushima nuclear restart" – Business Review, 13th Feb 2015**

Previously one of the world's largest producers of nuclear-generated electricity, Japan has relied heavily on fossil fuels following the meltdown at Fukushima Dai-ichi and subsequent shutdown of the country's nuclear fleet. In 2013, when almost all of Japan's nuclear fleet was shut down, more than 86% of Japan's generation mix was composed of fossil fuels (Figure 2.1). In 2014, Japan's nuclear generation was zero. The Japanese government anticipates bringing online a few nuclear facilities in 2015.

Following the Fukushima accident, nuclear's share of electricity generation declined, and energy conservation measures were enforced for larger businesses and highly encouraged for smaller consumers. Japan's utilities initially substituted the lost nuclear generation with natural gas, heavy fuel oil, crude oil, and coal, but oil-fired generation began declining in 2013, as Japan relied more on natural gas and coal.

Japan imports virtually all its fossil fuels. As a result of greater fossil fuel use and higher international oil prices during the past few years, Japan spent 60% more for fossil fuel imports in 2013 compared to 2010, an increase of $US270 billion over three years. This reversed Japan's trade surplus and created a widening trade deficit. Utilities have passed on some of the high cost for power production to consumers, and electricity prices have risen at least 20%.

The current Japanese government believes that the use of nuclear energy is necessary to help reduce current energy supply strains and alleviate high electricity prices. Japan's new energy policy, issued in 2014, emphasises energy security, economic efficiency, and greenhouse gas emissions reduction, although the plan has yet to provide details of the country's future power generation fuel mix.

2) **"France still sees nuclear appetite post-Fukushima" -- Green Business | Oct 10, 2011**

France still plans to build a 60th nuclear reactor at home despite delays and is eyeing a raft of possible deals for atomic power plants in Europe and emerging countries (Figure 2.2). The radiation leaks at Japan's quake-hit Fukushima power plant in March have not ended interest in nuclear power, and France hopes to cash in on decades of atomic experience to sell its technology in countries such as India, China, Britain, Poland, South Africa, Turkey and Brazil.

In October 2014 an Energy Transition for Green Growth bill was passed by the National Assembly and so went on to the Senate. This set a target of 50% for nuclear contribution to electricity supply by 2025, with a nuclear power capacity cap at the present level of 63.2 GWe, meaning that EDF would have to shut at least 1,650 GW of nuclear capacity at the end of 2016 when its Flamanville 3 EPR was scheduled to start commercial operation. The bill also sets long-term targets to reduce greenhouse gas emissions by 40% by 2030 compared with 1990 levels, and by 75% by 2050; to halve final energy consumption by 2050 compared with 2012 levels; to reduce fossil fuel consumption by 30% by 2030 relative to 2012; and to increase the share of renewables in final energy consumption to 32% by 2030. The Senate early in 2015 amended the bill to remove the nuclear cap, but this was not accepted in the lower house.

3) **"Germany's coalition government has announced a reversal of policy that will see all the country's nuclear power plants phased out by 2022" – BBC News, 30 May 2011**

Nuclear power in Germany accounted for 17.7% of national electricity supply in 2011, compared to 22.4% in 2010 (Figure 2.3). The anti-nuclear movement in Germany has a long history dating back to the early 1970s, when large demonstrations prevented the construction of a nuclear plant at Wyhl. In 1986, large parts of Germany were covered with radioactive contamination from the Chernobyl disaster and Germans went to great lengths to deal with the contamination.

Nuclear power has been a topical political issue in recent decades, with continuing debates about when the technology should be phased out. The topic received renewed attention at the start of 2007 due to the political impact of the Russia-Belarus energy dispute and in 2011 after the Fukushima I nuclear accidents in Japan. Within days of the March 2011 Fukushima Daiichi nuclear disaster, large anti-nuclear protests occurred in Germany. Protests continued and, on 29 May 2011, Merkel's government announced that it would close all of its nuclear power plants by 2022.Eight of the seventeen operating reactors in Germany were permanently shut down following Fukushima.

Chancellor Angela Merkel said the nuclear power phase-out, previously scheduled to go offline as late as 2036, would give Germany a competitive advantage in the renewable energy era, stating, "As the first big industrialized nation, we can achieve such a transformation toward efficient and renewable energies, with all the opportunities that brings for exports, developing new technologies and jobs". Merkel also pointed to Japan's "helplessness" – despite being an industrialized, technologically advanced nation – in the face of its nuclear disaster.

4) **"In this grim global scenario for nuclear energy, the Canadian sector remains largely unshaken." – Financial Post, October 12, 2012**

In 2010, the leading type of power generation by utilities in Canada is hydroelectricity, with a share of 63.7%, nuclear (15.0%), Coal(13.1%), natural gas (6.2%), wind (0.6%), fuel oil (0.5%), and wood (0.4%) follow. Other sources, such as petroleum coke make up the remaining 0.5% (Figure 2.4).

In Canada, where the debate on nuclear has been less visible, the Fukushima disaster still prompted the government to launch a full-force review of all nuclear operators in the country. A task force report, released in October 2011, confirmed that nuclear power plants in Canada are safe.

Canada's nuclear sector generates around CAD$6.6 billion in revenue, and CAD$1.5 billion in federal and provincial revenue, along with tens of thousands of jobs. Nevertheless, public opinion over nuclear operations and waste burial in Canada remains divided, something that is exemplified in the Kincardine, Ontario case. In addition, with a surplus of power in the province, the Ontario government has scrapped the plan to build new reactors due to concerns about waste and cost.

Nevertheless, Canada has no intention to abandon nuclear power; in fact, the government began cooperating with India on civil nuclear at the end of last year.A 2012 national nuclear attitude survey showed that in Canada, "strong support" for nuclear technology has increased since Fukushima. Another poll in the same year by the IAEA also

showed that 45% of Canadians support nuclear energy, an increase in net support since Fukushima.

5) **"Mainland China has 27 nuclear power reactors in operation, 24 under construction, and more about to start construction." – World Nuclear Association, October, 2015**

Most of mainland China's electricity is produced from fossil fuels, predominantly from coal (Figure 2.5). Rapid growth in demand has given rise to power shortages, and the reliance on fossil fuels has led to much air pollution. The economic loss due to pollution is put by the World Bank at almost 6% of GDP,1 and the new leadership from March 2013 has prioritised this.* Chronic and widespread smog in the east of the country is attributed to coal burning. In March 2014 the Premier said that the government was declaring "war on pollution" and would accelerate closing coal-fired power stations. In November 2014 the Premier announced that China intended about 20% of its primary energy consumption to be from non-fossil fuels by 2030, at which time it intended its peak of CO2emissions to occur.

6) **"India has a flourishing and largely indigenous nuclear power programme and expects to have 14,600 MWe nuclear capacity on line by 2020. It aims to supply 25% of electricity from nuclear power by 2050."-- World Nuclear Association, October, 2015**

Electricity demand in India is increasing rapidly, and the 1128 billion kilowatt hours (TWh) gross produced in 2012 was more than triple the 1990 output, though still represented only some 750 kWh per capita for the year. With large transmission losses – 193 TWh (17%) in 2012, this resulted in only about 869 billion kWh consumption. Gross generation comprised 801 TWh from coal, 94 TWh from gas, 23 TWh from oil, 33 TWh from nuclear, 126 TWh from hydro and 50 TWh from other renewables. Coal provides more than two-thirds of the electricity at present, but reserves are effectively limited* – in 2013, 159 million tonnes was imported, and 533 million tonnes produced domestically. The per capita electricity consumption figure is expected to double by 2020, with 6.3% annual growth, and reach 5000-6000 kWh by 2050, requiring about 8000 TWh/yr then. There is an acute demand for more and more reliable power supplies. One-third of the population is not connected to any grid.

In July 2014 the new Prime Minister urged DAE to triple the nuclear capacity to 17 GWe by 2024. He praised "India's self-reliance in the nuclear fuel cycle and the commercial success of the indigenous reactors." He also emphasized the importance of maintaining the commercial viability and competitiveness of nuclear energy compared with other clean energy sources. The target since about 2004 has been for nuclear power to provide 20 GWe by 2020, but in 2007 the Prime Minister referred to this as "modest" and capable of being "doubled with the opening up of international cooperation.

