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Published version

ALJAMEL, Suleiman Ahmed Mohamed. (2010). A conceptual framework for power generation technology management for developing countries. Doctoral, Sheffield Hallam University (United Kingdom)..

A CONCEPTUAL FRAMEWORK FOR POWER GENERATION TECHNOLOGY MANAGEMENT FOR DEVELOPING COUNTRIES

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THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

SHEFFIELD HALLAM UNIVERSITY

APRIL 2010

ABSTRACT

Most of the current approaches of technology management emphasis on the need of systematic technology management in both strategic and operational perspectives.

The majority of developing countries have a problem to manage technology systematically and fail to implement management techniques effectively. There is a big gap between developed and developing countries in most fields of technology and the power generation sector is among them.

The goal of this research work is to develop a conceptual framework for power generation technology management for developing countries. Also to draw a systematic guide lines and clear strategy to help decision makers to optimise their decisions to save resources and less harming to climate.

In this work, a systematic approach is developed to select a suitable hard technology for power generation technologies selection using the AHP software. A sensitivity analysis is carried out to show how the decision is affected with the change in criteria and sub-criteria. After this objective is achieved, some other soft technologies are identified with their limits and integrated with hard technologies for power generation. A validation of the proposed model is provided using the questionnaire technique.

DEDICATION

To my family and friends who supported me throughout my study and work. Thank you very much indeed for everything.

And to all people who worry about keeping the environment clean and safe, do not stop this struggle.

Suleiman

ACKNOWLEDGEMENT

I would like to express my gratitude to Professor Terrence Perera as a director of study for setting up the project and for his guidance and patience throughout the research work. Special thanks must go to Professor Sameh Saad for his help during my research as a second supervisor of my work.

My thanks go out to my sponsor the Ministry of Higher Education (Libya).

CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIW OF TECHNOLOGY MANAGEMENT IN DEVELOPING COUNTRIES

CHAPTER THREE: RESEARCH METHODOLOGY

CHAPTER FOUR: HARD TECHNOLOGY IDENTIFICATION AND CRITERIA FOR POWER GENERATION TECHNOLOGY

CHAPTER FIVE: HARD TECHNOLOGY SELECTION, RESULTS AND THE SENSITIVITY ANALYSIS

CHAPTER SIX: TECHNOLOGY INDICAORS, SOFT TECHNOLOGY IDENTIFICATION, AND INTEGRATION OF TECHNOLOGIES FOR POWER GENERATION

CHAPTER SEVEN: THE VALIDATION OF THE MODEL OF POWER GENERATION TECHNOLOGY

CHAPTER EIGHT: CONCLUSIONS AND RECOMMENDATIONS

REFERNCES AND BIBLIOGRAPHY

LIST OF FIGURES

LIST OF GRAPHS

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 General introduction

Technology plays a major role in the world development especially in developing countries. Therefore, management of technology (MOT) is an important and challenging issue in developing countries. Management of technology typically involves integration of different both hard and soft technologies. Some examples of hard technology include special manufacturing tools, power generation technologies, machines, instruments and appliances; mainly machine centred. Soft technology on the other hand is more human-centred. In the main, developed countries appear to have systematic and integrated approaches to the management of technology (Vilaschi, 2004). However, developing countries continue to face challenges in embracing and managing technologies (Li-Hu and Khalil, 2006) and (The unido report, 2001).

1.2 State of technology management in developing countries

According to Hug and Khalil (2004) three countries were under study Nepal, India and Bangladesh, there is a need for technology policy but have failed in varying degrees, there was a problem of appropriateness of policy design and the effectiveness of its implication. In Nepal, there is a lack of indigenous industrial skills and uncoordinated infrastructure. The lack of consistent government policy coupled with inadequate information network create a serious constrain on the identification, selection and technology development. In case of Bangladesh, a serious commitment to technology promotion has been missing despite the declaration in national plans of the need for promoting technological capability in the country. India has made some successful efforts especially in the atomic energy and space sectors. The Indian government has devised various initiatives to promote technological capability building but these efforts do not appear to have been effective and consequently fall short of coordinating the various actors involved in knowledge production and knowledge sharing.