Chapter 3: The Concern

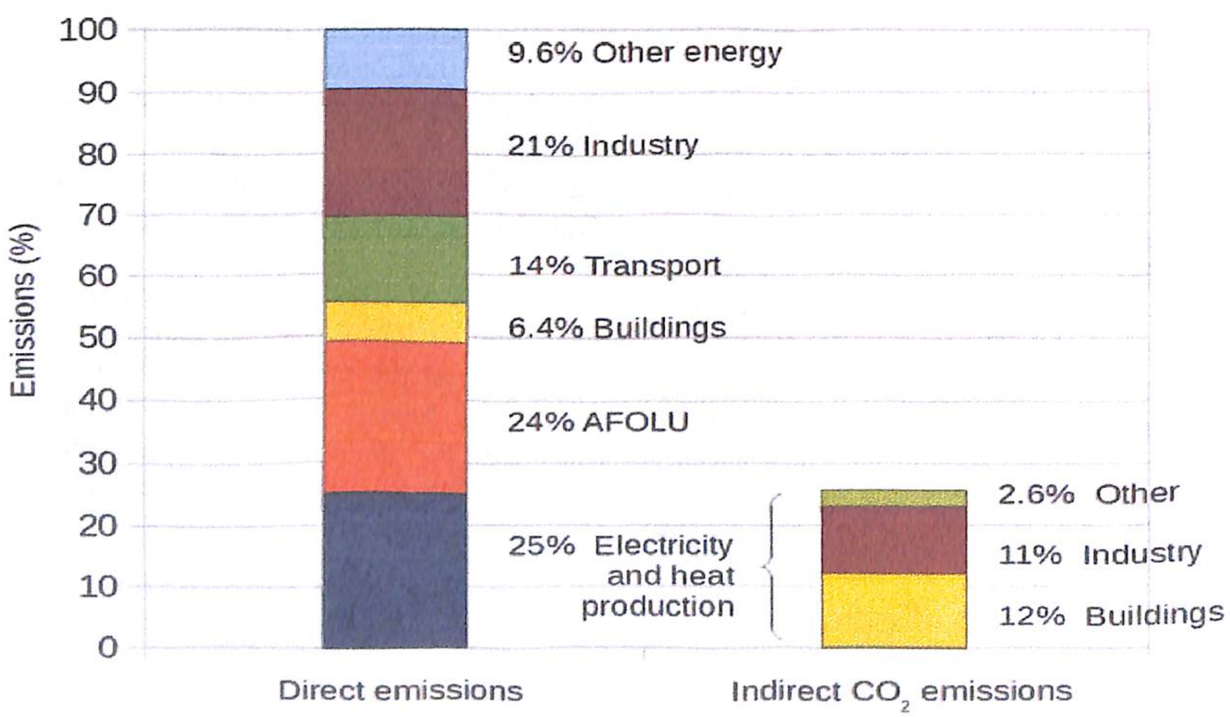
3.1 Global Warming

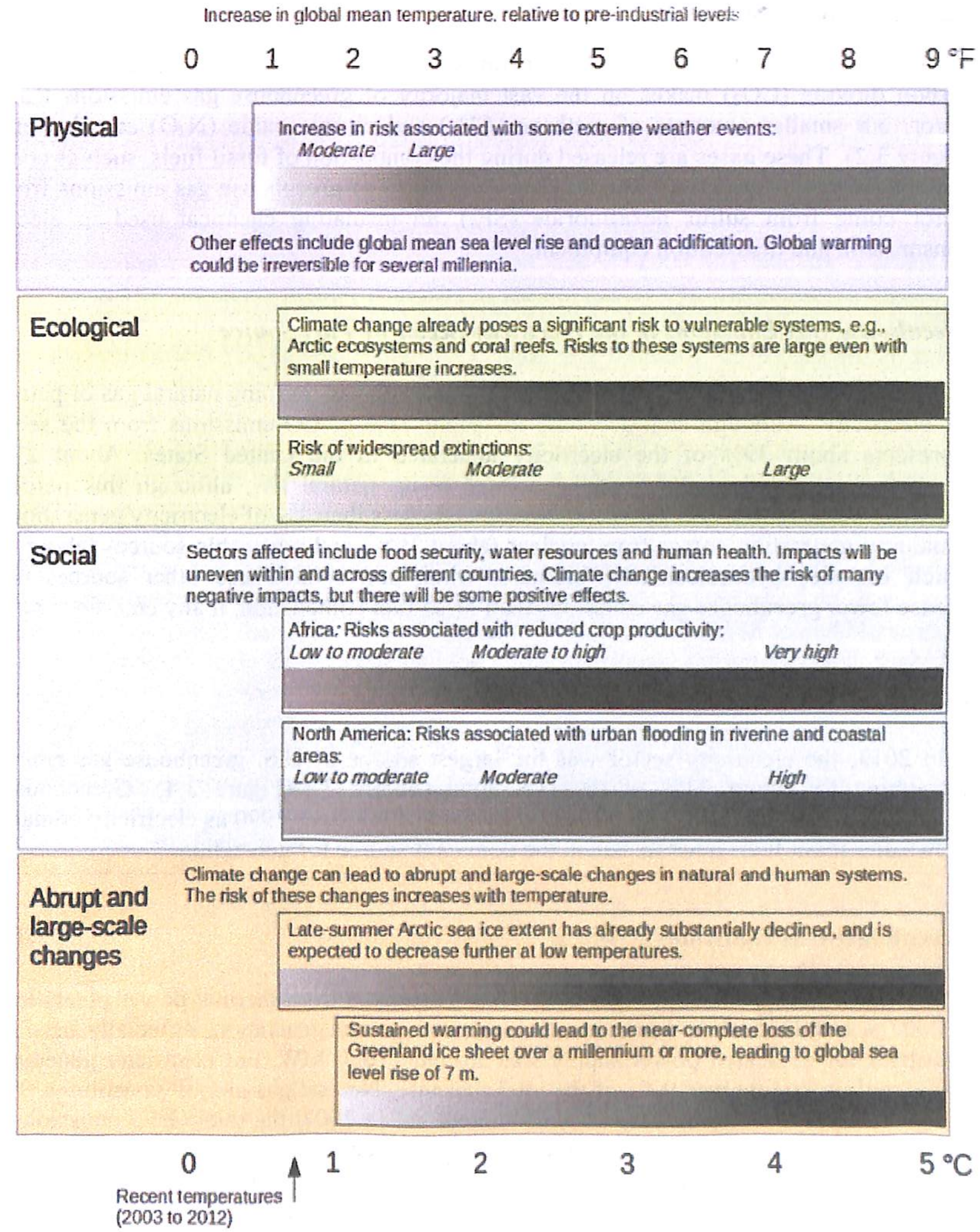
Global warming is the rise in the average temperature of Earth's oceans and atmosphere. Increased amount of greenhouse gases in the air is responsible for this. Burning fossil fuel is the main cause behind this environmental degradation. Industrialization, traction and power generation are major three areas where fossil fuels are burnt thus providing the air with more and more carbon. As it is a global problem, so it is affecting the whole world. But the developing nations are the worst victim of this situation. They are emitting the least amount of carbon in the air but they are affected more as their development or industrialization is not up to the standard of developed country.

The effects of global warming are the environmental and social changes caused (directly or indirectly) by human emissions of greenhouse gases. There is a scientific consensus that climate change is occurring, and that human activities are the primary driver (Figure 3.1). Many impacts of climate change have already been observed, including glacier retreat, changes in the timing of seasonal events (e.g., earlier flowering of plants), and changes in agricultural productivity.

Future effects of climate change will vary depending on climate change policies and social development. The two main policies to address climate change are reducing human greenhouse gas emissions (climate change mitigation) and adapting to the impacts of climate change. Geo-engineering is another policy option.

Near-term climate change policies could significantly affect long-term climate change impacts Stringent mitigation policies might be able to limit global warming (in 2100) to around 2 °C or below, relative to pre-industrial levels. Without mitigation, increased energy demand and extensive use of fossil fuels might lead to global warming of around 4 °C. Higher magnitudes of global warming would be more difficult to adapt to, and would increase the risk of negative impacts.





3.2 Electricity Sector Emissions

The Electricity sector involves the generation, transmission, and distribution of electricity. Carbon dioxide (CO_2) makes up the vast majority of greenhouse gas emissions from the sector, but smaller amounts of methane (CH_4) and nitrous oxide (N_2O) are also emitted (Figure 3.2). These gases are released during the combustion of fossil fuels, such as coal, oil, and natural gas, to produce electricity. Less than 1% of greenhouse gas emissions from the sector come from sulfur hexafluoride (SF_6), an insulating chemical used in electricity transmission and distribution equipment.

Greenhouse Gas Emissions in the Electricity Sector by Fuel Source

Coal combustion is generally more carbon intensive than burning natural gas or petroleum for electricity. Although coal accounts for about 77% of CO_2emissions from the sector, it represents about 39% of the electricity generated in the United States. About 27% of electricity generated in 2013 was generated using natural gas, although this percentage decreased relative to 2012. Petroleum accounts for less than 1% of electricity generation. The remaining generation comes from nuclear (about 19%) and renewable sources (about 13%), which includes hydroelectricity, biomass, wind, and solar. These other sources usually release fewer greenhouse gas emissions than fossil fuel combustion, if any emissions at all.

Emissions and Trends

In 2013, the electricity sector was the largest source of U.S. greenhouse gas emissions, accounting for about 31% of the U.S. total (Figure 3.3)(Figure 3.4). Greenhouse gas emissions from electricity have increased by about 11% since 1990 as electricity demand has grown and fossil fuels have remained the dominant source for generation.

Greenhouse Gas Emissions In India

The Total installed capacity for electricity generation from thermal power plants in India in 2007 was 89275.84 MW. Additionally captive power generation, especially used in the industries for dedicated power supply was around 11600 MW. For electricity generation in 2007, coal utilization was 90% of the total fuel mix. Natural gas and oil constituted 8% and 2% of the fuel mix respectively. It is estimated that in 2007, the total GHG emissions from electricity generation was 719.31 million tons CO_2 eq of which 715.83 million tons was emitted as CO_2 , 8.14 thousand tons as CH_4 and 10.66 thousand tons as N_2O (Figure 3.5). The distributions of the emissions by fuel type are shown in figure 3.6. It is clear that 90% of the emissions of CO_2 , CH_4 and N_2O were due to coal combusted in this activity (Table 1).

3.3 Depleting Fossil fuels

The End Of Fossil Fuels

Fossil fuels are fuels formed by natural processes such as anaerobic decomposition of buried dead organisms. The age of the organisms and their resulting fossil fuels is typically millions of years, and sometimes exceeds 650 million years. Fossil fuels contain high percentages of carbon and include coal, petroleum and natural gas.

The Energy Information Administration estimates that in 2007 the primary sources of energy consisted of petroleum 36.0%, coal 27.4%, natural gas 23.0%, amounting to an 86.4% share for fossil fuels in primary energy consumption in the world. Non-fossil sources in 2006 included hydroelectric 6.3%, nuclear 8.5%, and others (geothermal, solar, tidal, wind, wood, waste) amounting to 0.9%. World energy consumption was growing about 2.3% per year.

Although fossil fuels are continually being formed via natural processes, they are generally considered to be non-renewable resources because they take millions of years to form and the known viable reserves are being depleted much faster than new ones are being made.

Although humans probably used fossil fuels in ancient times, as far back as the Iron Age, it was the Industrial Revolution that led to their wide-scale extraction. And in the very short period of time since then – just over 200 years – we've consumed an incredible amount of them, leaving fossil fuels all but gone and the climate seriously impacted. Fossil fuels are an incredibly dense form of energy, and they took millions of years to become so. And when they're gone, they're gone pretty much forever.

Clearly fossil fuel reserves are finite - it's only a matter of when they run out - not if. Globally - every year we currently consume the equivalent of over 11 billion tonnes of oil in fossil fuels. Crude oil reserves are vanishing at the rate of 4 billion tonnes a year[1] – if we carry on at this rate without any increase for our growing population or aspirations, our known oil deposits will be gone by 2052 (Table 2).

We'll still have gas left, and coal too. But if we increase gas production to fill the energy gap left by oil, then those reserves will only give us an additional eight years, taking us to 2060. But the rate at which the world consumes fossil fuels is not standing still, it is increasing as the world's population increases and as living standards rise in parts of the world that until recently had consumed very little energy. Fossil Fuels will therefore run out earlier (Figure 3.7).