Zhouying (2005) suggested, the economic and technological gap between developed and developing countries can largely be explained by the gaps in levels of soft technology and soft environments between the two sets of countries. Shortage of soft technology experts is the core problem facing the Chinese enterprises. Too few of them know about commercial techniques and business strategy, including translating technologies into commodities that would enable them to coup with the challenges of competition in global market. In Brazil, there was very little cooperation between industry and local universities or training neither organisation, nor the enterprises themselves (Vilaschi, 2004) and (Stacey, 2003).

1.3 Project background and objectives

The above analysis indicates that, there is a lack of considerations of relevant factors that may affect technology management. In most cases, those factors are addressed in isolation and there is a need to develop an integrated solution by means of linking hard technology with soft technology for different industrial organisations at strategic level.

This research work aims to develop a conceptual framework for the management of technology at strategic level in developing countries.

The objectives of this research work are as follow:

1- Conduct an extensive literature review of the technology management in developing countries.

2- Establish key indicators of technology state and technology capabilities which can be used by in policy formulation at national and business levels.

3- Develop a methodology to identify, prioritise and select appropriate hard and soft technologies.

(4) Develop an integrated conceptual framework based on the outcomes of (2), (3) to support the management of technology at national level.

(5) Evaluate the conceptual framework using a questionnaire method related to the proposed model for power generation technology.

1.4 The organization of the thesis

This thesis is structured into eight chapters:

Chapter 2 briefly presents the literature study of the research work in the area of power generation technologies and management of technology for developing countries.

Chapter 3 explains the research methodologies for both soft and hard technologies for power generation for developing countries.

Chapter 4 presents the general model of hard technology identification and some important criteria used to identify the type of hard technology used to generate electricity. Also in this chapter, it is explained the environmental effects of different power generation technologies on the environment. Cost of electrical power generation using different technologies is discussed.

Chapter 5 presents the hard technology selection using the Analytic Hierarchy Process (AHP) and shows some important outcome and the sensitivity analysis of the decision making process for power generation technology prioritise.

Chapter 6 is concerned with technology indicators and the technological capabilities of some developing countries. This chapter also represents some important accepted indicators recognised by international organisations such as UNIDO, UNDP, WB, and IMF to show and monitor the sustainable development in some countries. These indicators help for soft technologies identification related to power generation. Here, also presents the integration of hard technologies with the soft ones. In chapter six, the developed conceptual framework is explained and justified.

Chapter 7 describes the validation of the AHP model of the power generation technologies and how a questionnaire methodology is used to verify the proposed model. Finally the conclusions and recommendations for the power generation technologies are presented in Chapter 8.

CHAPTER TWO

LITERATURE REVIEW OF TECHNOLOGY MANAGEMENT IN DEVELOPMENT COUNTRIES

2.1 Introduction

This chapter discusses some of the previous research work related to different approaches, tools and methodologies of technology management in developing countries.

The first part is focussing on literature review how to help the decision maker in a developing country to decide which technology is most appropriate to generate electrical power taking into account some important criteria. Also, discusses different electrical power generation technologies including forms of fossil fuels and renewable energy methods.

The second part concentrates on the technology management definitions in both forms of hard and soft technologies.

The third part focuses on research of technology management in power generation sector.

The fourth part focuses on the factors related to technology management such as national policies, R&D public and private institutes and their role in the development of different sectors in developing countries. The building of science and technology (S&T) infrastructure and its importance to help to left the technological capabilities of a country.

2.2 Power generation in developing countries

Yildirim and Erkan (2005) studied the growth of population and increasing consumption of electricity exposed countries to build additional power units. Because of the technical and economical differences of the energy sources, generation expansion planning is used to determine the best unit type for the additional capacity.