It's often claimed that we have enough coal to last hundreds of years. But if we step up production to fill the gap left through depleting our oil and gas reserves, the coal deposits we know about will only give us enough energy to take us as far as 2088. And let's not even think of the carbon dioxide emissions from burning all that coal.

India and Fossil fuels

India's dependence on imported fossil fuels rose to 38 per cent in 2012, despite the country having significant domestic fossil fuel resources (Figure 3.8). India ranked as the fourth-largest energy consumer in the world in 2011, following China, the US and Russia. The country's energy demand continues to climb as a result of its dynamic economic growth and modernisation. India is the third-largest economy on a purchasing power parity basis and has the world's second-largest population, according to World Bank affordable energy supplies, and to attract investment for domestic hydrocarbon production and infrastructure development.

In 2013, India was the fourth-largest consumer and net importer of crude oil and petroleum products in the world after the US, China, and Japan. India's petroleum product demand reached nearly 3.7 million barrels per day, far above the country's roughly 1 million bbl/d of total liquids production.

Most of India's demand is for motor gasoline and gasoil, fuels used mainly in the transportation and industrial sectors, and for kerosene and LPG in the residential and commercial sectors. Consumers receive large subsidies for retail purchases of diesel, LPG, and kerosene, placing upward pressure on overall oil demand. Insufficient investment in developing more crude oil and liquids production has caused production to grow at a slower rate than oil demand.

Net oil import dependency rose from 43 per cent in 1990 to an estimated 71 per cent in 2012. The Middle East was the major source of crude oil supply to India in 2013, followed by countries in the Americas (mostly Venezuela) and Africa. Despite being a net importer of crude oil, India has become a net exporter of petroleum products after investing in new refinery capacity.
data.

As India modernises and the population moves to urban areas, the country has shifted from using traditional biomass and waste to relying on other energy sources, including fossil fuels. India's government faces challenges to meet the country's growing energy demand, to secure

Natural gas

India did not import any natural gas until 2004, when it began to import liquefied natural gas. Because India has not been able to produce an adequate supply of domestic natural gas and has been unable to create sufficient natural gas pipeline infrastructure on a national level, it increasingly relies on imported LNG to meet domestic demand. India ranked as the fourth-largest LNG importer following Japan, South Korea, and China in 2013, and it accounted for nearly 6 per cent of the global market, according to data from IHS Energy.

In 2012, LNG imports, mostly from long-term contracts with Qatar, accounted for about 29 per cent of India's 2.1 trillion cubic feet of consumption. Natural gas mainly serves as a substitute for coal in electricity generation and as an alternative for liquefied petroleum gas and other petroleum products in fertiliser production and other sectors in India.

Coal

Coal is India's primary source of energy (equalling 44 per cent of total energy consumption), and the country ranked as the third-largest global coal producer, consumer, and importer of coal in 2012.

Despite its significant coal reserves, India has experienced increasing supply shortages as a result of a lack of competition among producers, insufficient investment, and systemic problems with its mining industry.

Although production has increased by about 4 per cent per year since 2007, producers have failed to reach the government's production targets. Meanwhile, demand grew more than 7 per cent annually over the past five years with the rise of electricity demand and lower power generation from natural gas and hydroelectricity as a result of recent supply disruptions. Because power plants rely so heavily on coal, shortages are a major contributor to shortfalls in electricity generation and consequent blackouts throughout the country.

Because coal production cannot keep pace with demand, India has met more of its coal needs with imports. Net coal import dependency has risen from practically nothing in 1990 to nearly 23 per cent in 2012. India imports thermal coal for power generation from Indonesia and South Africa. The steel and cement industries are also significant coal consumers. India has limited reserves of coking coal, used for steel production, and imports large quantities of coking coal from Australia.

3.4 Growing Electricity Demand

According to the Energy Information Administration, world energy consumption is projected to expand by 50 percent from 2005 to 2030 (Figure 3.9). The EIA attributes much of this rise to the rapidly developing economies of China and India, based on the fact that their combined share of energy consumption grew from less than 8 percent of total energy use in 1980 to roughly 18 percent (Figure 3.10). That increase in demand is only going to swell further with time. And while demand for energy in the United States is certainly on the rise as well, its percentage of global consumption, according to the EIA, is projected to decrease by 2030.

The energy landscape we expect to see in 2050 will be quite different from how it looks today. Meeting future energy demand will be a key challenge. The world's population will increase from approximately 7 billion in 2013 to approximately 8.7 billion in 2050, which is equal to a 26% increase. The GDP per capita will also increase from slightly more than 9,000 US$2010 on average globally) in 2010 to approximately 23,000 US$2010 in 2050. This represents an increase by 153%. Mobility will also increase, with car ownership in terms of cars per 1000 people increasing from 124 in 2010 to 244 in 2050. This equates to an increase by 98%. The WEC (World Energy Scenarios) estimates that total primary energy supply (equal to consumption) will increase globally from 546 EJ (152 PWh) in 2010 to 879 EJ (144 PWh) in 2050. This corresponds to an increase of 61%. Just to compare: from 1990 to 2010 – which is roughly half the time span covered in this scenario study – total global primary energy consumption rose by approximately 45% (Figure 3.11). It is expected that global primary energy consumption will continue to rise, but at a much lower rate than in previous decades. Meeting both global and regional energy demand will be a challenge

Global electricity generation will increase between now and 2050: in 2010, global electricity production was 21.5 billion MWh globally. This is expected to increase by 150% to 53.6 billion MWh by 2050. Simply due to the sheer increase in electricity production that is needed to meet future demand, the future electricity generation mix will be subject to tremendous changes up to 2050.

3.5 Renewable Resources limitations

Wind, solar, and biomass are three emerging renewable sources of energy. Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, air and water heating/cooling, motor fuels, and rural (off-grid) energy services.

Based on REN21's 2014 report, renewables contributed 19 percent to our global energy consumption and 22 percent to our electricity generation in 2012 and 2013, respectively. This energy consumption is divided as 9% coming from traditional biomass, 4.2% as heat energy (non-biomass), 3.8% hydro electricity and 2% is electricity from wind, solar, geothermal, and biomass (Figure 3.12). Worldwide investments in renewable technologies amounted to more than US$214 billion in 2013, with countries like China and the United States heavily investing in wind, hydro, solar and bio-fuels.

Renewable hydroelectric energy provides 16.3% of the worlds electricity. When hydroelectric is combined with other renewables such as wind, geothermal, solar, biomass and waste: together they make the "renewables" total, 21.7% of electricity generation worldwide as of 2013. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas: for example, 14% in the U.S. state of Iowa, 40% in the northern German state of Schleswig-Holstein, and 49% in Denmark. Some countries get most of their power from renewables, including Iceland (100%), Norway (98%), Brazil (86%), Austria (62%), New Zealand (65%), and Sweden (54%).

Disadvantages of Renewable sources of energy

1) The reliability of supply or The issue of intermittency

Intermittency is, quite simply, the fluctuating availability of an energy source. All power generating technology suffers from it. Things break and need mending. Supplies of fuel can get interrupted. Routine maintenance can shut down a plant for weeks. But where we are considering conventional power stations that rely on stored energy fuel sources - coal, gas or uranium and the stored renewables of hydroelectricity, geothermal , and biofuels - such loss of availability is the exception to the rule, and equally as importantly, generally characterised by being both infrequent and of significant duration. Taking down a coal plant for a boiler inspection is a week or more to let it cool down, inspect it and restart it. But it happens only once a year (and generally in summer when demand is lower anyway).

By contrast, when considering the intermission of 'intermittent' renewable energy - that is wind, solar, tidal and wave , the intermittency is characterised by being persistent and of short duration. Solar power varies from nothing at night to full power during the day every day , tidal does similar twice a day (roughly) . Wind power fluctuates randomly but with a general period that approximates to 3-5 days, that being the average time it takes for a low pressure system with associated wind to pass over a reasonable geographical area. When these resources are unavailable so is the capacity to make energy from them. This can be unpredictable and inconsistent.

2) Energy and power density

If a power station the size of Fukushima (4.7GW) were to be replaced with a wind farm of the same average output, it would render an area larger than the current temporary exclusion zone (about the size of Greater London in which ~10m people live) permanently uninhabitable (Table 3).

Renewable energy necessarily has a massive impact on the environment, simply because the scale of it has to be so large to collect what is a very diffuse and fleeting amount of energy.

Thus in order for intermittent renewable energy sources such as solar PV to effectively compete with fossil fuels like coal, both the price of installed solar panels and the price of

battery storage will need to reduce by a full order of magnitude. In addition, optimistic long-term projections state that both solar panels and battery storage will reach technological maturity at roughly triple the cost of their fossil fuel counterparts.

Like all power plants, hydroelectric plants are very expensive to build, and must be built to a very high standard. The high cost means that plants must operate for a long time to become profitable. The creation of dams can also create flooding of land, which means natural environment and the natural habitat of animals, and even people, may be destroyed.

The building of dams for hydroelectric power can also cause a lot of water access problems. The creation of a dam in one location may mean that those down river no longer have control of water flow. This can create controversy in places where neighbouring countries share a water supply.

3.6 Cost of electricity by source

In electrical power generation, the distinct ways of generating electricity incur significantly different costs. Calculations of these costs at the point of connection to a load or to the electricity grid can be made. The cost is typically given per kilowatt-hour or megawatt-hour. It includes the initial capital, discount rate, as well as the costs of continuous operation, fuel, and maintenance.

The levelized cost of electricity (LCOE) is a measure of a power source which attempts to compare different methods of electricity generation on a comparable basis. It is an economic assessment of the average total cost to build and operate a power generating asset over its lifetime divided by the total power output of the asset over that lifetime. The LCOE can also be regarded as the cost at which electricity must be generated in order to breakeven over the lifetime of the project.

(i) Cost factors

While calculating costs, several internal cost factors have to be considered.(Note the use of "costs," which is not the actual selling price, since this can be affected by a variety of factors such as subsidies and taxes):

1. Capital costs (including waste disposal and decommissioning costs for nuclear energy) tend to be low for fossil fuel power stations; high for wind turbines, solar PV; very high for waste to energy, wave and tidal, solar thermal, and nuclear.
2. Fuel costs high for fossil fuel and biomass sources, low for nuclear, and zero for many renewables.
3. Factors such as the costs of waste (and associated issues) and different insurance costs are not included in the following: Works power, own use or parasitic load that is, the portion of generated power actually used to run the stations pumps and fans has to be allowed for.

To evaluate the total cost of production of electricity, the streams of costs are converted to a net present value using the time value of money. These costs are all brought together using discounted cash flow.

(ii) Levelized cost of electricity

The levelized cost of electricity (LCOE), also known as Levelized Energy Cost (LEC), is the net present value of the unit cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime. It is a first order economic assessment of the cost competitiveness of an electricity generating system that incorporates all costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital.

The levelized cost is that value for which an equal valued fixed revenue delivered over the life of the asset's generating profile would cause the project to break even. This can be roughly calculated as the net present value of all costs over the lifetime of the asset divided by the total electricity output of the asset.

The levelized cost of electricity (LCOE) is given by:

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electricity produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t : investment expenditures in the year t

M_t : operations and maintenance expenditures in the year t

F_t : fuel expenditures in the year t

E_t : electricity generation in the year t

r : discount rate

n : expected lifetime of system or power station

Typically the LCOE is calculated over the design lifetime of a plant, which is usually 20 to 40 years, and given in the units of currency per kilowatt-hour or megawatt-day, for example AUD/kWh or EUR/kWh or per megawatt-hour, for example AUD/MWh (as tabulated below). However, care should be taken in comparing different LCOE studies and the sources of the information as the LCOE for a given energy source is highly dependent on the assumptions, financing terms and technological deployment analyzed. In particular, assumption of capacity factor has significant impact on the calculation of LCOE. Thus, a key requirement for the analysis is a clear statement of the applicability of the analysis based on justified assumptions.

Many scholars, such as Paul Joskow, have described limits to the "levelized cost of electricity" metric for comparing new generating sources. In particular, LCOE ignores time effects associated with matching production to demand. This happens at two levels: (1) dispatchability, the ability of a generating system to come online, go offline, or ramp up or down, quickly as demand swings; and (2) the extent to which the availability profile matches or conflicts with the market demand profile. Thermally lethargic technologies like coal and nuclear are physically incapable of fast ramping. Capital intensive technologies such as wind, solar, and nuclear are economically disadvantaged unless generating at maximum availability since the LCOE is nearly all sunk cost capital investment. Intermittent power sources, such as wind and solar, may incur extra costs associated with needing to have storage or backup generation available. At the same time, intermittent sources can be competitive if they are available to produce when demand and prices are highest, such as solar during midday peaks seen in summertime load profiles. Despite these time limitations, levelling costs is often a

necessary prerequisite for making comparisons on an equal footing before demand profiles are considered, and the levelized cost metric is widely used for comparing technologies at the margin, where grid implications of new generation can be neglected.

(iii) External costs of energy sources

Typically pricing of electricity from various energy sources may not include all external costs that is, the costs indirectly borne by society as a whole as a consequence of using that energy source. These may include enabling costs, environmental impacts, usage life-spans, energy storage, recycling costs, or beyond insurance accident effects.

The US Energy Information Administration predicts that coal and gas are set to be continually used to deliver the majority of the world's electricity, this is expected to result in the evacuation of millions of homes in low lying areas, and an annual cost of hundreds of billions of dollars' worth of property damage.

Furthermore, with a number of island nations becoming slowly submerged underwater due to rising sea levels, massive international climate litigation lawsuits against fossil fuel users are currently beginning in the International Court of Justice.

An EU funded research study known as ExternE, or Externalities of Energy, undertaken over the period of 1995 to 2005 found that the cost of producing electricity from coal or oil would double over its present value, and the cost of electricity production from gas would increase by 30% if external costs such as damage to the environment and to human health, from the particulate matter, nitrogen oxides, chromium VI, river water alkalinity, mercury poisoning and arsenic emissions produced by these sources, were taken into account. It was estimated in the study that these external, downstream, fossil fuel costs amount up to 1% - 2% of the EU's entire Gross Domestic Product (GDP), and this was before the external cost of global warming from these sources was even included. Coal has the highest external cost in the EU, and global warming is the largest part of that cost.

A means to address a part of the external costs of fossil fuel generation is carbon pricing — the method most favoured by economics for reducing global-warming emissions. Carbon pricing charges those who emit carbon dioxide (CO2) for their emissions. That charge, called a 'carbon price', is the amount that must be paid for the right to emit one tonne of CO2 into the atmosphere. Carbon pricing usually takes the form of a carbon tax or a requirement to purchase permits to emit (also called "allowances").

Depending on the assumptions of possible accidents and their probabilities external costs for nuclear power vary significantly and can reach between 0.2 to 200 ct/kWh. Furthermore, nuclear power is working under an insurance framework that limits or structures accident liabilities in accordance with the Paris convention on nuclear third-party liability, the Brussels supplementary convention, and the Vienna convention on civil liability for nuclear damage and in the U.S. the Price Anderson Act. It is often argued that this potential shortfall in liability represents an external cost not included in the cost of nuclear electricity; but the cost is small, amounting to about 0.1% of the levelized cost of electricity, according to a CBO study.

These beyond insurance costs for worst case scenarios are not unique to nuclear power, as hydroelectric power plants are similarly not fully insured against a catastrophic event such as the Banqiao Dam disaster, where 11 million people lost their homes and from 30,000 to 200,000 people died, or large dam failures in general. As private insurers base dam insurance premiums on limited scenarios, major disaster insurance in this sector is likewise provided by the state.

Because externalities are diffuse in their effect, external costs cannot be measured directly, but must be estimated. One approach estimate external costs of environmental impact of electricity is the Methodological Convention of Federal Environment Agency of Germany. That method arrives at external costs of electricity from lignite at 10.75 Eurocent/kWh, from hard coal 8.94 Eurocent/kWh, from natural gas 4.91 Eurocent/kWh, from photovoltaic 1.18 Eurocent/kWh, from wind 0.26 Eurocent/kWh and from hydro 0.18 Eurocent/kWh. For nuclear the Federal Environment Agency indicates no value, as different studies have results that vary by a factor of 1,000. It recommends the nuclear given the huge uncertainty, with the cost of the next inferior energy source to evaluate. Based on this recommendation the Federal Environment Agency, and with their own method, the Forum Ecological-social market economy, arrive at external environmental costs of nuclear energy at 10.7 to 34 ct/kWh.

(iv) Additional cost factors

Calculations often do not include wider system costs associated with each type of plant, such as long distance transmission connections to grids, or balancing and reserve costs. Calculations do not include externalities such as health damage by coal plants, nor the effect of CO2 emissions on the climate change, ocean acidification and eutrophication, ocean current shifts. Decommissioning costs of nuclear plants are usually not included (The USA is an exception, because the cost of decommissioning is included in the price of electricity, per the Nuclear Waste Policy Act), is therefore not full cost accounting. These types of items can be explicitly added as necessary depending on the purpose of the calculation. It has little relation to actual price of power, but assists policy makers and others to guide discussions and decision making.

These are not minor factors but very significantly affect all responsible power decisions:

1. Comparisons of lifecycle greenhouse gas emissions show coal, for instance, to be radically higher in terms of GHGs than any alternative. Accordingly, in the analysis below, carbon captured coal is generally treated as a separate source rather than being averaged in with other coal.
2. Other environmental concerns with electricity generation include acid rain, ocean acidification and effect of coal extraction on watersheds.
3. Various human health concerns with electricity generation, including asthma and smog, now dominate decisions in developed nations that incur health care costs publicly. A Harvard University Medical School study estimates the US health costs of coal alone at between 300 and 500 billion US dollars annually.
4. While cost per kWh of transmission varies drastically with distance, the long complex projects required to clear or even upgrade transmission routes make even attractive new supplies often uncompetitive with conservation measures, because the timing of payoff must take the transmission upgrade into account.

(v) LCOE in various countries

Australia

Table 4 gives a selection of LCOE from two major government reports from Australia. These figures do not include any cost for the greenhouse gas emissions (such as under carbon tax or emissions trading scenarios) associated with the different technologies. It should also be noted that the cost for wind and solar has dramatically reduced since 2006, for example, over the 5 years 2009 - 2014 solar costs fell by 75% making them comparable to coal, and are expected to continue dropping over the next 5 years by another 45% from 2014 prices. Also, wind has been cheaper than coal since 2013, whereas coal and gas will only become less viable as subsidies may be withdrawn and there is the expectation that they will eventually have to pay the costs of pollution.

France

The International Agency for the Energy and EDF have estimated for 2011 the following costs (Table 5). For the nuclear power they include the costs due to new safety investments to upgrade the French nuclear plant after the Fukushima Daiichi nuclear disaster; the cost for those investments is estimated at 4 €/MWh. Concerning the solar power the estimate at 293 €/MWh is for a large plant capable to produce in the range of 50–100 GWh/year located in a favorable location (such as in Southern Europe). For a small household plant capable to produce typically around 3 MWh/year the cost is according to the location between 400 and 700 €/MWh. Currently solar power is by far the most expensive renewable source to produce electricity, although increasing efficiency and longer lifespan of photovoltaic panels together with reduced production costs could make this source of energy more competitive.

Germany

In November 2013, the Fraunhofer Institute assessed the levelised generation costs for newly built power plants in the German electricity sector. PV systems reached LCOE between 0.078 and 0.142 Euro/kWh in the third quarter of 2013, depending on the type of power plant (ground mounted utility scale or small rooftop solar PV) and average German insolation of 1000 to 1200 kWh/m² per year (GHI)(Table 6). There are no LCOE figures available for electricity generated by recently built German nuclear power plants as none have been constructed since the late 1980s.

Japan

A 2010 study by the Japanese government (pre-Fukushima disaster), called the Energy White Paper, concluded the cost for kilowatt hour was ¥49 for solar, ¥10 to ¥14 for wind, and ¥5 or ¥6 for nuclear power. Masayoshi Son, an advocate for renewable energy, however, has pointed out that the government estimates for nuclear power did not include the costs for reprocessing the fuel or disaster insurance liability. Son estimated that if these costs were included, the cost of nuclear power was about the same as wind power.

United Kingdom

More recent UK estimates are the Mott MacDonald study released by DECC in June 2010 and the Arupstudy for DECC published in 2011 (Table 7).

3.7 Electricity sector in India

India depends upon various sources for her power requirements. The break-up of the power is as given in figure 3.13.

The utility electricity sector in India had an installed capacity of 275.912 GW as of 31 July 2015. Renewable Power plants constituted 28% of total installed capacity and Non-Renewable Power Plants constituted the remaining 72%. The gross electricity generated by utilities is 1,106 TWh (1,106,000 GWh) and 166 TWh by captive power plants during the 2014–15 fiscal (Table 8). The gross electricity generation includes auxiliary power consumption of power generation plants. India became the world's third largest producer of electricity in the year 2013 with 4.8% global share in electricity generation surpassing Japan and Russia.