Costs have always been a very important factor in decision making, in particular for choices between alternative energy sources and electricity generation technologies. Eventually, costs, risks, and benefits of energy source need to be analysed comparison with those of other energy sources and options. Generally, nationally energy policies aim at implementing systems ensuring diversity and security of supply, including various primary energy sources and conversion technologies. The assessment of costs in support of decision making should reflect this policy objective.

The costs of power units consist of two groups: construction cost and operating cost including fuel and, operating and maintenance (O&M) costs. The construction cost is independent of the production quantity, whereas the operating cost depends on the production quantity. The amount of fuel cost changes with fuel type, fuel price and energy conversion technology. In addition to this, the fluctuating fuel price over time influences the variable costs considerably. It is obvious that not only the technical parameters but also the economic parameters affect the determination of the best additional power units. In electricity generating technologies, are the interest rate, escalation rate and discount factor. The economic parameters vary between countries, even between regions, also change with time.

The cost of nuclear unit consists of capital costs, fuel costs, O&M costs, waste related costs and decommissioning costs. The operating cost, which is a variable cost, includes the fuel and O&M costs. Fuel cost is associated with mining of the uranium ore, conversion of uranium, enrichment, conversion to uranium dioxide pellets, loading of the pellets into rods. O&M cost are associated with costs of labour and overheads, expandable materials, regulatory, state fees, ongoing capital additions, and property taxes.

Like the other type of units, the decision of constructing a nuclear unit depends on the long-term and least-cost generation expansion planning (GEP). Candidate unit types compete against each other in the planning. The acceptance of the nuclear unit is heavily related to costs of other unit types as related as the cost of nuclear unit itself. In this study, an acceptable level of the operating cost for nuclear unit is determined by GEP of Turkey's power system. In order to realise this aim, operating costs of nuclear unit is gradually lowered from the level 7.5 cent/kWh to the level of 1.6cent/kWh by utilising four different scenarios.

Nuclear energy is able to compete with other unit types when the operating cost is 2.4 cent/KWh or laser in the case that it is not permitted natural gas, imported coal, fuel-oil and hydraulic capacities to exceed the 35% of total capacity in each period. If the obligatory limits of natural gas, imported coal, fuel-oil and hydraulic are cancelled, it is not able to compete with other unit types even though the operating cost is decreased to 1.6 cent/kWh or laser.

Consequently, in Turkey's power system, nuclear energy is able to compete with other energy sources when the operating cost is less than 2.4cent/kWh. However, this value is generally low when compared with operating costs of existing nuclear units in OWCD countries, therefore it is not realistic.

According to Shata and Hanitsch (2006), the study considered the potential of electricity generation on the east coast of Red Sea in Egypt. Wind characteristics have been analysed based on long-term measured data of monthly mean wind speed of seven meteorological stations along the east coast of Red Sea in Egypt. Numerical estimations using measured wind speeds and frequencies to calculate the two Weibull parameters were carried out and two methods were applied.

A technical and economic assessment has been made of electricity generation from two turbines machines having capacity of (1000 and 600 kW) considered in regions A & B, respectively, using WASP program. The yearly energy output, capacity factor and the electric energy cost of kWh produced by the two different turbines in each region were estimated. The production costs of four stations in Region A was found to be less than 2€ cent/kWh and compared with retail tariff.

The contribution of fossil fuels (oil and natural gas) to electrical production in Egypt accounts for about 79% of total production, while 21% is hydropower. The electricity demand is expected to grow rapidly to meet the large requirements of future projects. Studies showed that there was an additional need of annual electricity generation capacity around 1000MW/year up to 2017.

Finally, the conclusion in this study is that the expected electricity generation costs of 1kWh in four locations of region A along the Red Sea in Egypt is less than 2€ cent/kWh, which is very competitive compared to the actual tariff system in Egypt.

Streimikiene (2004) mentioned that Lithuania has very limited energy sources of its own. The main source of electricity production in Lithuania is Ignalina NPP. Over the last five years, it has generated 80 to 85% of the total electricity production. The anticipated closure of this nuclear power plant in 2010 will decrease the diversification of fuel supply and there is no huge potential for renewable energy use in Lithuania. Only bio-fuel, hydro and wind power can be considered as potential renewable energy sources in Lithuania.