During the year 2014-15, the per capita electricity generation in India was 1,010 kWh with total electricity consumption (utilities and non utilities) of 938.823 billion or 746 kWh per capita electricity consumption. Electric energy consumption in agriculture was recorded highest (18.45%) in 2014-15 among all countries. The per capita electricity consumption is lower compared to many countries despite cheaper electricity tariff in India.

Of the 1.4 billion people in the world who have no access to electricity, India accounts for over 300 million. The International Energy Agency estimates India will add between 600 GW to 1,200 GW of additional new power generation capacity before 2050. This added new capacity is equivalent to the 740 GW of total power generation capacity of European Union in 2005. The technologies and fuel sources India adopts, as it adds this electricity generation capacity, may make significant impact to global resource usage and environmental issues.

Some 800 million Indians use traditional fuels – fuel-wood, agricultural waste and biomass cakes – for cooking and general heating needs. These traditional fuels are burnt in cook stoves, known as *chulah* or *chulha* in some parts of India. Traditional fuel is inefficient source of energy, its burning releases high levels of smoke, PM10 particulate matter, NOX, SOX, PAHs, poly-aromatics, formaldehyde, carbon monoxide and other air pollutants. Some reports, including one by the World Health Organisation, claim 300,000 to 400,000 people in India die of indoor air pollution and carbon monoxide poisoning every year because of biomass burning and use of chullahs. Traditional fuel burning in conventional cook stoves releases unnecessarily large amounts of pollutants, between 5 to 15 times higher than industrial combustion of coal, thereby affecting outdoor air quality, haze and smog, chronic health problems, damage to forests, ecosystems and global climate. Burning of biomass and firewood will not stop, these reports claim, unless electricity or clean burning fuel and combustion technologies become reliably available and widely adopted in rural and urban

India. The growth of electricity sector in India may help find a sustainable alternative to traditional fuel burning.

In addition to air pollution problems, a 2007 study finds that discharge of untreated sewage is single most important cause for pollution of surface and ground water in India. There is a large gap between generation and treatment of domestic wastewater in India. The problem is not only that India lacks sufficient treatment capacity but also that the sewage treatment plants that exist do not operate and are not maintained. Majority of the government owned sewage treatment plants remain closed most of the time in part because of the lack of reliable electricity supply to operate the plants. The wastewater generated in these areas normally percolates in the soil or evaporates. The uncollected wastes accumulate in the urban areas cause unhygienic conditions, release heavy metals and pollutants that leaches to surface and groundwater. Almost all rivers, lakes and water bodies are severely polluted in India. Water pollution also adversely impacts river, wetland and ocean life. Reliable generation and supply of electricity is essential for addressing India's water pollution and associated environmental issues. Other drivers for India's electricity sector are its rapidly growing economy, rising exports, improving infrastructure and increasing household incomes.

Demand trends

During the fiscal year 2014-15, the electricity generated in utility sector is 1,030.785 billion KWh with a short fall of requirement by 38.138 billion KWh (3.6%) against the 5.1% deficit anticipated. The peak load met was 141,180 MW with a short fall of requirement by 7,006 MW (4.7%) against the 2.0% deficit anticipated. In a May 2015 report, India's Central Electricity Authority anticipated, for the 2015–16 fiscal year, a base load energy deficit and peaking shortage to be 2.1% and 2.6% respectively (Table 9). Southern and North Eastern regions are anticipated to face energy shortage up to 11.3%. The marginal deficit figures clearly reflect that India would become electricity surplus during the 12th five year plan period.

Despite an ambitious rural electrification programme, some 400 million Indians lose electricity access during blackouts. While 80% of Indian villages have at least an electricity line, just 52.5% of rural households have access to electricity. In urban areas, the access to electricity is 93.1% in 2008. The overall electrification rate in India is 64.5% while 35.5% of the population still live without access to electricity.

The 17th electric power survey of India report claims:

- Over 2010–11, India's industrial demand accounted for 35% of electrical power requirement, domestic household use accounted for 28%, agriculture 21%, commercial 9%, public lighting and other miscellaneous applications accounted for the rest.
- The electrical energy demand for 2016–17 is expected to be at least 1,392 Tera Watt Hours, with a peak electric demand of 218 GW.
- The electrical energy demand for 2021–22 is expected to be at least 1,915 Tera Watt Hours, with a peak electric demand of 298 GW.

If current average transmission and distribution average losses remain same (32%), India needs to add about 135 GW of power generation capacity, before 2017, to satisfy the projected demand after losses. McKinsey claims that India's demand for electricity may cross 300 GW, earlier than most estimates. To explain their estimates, they point to four reasons:

- India's manufacturing sector is likely to grow faster than in the past
- Domestic demand will increase more rapidly as the quality of life for more Indians improve
- About 125,000 villages are likely to get connected to India's electricity grid
- Blackouts and load shedding artificially suppresses demand; this demand will be sought as revenue potential by power distribution companies

A demand of 300 GW will require about 400 GW of installed capacity, McKinsey notes. The extra capacity is necessary to account for plant availability, infrastructure maintenance, spinning reserve and losses.

Chapter 4 : The Analysis

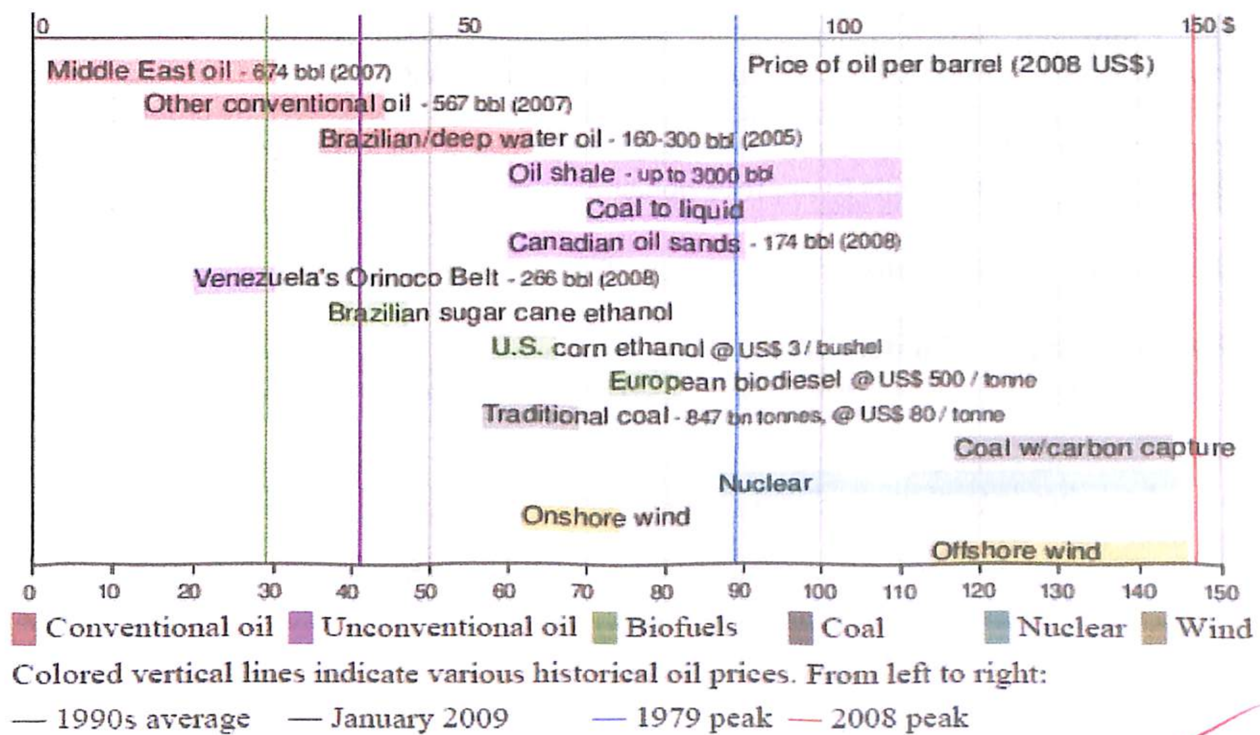
4.1 Cost Comparison: Nuclear vs. Coal

To accurately compare the cost of nuclear against other energy sources, one must include the following costs:

(i) Fuel costs:
Costs associated with the fuel used in the production of energy.

For a nuclear plant, these tend to be lower even though the following steps occur in the production of the fuel assemblies used in the reactor:
1. mining of the uranium ore,
2. conversion to U3O8 (uranium oxide yellowcake form),
3. conversion to uranium hexafluoride,
4. enrichment from 0.7% U235 to 25% U235,
5. conversion to uranium dioxide (UO2) pellets,
6. loading of the pellets into rods, then into fuel assemblies.

Transportation costs are high for coal because of the amount of material needed to generate the same energy as the nuclear fuel.



Price of oil per barrel (bbl) at which energy sources are competitive.

- **Right end of bar** is viability without subsidy.
- **Left end of bar** requires regulation or government subsidies.
- **Wider bars** indicate uncertainty.

Source: *Financial Times* (edit)

(ii) Capital costs:

Costs associated with initial construction of the plant and the modifications. These end up as embedded costs.

For a nuclear plant these may be higher than for other energy forms because the buildings used for containment or for safety related equipment must meet higher standards than the traditional structures. Also, safety related systems are redundant. Such considerations are not important in other energy forms. On the other hand, coal plants are required to include scrubbers to remove airborne pollutants as sulphur dioxide, nitrous oxides, and particulates.

However, these costs are influenced by factors as:

1. When the plant was built (capital costs for plants finished in the 80's were higher due to inflation. Following the Arab oil embargoes in 1973 and 1979, there was considerable emphasis on energy conservation. Also, energy costs rose which had a significant impact on inflation. Because of the drop in expected energy demand, utilities delayed plants under construction, many of which were nuclear and had long lead times for completion. The debt for the delayed plant still incurred interest charges in times when rates exceeded 15%. Short term interest rates in the 80-81 timeframe was 20%. As with the federal government debt, that total interest kept increasing so that when the plant went online, the total cost of the plant was higher than if the plant had been completed on time. Another related factor was that the delays resulted in higher labour costs the plants were completed when wages had risen because of inflation. Also, following the Three Mile Island event in 1979, the NRC mandated a number of plant design changes for plants coming on line.

2. Major equipment replacements. During the 1980's, many older BWRs replaced the recirculation system piping due to corrosion cracking. Some PWRs have had to replace steam generators. Eventually it is expected that most, if not all, PWRs will have to replace steam generators prior to the end of their NRC operating license. In some cases, plants have upgraded turbine generator units to improve power output.

Capital costs are usually amortized over a period of time as allowed by IRS regulations.

(iii) Operation and Maintenance costs

The day to day costs associated with operating the nuclear power plant.

This includes the costs of:

1. labor and overheads (e.g. medical and pension benefits),
2. expendable materials,
3. NRC (e.g. license changes, onsite and regional inspectors, and headquarters staff) and state (e.g. health department, emergency planning) fees,
4. local property taxes (varies from state to state).

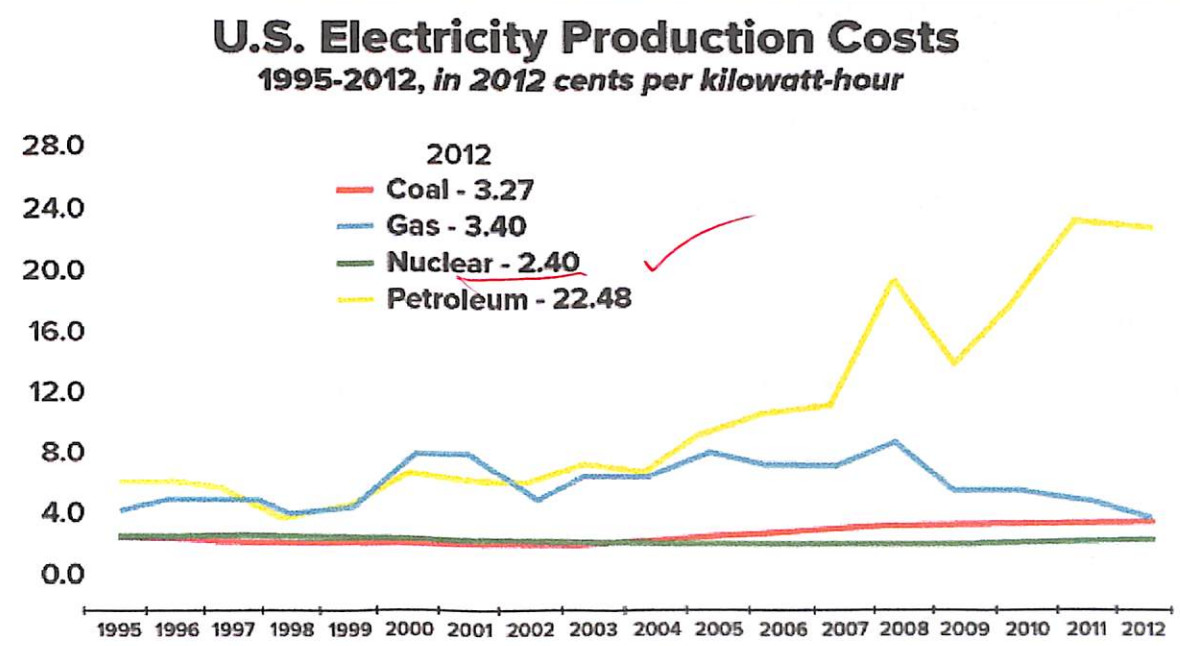
Labour costs in a nuclear plant include those for operators, maintenance personnel (electrical, mechanical, instrument and controls), health physics technicians, engineering personnel (mechanical, electrical, nuclear, chemical, radiological, computer). Materials costs include replacement parts, computer parts, expendable office and other supplies.

(iv) Waste Related Costs

The costs associated with the byproduct waste. For a coal plant this is ash. For a nuclear plant, these costs include the surcharge levied by the Department of Energy for ultimate storage of the high level waste. The DOE charge is a flat fee based on energy use.

(v) Decommissioning Costs

The costs associated with restoration of the plant site back to "Greenfield" status. Usually restoration would occur over a long period of time, e.g. 20 years. Parts of the plant could be used for energy generation by other sources.



Source: Nuclear Energy Institute. U.S. Electricity Production Costs. http://www.nei.org/Knowledge-Center/Nuclear-Statistics/Costs-Fuel,-Operation,-Waste-Disposal-Life-Cycle/US-Electricity-Production-Costs

4.2 Advantages of nuclear power plants in India

(i) Nuclear power in India

Nuclear power is the fourth largest source of electricity in India after thermal, hydroelectric and renewable sources of electricity. As of 2013, India has 21 nuclear reactors in operation in 7 nuclear power plants, having an installed capacity of 5780 MW and producing a total of 30,292.91 GWh of electricity while 6 more reactors are under construction and are expected to generate an additional 4,300 MW.

Power station	Operator	State	Type	Units	Total capacity (MW)
Kaiga	NPCIL	Karnataka	PHWR	220 x 4	880
Kakrapar	NPCIL	Gujarat	PHWR	220 x 2	440
Madras	NPCIL	Tamil Nadu	PHWR	220 x 2	440
Narora	NPCIL	Uttar Pradesh	PHWR	220 x 2	440
Rajasthan	NPCIL	Kota Rajasthan	PHWR	100 x 1 200 x 1 220 x 4	1180
Tarapur	NPCIL	Maharashtra	BWR PHWR	160 x 2 540 x 2	1440
Kudankulam	NPCIL	Tamil Nadu	VVER-1000	1000 x 1	1000
			Total	21	5780

The planned projects are:

Power station	Operator	State	Type	Units	Total capacity (MW)
Gorakhpur	NPCIL	Haryana	PHWR	630 x 4	2.800
Chutka	NPCIL	Madhya Pradesh	PHWR	700 x 2	1400
Mahi Banswara	NPCIL	Rajasthan	PHWR	700 x 2	1400
Kaiga	NPCIL	Karnataka	PHWR	700 x 2	1400
Madras	NPCIL	Tamil Nadu	FBR	500 x 2	1000
Site to be decided			AHWR	300 x 1	300
Kudankulam		Tamil Nadu	VVER-1000	1000 x 2	2000
Jaitapur		Maharashtra	EPR	1650 x 6	9900
Kovvada		Andhra Pradesh	ESBWR	1594 x 6	9564
Mithi Virdi (Viradi)		Gujarat	AP1000	1100 x 6	6600
			Total	33	33564

Salient features of India's Nuclear Power Program :

- India has a flourishing and largely indigenous nuclear power program and expects to have 14,600 MWe nuclear capacity on line by 2020. It aims to supply 25% of electricity from nuclear power by 2050.
- Because India is outside the Nuclear Non-Proliferation Treaty due to its weapons program, it was for 34 years largely excluded from trade in nuclear plant or materials, which has hampered its development of civil nuclear energy until 2009.
- Due to earlier trade bans and lack of indigenous uranium, India has uniquely been developing a nuclear fuel cycle to exploit its reserves of thorium.
- Since 2010, a fundamental incompatibility between India's civil liability law and international conventions limits foreign technology provision.
- India has a vision of becoming a world leader in nuclear technology due to its expertise in fast reactors and thorium fuel cycle.

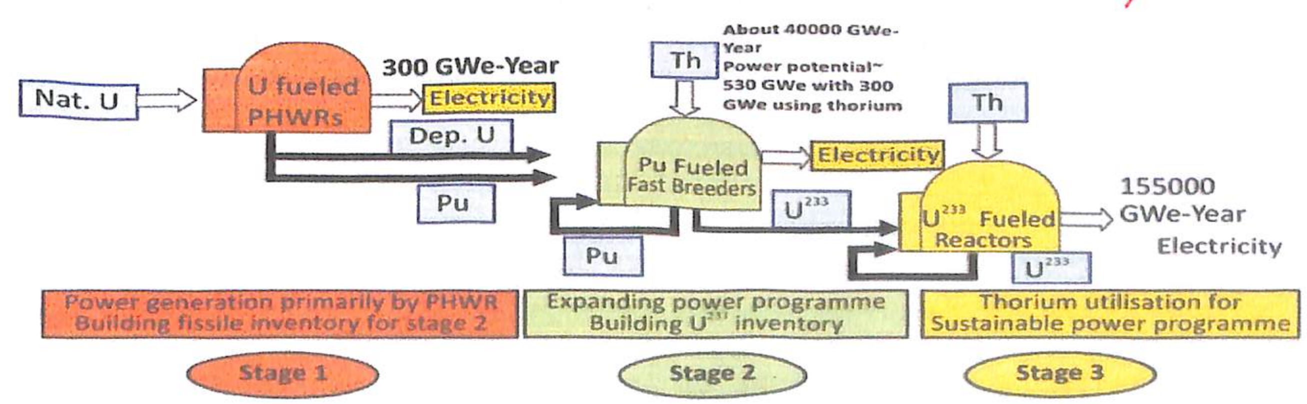
NPCIL supplied 35 TWh of India's electricity in 2013-14 from 5.3 GWe nuclear capacity, with overall capacity factor of 83% and availability of 88%. Some 410 reactor years of operation had been achieved to December 2014. India's fuel situation, with shortage of fossil fuels, is driving the nuclear investment for electricity, and 25% nuclear contribution is the ambition for 2050, when 1094 GWe of base load capacity is expected to be required. Almost as much investment in the grid system as in power plants is necessary.

We can see from figure 4.1 that the nuclear power plants are strategically located at a distance greater than 800 km from the coal fields this has been done to make the nuclear power competitive with thermal power in the area it is located.

(ii) India's 3 stage Nuclear program and India's vast Thorium reserves

India's three-stage nuclear power programme was formulated by Homi Bhabha in the 1950s to secure the country's long term energy independence, through the use of uranium and thorium reserves found in the monazite sands of coastal regions of South India. The ultimate focus of the programme is on enabling the thorium reserves of India to be utilised in meeting the country's energy requirements (Table 10). Thorium is particularly attractive for India, as it has only around 1–2% of the global uranium reserves, but one of the largest shares of global thorium reserves at about 25% of the world's known thorium reserves (Figure 4.2).

Three Stage Indian Nuclear Power Programme incorporates closed fuel cycle and thorium utilisation as a main-stay for sustained growth.