The share of renewable energy sources in the Lithuanian primary energy supply is the lowest among the three Baltic States (Estonia, Latvia and Lithuania), though the trends of development are positive. The Lithuanian national energy strategy adopted in 2002 sets the strategic priorities of Lithuanian energy sector development. One of the main strategic priorities is striving to achieve a share of renewable energy sources in primary of energy supply of 12% by 2010. The price of electricity in Lithuania is about of € 5.8cent/kWh for hydropower power plants HPP's, € 6.4cent/kWh for wind power plants and € 5.8cent/kWh for power plants using biomass.

It is suggested by Silveira (2004), the comparative between 1000 MW combined cycle power plant and 1000 KW diesel power plant and permits some emission and economic output results. The results for pollutant emissions comparison between them respectively came out with 200.139 to 424.019 mg/KWh of carbon dioxide CO2 or 1:2 as a percentage. Taking the second pollutant of sulphur oxides SO2 came out with 0.00 to 826.45 mg/KWh and the third pollutant of NOx came out with 61.87 to 233.02 mg/KWh of Nitrogen Oxides or 1:3.8 times as a percentage respectively. From these three gases comparison, the total emission is 195.504 to 262.67 mg/KWh, or 1:1.3 times respectively. The ecology efficiency (%) is 95.6 to 91.2.

The economic analysis that is the comparison between the electricity production costs came out with 0.053 to 0.15 US $/KWh or the ratio between costs of combined cycle and diesel plant is 1:3 or the electricity generated from the natural gas is cheaper three times than the diesel.

2.3 Technology management definition (hard and soft)

According to Laio (2005), technology management is a process, which includes planning, directing, control and coordination of the development and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organisation. This paper surveys technology management development using literature review and classification of articles from 1995 to 2003 with the key word index in order to explore how technology management (TM) methodologies and applications have developed in this period. This work uses the eight categories of: TM framework, General and policy research, Information systems, Information and communication technology, Artificial intelligence/expert systems, Database technology, Modelling, Statistics methodology, together with their applications for different research and problem domains. Laio suggested that integration of qualitative and quantitative method. The qualitative and quantitative methods are different in both methodology and problem domain. Some articles have presented their TM concepts without a scientific approach, which leads TM methodology to remain at the stage of discussion. Also, he suggested the integration of different technologies, and this integration of technologies and cross-interdisciplinary research may offer more methodologies to investigate TM problems.

According to Linn and Zhang (2000), current approaches to technology management express the need to mange technology systematically from both strategic and operational perspectives. However, considerable ambiguity seems to prevail over the exact way of managing it. This work presents an object-oriented intelligent management system for technology management by using the methodology of Intelligent Engineering. A hierarchical model is proposed to manage the complex and ill-formulated technology management process. The design and implementation for the Intelligent Management System for Technology Management (IMS-MS) using the hierarchical model are described. A meta-system, which serves IMS-TM kernel to manage and control the operation of the system, is presented. This intelligent management system framework has been implemented in a government technology supervision bureau to assist the management of their technology development policy and project management. The implementation has demonstrated the great potential of IMS-TM to enhance the automation, intelligence and integration of technology management.

According to Hipkin (2003), a study described of South African managers' current perceptions of managing technology, and what they envisage for the future. The most significant issues in technology transfer (TT) relate to technology and operations strategy, where assimilation of technology must yield more and improved products. Limited financial resources will restrain technological adoption and expansion. A poorly educated and inadequately trained workforce, characterised by low productivity, will impose further sever constrains. Knowledge management is in its infancy, and will require concerted efforts by managers to create appropriate support frameworks before knowledge can play its rightful role in achieving competitive advantage. Operations and maintenance staff will be challenged to handle new technology with existing systems and procedures. Organisations must take the initiative to use suppliers and networks for a full range of benefits to accrue from new technologies. With South Africa's history, it is perhaps not surprising that managers are divided on the role of the government and politics in business. Those who mistrust political motives seem resigned to accept that the political agenda will not go away.