(iii) Advantages

1. India has an electricity supply problem.

Standards of living are directly tied to the per capita consumption of electricity. India has been plagued with blackouts in recent years. Just two months ago, India had a blackout in 20 of 28 states leaving 710 million people without power. That's more than double the population of the entire U.S. Think about that for a second. No electricity to hospitals. To refrigerators storing food. To factories producing goods. Air conditioning units cooling elderly and children in 89% humidity. A lot of facilities don't have backup power for 14 hours. It can become a scary situation outside of being extremely disruptive.

2. India needs electricity to grow

India has a rapidly developing economy and needs to increase their electricity generation to sustain growth. We can easily relate this to more factories requiring more power. India's economic expansion is rather similar to Brazil, Russia, and China.

3. India is running out of fossil reserves.

The motivation for nuclear power in many countries currently and historically has come from the lack of fossil fuels to power conventional plants. Both France and Japan were driven to expand their nuclear power programs for this reason. France doesn't have the coal or natural gas reserves of other countries. Japan also imports almost all of their fossil fuel. India is running out of good quality domestic fossil fuel so they need to look in another direction to not import more gas and coal.

4. Nuclear economics benefit a growing country.

Nuclear power plants are known to have very high upfront capital costs but very low operating costs. Think about it like buying a hybrid car. The purchase price can be significantly more than a car with a gas engine but your fuel costs are much lower. You buy it because it'll be cheaper in the long run to pay more upfront and less over time. Nuclear economics are similar.

Capital costs go back to India
High upfront capital costs are typical welcomed by the country that is building the plant. A large amount of work will go to Indian contractors to pour concrete, lay rebar, erect structural steel, weld pipe, install equipment, etc. Much on the equipment will be purchased from Indian suppliers. Because of this, the money spent on the plant goes right back into the country's economy.

Low cost fuel is imported
Importing uranium is significantly cheaper than importing gas, coal, or petroleum. This is important for a country low on natural resources. In this way, more money is directed domestically towards growth.

5. Nuclear is mature, relatively clean, and the best alternative to coal.

In terms of displacing coal power plants, nuclear is the best viable alternative that is ready to be deployed on such a large scale. China developed their coal program and is dealing with the consequences of pollution. Political pressure has influenced the country to reduce its greenhouse gas emissions. Now they have more new nuclear power plants under construction than the rest of the world *combined.*

4.3 Nuclear fuel reserves

Fuel for nuclear power is abundant, and uranium is even available from sea water at costs which would have little impact on electricity prices. Furthermore, if well-proven but currently uneconomic fast neutron reactor technology is used, or thorium becomes a nuclear fuel, the supply is almost limitless.

Uranium is a relatively common element in the crust of the Earth (very much more than in the mantle). It is a metal approximately as common as tin or zinc, and it is a constituent of most rocks and even of the sea. Some typical concentrations are shown in Table 11 (ppm = parts per million).

Australia has a substantial part (about 29 percent) of the world's uranium, Kazakhstan 12 percent, Russia nine percent and Canada eight percent (Table 12).

It is clear from Figure 4.3 that known uranium resources have increased almost threefold since 1975, in line with expenditure on uranium exploration.

The world's power reactors, with combined capacity of some 375 GWe, require about 68,000 tonnes of uranium from mines or elsewhere each year. While this capacity is being run more productively, with higher capacity factors and reactor power levels, the uranium fuel requirement is increasing, but not necessarily at the same rate. The factors increasing fuel demand are offset by a trend for higher burn-up of fuel and other efficiencies, so demand is steady.

Thorium as a nuclear fuel
Today uranium is the only fuel supplied for nuclear reactors. However, thorium can also be utilised as a fuel for CANDU reactors or in reactors specially designed for this purpose. Neutron efficient reactors, such as CANDU, are capable of operating on a thorium fuel cycle, once they are started using a fissile material such as U-235 or Pu-239. The thorium fuel cycle has some attractive features, though it is not yet in commercial use. Thorium is reported to be about three times as abundant in the earth's crust as uranium.

4.4 Nuclear Power: Sustainable Energy

From a national perspective, the security of future energy supplies is a major factor in assessing their sustainability. Whenever objective assessment is made of national or regional energy policies, security of supply is a priority.

France's decision in 1974 to expand dramatically its use of nuclear energy was driven primarily by considerations of energy security. However, the economic virtues have since become more prominent. Various EU reports over the last decade have highlighted the importance of nuclear power for Europe's energy security and climate goals. Many governments are clear that nuclear energy must play an increasing role by 2030, and in recent years the formerly rather negative UK government has been foremost in declaring this.

4.5 Nuclear Power: Green Power

Uranium can supply energy for the world's electricity with less greenhouse effect than virtually any other energy source.

A 1,000 megawatt electrical (MWe) coal-fired power station burning coal has a typical fuel requirement of almost 3.2 million tonnes(assumes coal yielding 24 MJ/kg and plant operating at 80% capacity. Burning brown coal at 8.15 MJ/kg would require 9.3 million tonnes of fuel.) of black coal a year. A nuclear power reactor of the same capacity, (after its initial fuel loading of uranium), has an annual requirement of around 27 tonnes of fuel. Producing this amount of uranium fuel requires the mining of 45-70,000 tonnes of typical Australian uranium ore, or even less Canadian ore. This yields about 200 tonnes of uranium oxide concentrate which is sold, the rest stays at the mine, as tailings. The uranium oxide is enriched to yield the 27 tonnes of actual fuel.

Emissions of carbon dioxide from burning fossil fuels are about 28 billion tonnes a year worldwide, of which around 38% comes from coal, 21% from gas and 41% from oil. Each year the 1000 MWe coal-fired power station produces about 7 million tonnes of carbon dioxide, perhaps 200,000 tonnes of sulphur dioxide (depending on the particular coal) and typically about 200,000 tonnes of solids, mostly fly ash. The ash contains several hundred tonnes of toxic heavy metals including arsenic, cadmium, lead, vanadium and mercury which remain toxic forever. If brown coal is used the carbon dioxide figure is about 9 million tonnes (Figure 4.4).

Methods exist for removing sulphur dioxide and nitrous oxide although the cost is high. Fly ash is generally captured and dumped in landfill. However there is no economically feasible way to remove or reduce carbon dioxide from the burning of coal. None of these emissions occur at a nuclear power station, where virtually all wastes are contained in the 27 tonnes or so of used fuel, and are therefore not released to the environment.

The combustion of coal may also release radioactive heavy metals (including uranium and thorium) contained in it, though these are mostly retained in the ash. The use of natural gas releases radioactive radon. The amount of radioactivity released is negligible relative to the natural background radiation levels, but is often greater than that from nuclear power generation.

If the electricity produced worldwide by nuclear reactors were generated instead by burning coal, an additional 2600 million tonnes of carbon dioxide would be released into the atmosphere each year. This can be compared with the target of a 5% reduction (600 million tonnes per year) in carbon dioxide emissions by the year 2010, as agreed in 1997 at Kyoto just for the developed countries.

Every 22 tonnes of uranium used avoids the emission of one million tonnes of carbon dioxide, relative to coal. When the electricity comes from coal, every kilowatt hour of it results in about a kilogram of carbon dioxide being emitted.

The total amount of used fuel resulting from operation of all the world's commercial nuclear power stations is about 12,000 tonnes per year. About two thirds of this is treated as waste, while the rest is reprocessed to recover useful fuel material. The reprocessing of used fuel results in only about 3% of it being high-level radioactive waste (which is then incorporated into glass), with the balance being recycled as fresh fuel.

Handling, storage and treatment of these radioactive wastes has been undertaken in many countries for several decades without incident. Nuclear power is the only energy-producing industry which takes full responsibility for all its wastes and costs this into the product.

The used nuclear fuel elements - or the separated high level wastes - are stored for up to 50 years to allow for the decay of most of the radioactivity and heat (to about 0.1% of what it was when removed from the reactor) before final disposal. Today the waste disposal issue is not a technical problem but one of public and political acceptance.

4.6 Nuclear Power: Proliferation concern

The technologies and materials used in the manufacture of nuclear weapons overlap with those used in peaceful nuclear power applications. The extent to which nuclear power will be an acceptable and enduring option to meeting future energy requirements in many regions of the world will therefore depend in part upon the ability to minimize the associated proliferation risks.

The elements of a nuclear power system include: facilities that mine and mill uranium ore, facilities that enrich uranium to create fuel, fuel fabrication facilities, reactors that burn that fuel to generate electricity, possibly facilities to reprocess the spent fuel, and waste storage sites (Figure 4.5).

Nuclear reactors themselves are not the primary proliferation risk. The principal proliferation concern among the various elements of a nuclear power system are the enrichment and reprocessing facilities, which can produce materials directly usable in weapons. In addition, the spent fuel is a potential source of plutonium that must be safeguarded to prevent its clandestine separation for use in weapons, and fresh low-enriched uranium (LEU) fuel materials are a potential source for clandestine enrichment to nuclear weapons grade material. Further, poorly secured nuclear materials, including plutonium separated for fabrication into reactor fuel, present a risk of proliferation through theft and transfer to another country or terrorist group.

There are a number of diplomatic, economic, military, and scientific and technical (S&T) approaches to reducing the proliferation risks of nuclear power.9 President Bush made a two part proposal to restrict the spread of enrichment and reprocessing technologies: 1) the world's leading nuclear exporters should ensure that states have reliable access at reasonable cost to fuel for civilian reactors, so long as those states renounce enrichment and reprocessing; and 2) The 40 nations of the Nuclear Suppliers Group should refuse to sell enrichment and reprocessing equipment and technologies to any state that does not already possess full-scale, functioning enrichment and reprocessing plants.10 IAEA director, Mohammed ElBaradei proposed a 5-year moratorium on construction of new enrichment or reprocessing plants while an effort is made to establish a multi-national alternative to nationally owned plants.11 Such fuel assurances and pledges to restrict sales are important components of a strategy to reduce the proliferation risks of nuclear power. However, no single diplomatic, military, economic, or technical initiative alone will be able to fully deal with the proliferation challenge. The best prospect for achieving non-proliferation goals while expanding nuclear power is to engage all appropriate means and to maximize their respective contributions. From a technical point of view, nuclear power cannot be made "proliferation proof". However, numerous steps can be taken -- and must be taken -- to make it as "proliferation-resistant" as reasonably possible.