The findings in this study suggests areas for further research into technology transfer (TT) in developing countries DC's. The high importance scores for maintenance support Leonard-Barton's (1995) assertion that maintenance is one of the most problematic issues in technology management. The results of this study provide a basis for more detailed investigation of the relationship between the maintenance function and TT, particularly as skills and knowledge deficiencies in DC's have a significant impact on maintenance policies and practice.

The role of technology in strategic decision is still ill defined in South Africa, but global forces are likely to pressurise managers to introduce new technologies wherever possible. For the foreseeable future, South Africa will import technology with limited local technical and operational input. This is to be expected in a developing country where research and innovation initiatives are limited, and whose economy is still greatly dependent on technical expertise from abroad.

Li-Hua and Khalil (2006), the workshop report of the US National Research Council (NRC), "MOT" is the hidden competitive advantage bridging "the knowledge and practice gap" between science, engineering and business management. MOT as a field links "engineering, science and management disciplines to plan, develop, implement technological capabilities to shape and accomplish the strategic and operational objectives of an organisation". Enterprises must continue to ensure that the systems responsible for the generation of knowledge and acquisition of new technologies are effective. Knowledge generation is always a key-entry point for effectively managing technology, and must be supported by innovative policy development and an infusion of research funding in the development of new technology.

According to Zhouying (2004), technology came to being when humans first walked on two legs and use their two hands as a tool. Then the technology of making and using artificial tools gradually developed; and with it came the increasing application of human body as a tool, followed by labour-saved technology as popularised in economics. In the recent years, automatic technologies and robotics-based production have been pursued. Thus human beings have, as a result of technology progress, become increasingly separated from the 'human body technology', and technological progress has turned on what is external to human beings - i.e. nature or matter - rather than what is internal to them - i.e. dimensions of the human mind and spirit.

From the point of view of problem-solving, technology is seen as an extension of human abilities reflected through the human body, sense, and consciousness, etc.

With improvements in the level of material civilisation, people have come to care more about the sensate aspects of life, involving sight, sound, taste, smell, and touch; and also the intangible aspects of life. These aspects of human experience are associated with the quality of life particularly in the post-industrial societies. Further trends in technological progress should therefore be driven not merely by the signals of conventional soft-benefit analysis, but rather by the aim improve living and working conditions and to respect human moods, feelings, and morals that have significant bearing on the overall quality of life. These factors relating to the sensate aspects of life are the driving force behind the recent 'softening' of hard technology and the rise of soft technology through the inclusion of values and important service innovation alongside technical considerations in the design of technologies.

It is discussed above the importance of understanding technology in abroad sense, incorporating the range of intangible and psychological dimensions of human life. Technology is, strictly speaking, more than the hardware with which we are more familiar and which has been the focus of most conventional studies. Soft technology includes commercial technology, social technology, cultural technology and LPFE technology. In the course of twenty-first century, the advance of globalisation, the explosion of knowledge, the softening of economy, changes in value systems, the integration of art and science, and the human mission of sustainable development would render the traditional understanding of technology obsolete, and call a shift from a narrowly defined to a broadly defined concept of technology in research and development. This would involve the synergistic application of both hard and soft technologies that would help provide a robust basis for sustainable development.