4.7 Nuclear Power: Safety

The safety of nuclear energy has been well demonstrated, notwithstanding the continued operation of a small number of reactors which are, by western standards, distinctly unsatisfactory. These include two old Soviet designs, one of which – before some very extensive modifications to the type – precipitated the 1986 Chernobyl disaster. Over 14,500 reactor-years of operation have shown a remarkable lack of problems in any of the reactors which are licensable in most of the world. The only serious accident to a Western plant in over 30 years was that precipitated by an unprecedented tsunami at Fukushima in March 2011. Even then, and despite massive inconvenience to many people due to evacuation, the lack of human casualties from the accident contrasted with some 25,000 killed by the actual tsunami.

There is probably no other large-scale technology used worldwide with a comparable safety record. This is largely because safety was given a very high priority from the outset of the civil nuclear energy program, at least in the West. The safety provisions include a series of physical barriers between the hot radioactive reactor core and the environment, and the provision of multiple safety systems, each with back-up, and designed to accommodate human error. Safety systems, in the sense of back-ups and containment, account for a substantial part of the capital cost of nuclear power reactors - a higher proportion even than in aircraft design and construction.

Any statistics comparing the safety of nuclear energy with alternative means of generating electricity show nuclear to be the safest.

4.8 Nuclear Power: Waste Management

Burning fossil fuels produces primarily carbon dioxide as waste, which is inevitably dumped into the atmosphere. With black coal, approximately one tonne of carbon dioxide results from every thousand kilowatt hours generated. Natural gas contributes about half as much CO2 as coal from actual combustion, and also some (including methane leakage) from its extraction and distribution. Oil and gas burned in transporting fossil fuels adds to the global total. As yet, there is no satisfactory way to avoid or dispose of the greenhouse gases which result from fossil fuel combustion.

Nuclear wastes

Nuclear energy produces both operational and decommissioning wastes, which are contained and managed. Although experience with both storage and transport over half a century clearly shows that there is no technical problem in managing any civil nuclear wastes without environmental impact, the question has become political, focussing on final disposal. In fact, nuclear power is the only energy-producing industry which takes full responsibility for all its wastes, and costs this into the product .

Ethical, environmental and health issues related to nuclear wastes are topical, and their prominence has tended to obscure the fact that such wastes are a declining hazard, while other industrial wastes retain their toxicity indefinitely.

Regardless of whether particular wastes remain a problem for centuries or millennia or forever, there is a clear need to address the question of their safe disposal. If they cannot readily be destroyed or denatured, this generally means that they need to be removed and isolated from the biosphere. This may be permanent, or retrievable.

An alternative view asserts that indefinite surface storage of high-level wastes under supervision is preferable. This may be because such materials have some potential for recycling as a fuel source, or negatively because progress towards successful geological disposal would simply encourage continued use and expansion of nuclear energy. However, there is wide consensus that dealing effectively with wastes to achieve high levels of safety and security is desirable in a 50-year perspective, ensuring that each generation deals with its own wastes.

Chapter 5 : Case study

5.1 Levelised cost of electricity of Kaiga I and II NPP, India

The approach of levelised cost of electricity is one of the most popular approaches to compare the cost of power. First the present value of the plant is calculated by discounting all the future expenses to the present and then deciding at what price of electricity one can recover all the expenses that will be incurred during the construction, operation and decommissioning periods.Present value is calculated by using the following mathematical expression

$$PV(Costs) = \sum_{l=-M}^{0} \frac{C_l}{(1+i)^l} + \sum_{k=1}^{N} \left[\frac{(O_k + F_k)}{(1+i)^k} \right] + \sum_{j=P+1}^{N+P+1} \frac{W_j}{(1+i)^j} + \sum_{q=N}^{N+T} \frac{D_q}{(1+i)^q}$$

Where
C1 = capital cost in year 1.
M = total number of years of construction before reactor becomes commercial.
i = real discount rate.
N = number of years in operation
Ok = O and M costs in Kth year of operation.
Fk = fuel cost in year K of operation
Wj = waste disposal cost in year j
P = cooling time for spent fuel
Dq = decommissioning cost.
T = time difference in stopping of reactor function and decommissioning.
And

$$PV(revenues) = C_e \sum_{k=1}^{N} \frac{E_k}{(1+i)^k}$$

Where Ce is the levelised cost of electricity and Ek are the units of electricity sold in year k. i is the real discount rate.Thus we can calculate the LCOE of the plant by equating both the expressions. The values of the symbols for Kaiga I and II are as follows:

Field	Units
Sum of annual construction costs	Rs 1816 Crore (Without IDC)
Capacity	440 MW
Auxiliary consumption	12 %
Economic lifetime	40 years
Uranium fuel price	Rs 16450 /kg
Initial Uranium loading	111.6 tonnes
Uranium consumption	2.05E-05 kg/kwh
Heavy water price	Rs 24880 / kg
Initial heavy water loading	420 tonnes
Heavy water losses	14000 kg/ year
Transport of spent fuel	878 Rs/ kg
Decommissioning cost	10% of capital cost
Operation and Maintenance	2% of the capital cost

Source Ramanna, D'Sa, Reddy, 2005

Using the discount rate as 1% and power production to run at 80% of sanctioned capacity we get LCOE for Kaiga I and II= Rs 1.18 /kWh.Plant life was assumed to be 40 years.

5.2 Economic analysis of a coal power plant

Similar to the nuclear power plant the factors that affect the coal power plant are nearly the same. Factors affecting the cost of production :
1. Capital cost
2. Fuel cost
3. O & M
4. Waste disposal
5. Economic lifetime of power plant

Field	Units
Sum of Capital Cost during Construction	Rs 491.3 Crore
Capacity	210 MW
In plant consumption rate	8.5 %
Economic lifetime	30 years
Coal cost (domestic)	Rs 1412 per tonne
Coal consumption	0.63 kg/kWh
Heat Rate	2.362.5 kCal/kWh
Ash disposal cost	Rs 174 per tonne
Furnace oil consumption	2 mL/kWh
Furnace oil cost	Rs 18 per litre
O & M	2 % of the capital

Source: et al Ramanna 2005

We can calculate the LCOE is 1.33 Rs. Economic life of 30 years for a thermal power plant has been assumed.

We can compare our results now.

	Kaiga I & II	RTPS VII(D)
Capacity cost (including O&M) Rs/kWh	0.65	0.27
Heavy Water make-up cost Rs/net kWh	0.13	0.00
Fuel cost Rs/net kWh	0.38	1.01
LCOE Rs /kWh	1.18	1.33

The results for different values of discount rate are given below-

Discount Rate Percentage	Kaiga I & II	RTPS VII Rs/kWh
1	1.18	1.33
2	1.32	1.36
3	1.48	1.39
4	1.66	1.42
5	1.87	1.45
6	2.10	1.49

Clearly nuclear power becomes cheaper for realistic values of discount rates greater than 5%. Considering 6% discount rate for 2007 at 5% inflation we get LCOE for Kaiga I and II as 2.68 Rs/kWh and for RTPS VII as 1.90 Rs/kWh. It is to be noted that distance of this nuclear power plant is greater than 1200 km from the coal fields but we find that the cost still fail to compete with that of the coal power plant. Also the waste disposal expenses have not been considered, which are going to be substantial, and are nascent at present. On the other hand ash waste disposal in coal plants is cheaper as establishments are ready to buy it against the assumption that the plant pays for it.

5.3 Nuclear Power Vs Hydro power

Due to less data available the subject has been chosen to be the Nungleiban H.E. Project in the Bishnupur district of Manipur.
Following is the projected data on this plant which will be constructed in near future :

Sum of Initial cost of construction without IDC	Rs 841.99 crore
Capacity	105 MW
Economic Life	35-40 years

Assuming the O and M costs to be 2.5 % of the initial cost we get the LCOE as 3.37 Rs/kWh. However such high LCOE is certainly due to the fact of the hilly and tough terrain on which the plant is to be constructed and because there is no economy of scale. As there is no fuel cost there are quite a few examples which impress the fact that hydro power is one of the cleanest options which is cheap and economic.

This is clearly indicative of the fact that the current trend indicates that on an average nuclear power is more expensive than other options. Following are the average tariffs of the nuclear power plants in India.

Tarapur I and II	0.93 Rs/kWh
Madras I and II	1.81 Rs/kWh
Narora I and II	1.91 Rs/kWh
Kakrapar I and II	2.04 Rs/kWh
Tarapur III and IV	2.65 Rs/kWh
Kaiga I and II	2.79 Rs/kWh
Rajasthan II, III and IV	2.79 Rs/kWh

Considering this and that they have been established for quite some time we can compare them with the prices that have been offered by the various UMPP projects that have been awarded recently the tariffs are as follows:

Tata Mundra UMPP:	2.26 Rs/kWh
RPL Sasan UMPP :	1.20 Rs/kWh
RPL Krisnapatnam :UMPP	2.33 Rs/kWh

Chapter 6: Conclusion

Global warming has become the greatest problem of the world in the last few decades. The effects of global warming are the environmental and social changes caused (directly or indirectly) by human emissions of greenhouse gases. There is a scientific consensus that climate change is occurring, and that human activities are the primary driver. Many impacts of climate change have already been observed, including glacier retreat, changes in the timing of seasonal events (e.g., earlier flowering of plants), and changes in agricultural productivity.

The harsh realities of the events of the energy crisis had compelled the mankind to introduce a series of structural changes and technological and administrative interventions at the national, regional and international levels in order to help mitigating the effects of such situations if and when they appear in the future.

Thus, the availability of reliable and quality energy on a long-term perspective of any country now assumes the same importance as any other form of security. The scenario has been further compounded with the almost coincidental with the advent of the global concern on environment. Today, environmental dimension of energy has to be considered with as serious issue as any other technological, economic or financial factors of the overall matrix of its demand-supply balancing of any country.

Advantages of nuclear power in terms of environment, economics, reliability, long-term energy security, base load power supply, etc make it an appropriate, indispensable and inevitable option of electricity generation mix for the mid to long-term future for nations.

The problems faced globally by nuclear power are: cost, safety, waste disposal and proliferation. Technical feasibility of building nuclear power plants has been proved and prioritizing energy sector over other sectors to implement green technology has been justified. Economic feasibility of the proposal has also been proved from the statistics.

Clearly we need to focus our attention on nuclear energy with a degree of high priority. In India we have been pursuing development of nuclear energy right since the beginning. Given our known endowment of very modest Uranium and vast Thorium resources, we have pursued a three stage technology development programme that would enable us to exploit our Thorium resources on a large enough scale.

NUCLEAR POWER – AN INEVITABLE OPTION

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