Zhouyiing (2005) indicated and pointed out the economic and technological gap between developed and developing countries can largely be explained by the gaps in the levels of soft technology and soft environments between the two sets of countries. Shortage of soft-technology experts is the core problem. The problems faced by Chinese enterprises since the early 1980s, following their conversion to the ideals of market economy and their access to the global market, stem from irregularities in the operation of the soft-technology system and prevalence of unfavourable soft environments governing the operation of the system. Although China has an abundance of scientific and technical specialists, too few of them know about commercial techniques and business strategies, including translating technologies into commodities that would enable them to coup the challenges of competition in global market. Take for example, the Zhongguancun Science Park in Beijing, where the correct application of property rights has created a 'bottleneck' for the development of enterprises in the Park. There are more that one thousand intermediary organisations engaging in technical consultations for Zhongguancun enterprises. However, a large proportion of the scientific achievements cannot find a place where they may be transferred despite the fact that many enterprises are thirsty for projects and despite the provision of venture capital looking for 'good projects' every day. A major factor behind this situation is that there is shortage in the supply of soft-technology experts capable of tracking long-term market and technology trends, and understanding market environments (including the law and the management of enterprise). When China shifted from a planned economy to a market economy, it desperately needed the skills of soft-technology experts. Such skills cannot, however, be cultivated completely within the purview of the school education system. Rather they would be expected to evolve through the alternating experiences of success and failure upon exposure of enterprises to competition the open market.

The lack of competitive methodologies and high-technology products in China and developing countries, more generally, is primarily a reflection of shortfalls in the supply of the soft technology and soft environments in these countries. This means that in their endeavour to be on the path of sustainable development, developing countries should not seek to simply copy developed countries by adopting whatever the developed countries have done and are doing. Neither should they place too much emphasis on the 'highness' and 'newness' of hard technology, nor be limited to the short-term objective of 'striving for temporary superiority and enjoyment of the temporary satisfaction' (as the old Chinese adage has it). They should rather seek to beat a well-grounded pathway of development drawing balance between soft technology and hard technology and recognising the criticality of soft technology and soft environment for the achievement of competitive performance in an ever-changing global market place.

2.4 Research of technology management in power generation sector

Widiyanto (2004), the set of nine energy alternatives includes conventional and new energy technologies of oil fired, natural gas fired, coal fired, nuclear power, hydropower, geothermal, solar photovoltaic, wind power and solar thermal plants. Also a set of criteria for optimized selection includes five areas of concern; energy economy, energy security, environmental protection, socio-economic development and technological aspects for electrical power generation.

However as the complexity of the problem increase due to the inclusion of objectives, the extension of model brings about more complexity in mathematical formulation, and creates a tedious computational process, which tends to reduce analysis efficiency.

An exception to the situation is the model that based on matrix operation, such as the Analytic Hierarchy Process (AHP), that has been proven to be practicable for solving complicated and elusive problem in many decision areas. However, this model was applied in far more problems which involved qualitative elements, as opposed to quantitative, that play an essential role in the decision problem. There was a need to develop a relatively simple mathematical formulation method for solving complicated and elusive multi attribute decision problem, as in the AHP.

The method should be able to take any number of decision variables, without reducing its computational efficiency. The DBA (Distance Based Approach) method proposed in their work was one such attempt to accomplish these requirements. In the work there were twenty three attributes drawn from the set criteria of the five areas of concerns.

The result of the model application using data related to power expansion in Japan demonstrated that, once a complete set of criteria for energy system selection, along with a set of alternatives and their levels of attribute are laid out, an effective justification process around multi attribute decision model DBA can be performed, not just a general analysis, but also other various focused analysis regarding his or her personnel preferences. Literally, the decision maker has unlimited choices in exploring the influences of different sets of attributes to the final decision.

As the result of the analysis, it came out with the natural gas option has the best numerical score followed by nuclear, oil fired, hydropower, coal fired, wind power, solar thermal , geothermal, and solar PV. The findings validate the effectiveness of the model, that even though it employs a relatively simple mathematical formulation and straight-forward matrix operation, it is capable of solving complex of multi-attribute decision problems, incorporating both quantitative and qualitative factors. The usefulness of this model, however, can only be ascertained through extensive field testing, followed by further refinements.

According to Kitz and Glaspey (2005), the moderate temperature (140 to 146°C) geothermal field at Raft River in the state of Idaho, United States was extensively explored and drilled during the 1970s. Total depths of the production wells, which are mainly vertical, are 1520 to 1980m. By the early 1980s, production and injection wells had been tested many times and an experimental 5MW binary power plant was installed and in operated briefly to demonstrate the feasibility of power generation at Raft River. But the project was abandoned because of two major technological barriers at that time to commercial power production from this resource. The well was too cool to allow self-flowing for routine production, but down hole geothermal pump technology had not become routine by the early 1980s. The second, the resource was too cool for cycle power plants, which were the only plants commercially available at that time. Therefore, an experimental binary cycle demonstration power plant was used at Raft River, with disappointing results.

Fortunately, both down holes pump technology and binary power generation are no longer technological barriers; and are routinely used today in commercial power projects. The field is now being developed for commercial power generations.

Even with a conservative set of assumptions it could be concluded that it should be possible to supply a 10MW (net) power plant at Raft River using binary-cycle power conversion and down hole submersible pumps if only 3 of the existing production wells can be restored to their full productivity by working them over. If all 5 wells can be made fully productive, it should be possible to supply a 17MW (net) power plant by either deepening the pump setting with time, or drilling up to 3 make-up wells over a 20-year project life, or a combination of these options. In this case, one to three new injection wells will need to be drilled.

A 30 MW (net) plant capacity is likely to be supportable by 9 to 10 production wells and 7 to 9 injection wells, including the existing wells refurbished for production or injection.

Wong (2006) studied and updates the Pembina Institute's 2001 publication. A Comparison of Combustion Technologies for Electricity Generation, republished in 2004 in power for the future: towards a sustainable electricity system in Ontario.

The electricity generation technologies examined included the following:

- High efficiency coal combustion technologies: Pulverised Coal Combustion (PCC), Atmospheric Fluidised Bed Combustion (AFBC), Pressurised Fluidised Bed Combustion (PFBC) and Integration Gasification Combined Cycle (IGCC).
- "End-of-Pipe" or add-on pollution control options for coal such as Flue Gas Desulphurisation (FGD), Low NOx Burns (LNB), Selective Catalytic or Non-Catalytic Reduction (SCR/SNCR), Electrostatic Precipitators (ESP) and Bag houses.
- Natural Gas-fired options: Natural Gas Combined cycle (NGCC) and Combined Heat and Power.

The review concluded that none of the coal-fired options are as environmentally favourable as the natural gas-fired options. Among the coal-fired options, IGCC showed the best opportunity for environmental performance, although it still has high CO2 emissions relative to natural gas-fired options.

The review also noted that IGCC technologies may theoretically be combined with carbon capture and storage (CCS) technologies. However, the review concludes that carbon storage options for Ontario are unproven and speculative, and that, given the extent of the research required demonstrating their viability, they can not be considered a series possibility within the current 20-year electricity policy planning horizon.

The plant efficiency (%) for the different Coal combustion (PCC) is about 33% but the Natural Gas Combined Heat and Power is around 52 to 60 %.

The overall cost to produce Electricity ($/MWh) is about 42.45 and 48.54 for the Coal combustion (AFBC) and Natural Gas Combined Cycle (NGCC) respectively.

The emissions of CO2 (kg/MWh) is about 1000 and 350 for the Coal Combustion (PCC) and the Natural Gas Combined Heat and Power Cycle (NGCHP) respectively.

According to Kannan & Osman (2005), Life cost assessment (LCA) and Life cycle cost analyses (LCCA) models were developed and the life cycle energy, emissions and cost inventory was established for potential power generation technologies in Singapore. Power generation from clean/renewable power generation technologies are costlier than fossil fuel based power generation. However, their low environmental impacts can compensate for unfavourable economics if environmental externalities become an accepted paradigm in appraisal. Unfortunately, a reliable externality cost estimates is not yet established and path to assessing externalities is still fraught with difficulties and uncertainties.

Considering limited potential for renewable energy sources in Singapore, power demand can be reduced through energy efficiency measures instead of catering to increasing power demand. Energy efficiency will be effective regardless of the future power supply scenario. However, it is not easy task as there are many barriers to implementing energy-efficient technologies. Making changes in traditional economic evaluation are important to the adoption of energy-efficient technologies on the demand side. If the costs of energy efficiency measures are compared with clean/renewable based power generation technologies instead of market electricity price, some transition barriers can be overcome.

Therefore, implementing policies with a mix of financial incentives and disincentives and direct investment in energy efficient technology would be an effective strategy for Singapore. Consumer education and supportive political/regulatory environment are vital in this context.

Fetescu (2003) suggested the usage of gas turbine technology and cycle selection have a major impact on the economic performance of combined cycle power plants projects. The main objective of this paper is to investigate decision criteria and their relative importance in the selection of gas turbine technology and cycle configuration. The levelised cost of electricity (LevCoe) is a simplified tool for comparing power generation technologies using the cost of generation criteria based on PV (present value) models for capital, fuel and O&M costs. Using input data as defined, it provides the total LevCoe and the contribution split: capital, O&M and fuel costs.

LevCoe allows comparison and ranking of alternative generation technologies. LevCoe is not size dependent and allows comparison of different technologies without imposing the same capacity.

Graus (2007) mentioned the international comparisons of energy efficiency can provide a benchmark against which a country's performance can be measured against that of other countries. The results can be used to determine potential energy savings and greenhouse gas emission reduction potentials.

Energy-efficiency analyses for power generation on a country level have been performed in the past, but few recent studies are available. Furthermore benchmarks for overall fossil-fired power generation are not available.

The analysis aimed to make a comparison of the efficiency of fossil-fired power generation (coal, oil and natural gas). For this purpose, specific benchmark indicators are developed for natural gas, oil and coal-fired generations efficiencies. These indicators are aggregated to a benchmark for fossil-fired generation efficiencies.

The countries evaluated in this study were Australia, China, France, Germany, India, Japan, Nordic countries (Denmark, Finland, Sweden and Norway aggregated), South Korea, United Kingdom and Ireland, and United States. Together these countries generate 65% of world wide fossil power generation.

The results of the study showed that the efficiency trend for coal, gas and oil-fired power production, respectively, for the period 1990—2003.

The energy efficiencies for coal-fired power generation range from 30% for India to 42% for Japan in 2003. The average efficiency of the countries is 37% and the weighted average efficiency is 35% in 2003.

For gas-fired power generation, the efficiencies range from 39% for Australia to 52% in 2003. The average efficiency for gas was 46% and the weight average was 45% in 2003.

For oil-fired power generation, the efficiencies range from 30% for India to 45% for Japan in 2003. The average efficiency for oil was 37% and the weighted average efficiency is 38% in 2003.

For overall fossil-fired generation, the efficiencies range from 32% for India to 43% for United Kingdom and Ireland and Japan in 2003.

According to Breeze (2005), at the beginning of the twenty-first century, the new power plant offering the cheapest source of electricity appears to be the gas-fired combined cycle power station. It is cheap and quick to build and relatively easy to maintain. The fuel is the most significant determinant of electricity price, so while gas is cheap, so is electricity. There are some other factors such as the effect of power production on the environment and on human health, factors which society pays for but not the electricity producer or consumer directly. These factors are called externalities.

A major study carried out by the European Union (EU) and the USA over a decade in the 1990s estimated that the cost of these externalities, excluding the cost of global warming, were equivalent to 1-2% of the EU Gross Domestic Product.

The cost of electricity in the EU in 2001, when the report of the study was published, was around €0.04/kWh. These figures indicate that coal combustion costs at least.

The economics of the gas turbine plant are complex. Even so, many planners assume that is currently the cheapest cost option, quoting a generation cost of around $0.03/kWh. This figure depends on a number of assumptions, particularly discount rate over the life time of the plant.

A recent challenge to conventional thinking put the generating cost in the range $0.05-$0.07/kWh. That would make some renewable sources cheaper. Even so, there was no evidence yet for a waning in the popularity of the gas turbine for power generation.

Power production cost from first generation the Proton-Exchange Membrane (PEM) fuel cell systems of $0.10/kWh had been suggested.

The cost of electricity from a hydropower plant will depend on the cost of building and financing the project and on the amount of electricity it generates when operating. For recent hydropower projects built by private sector with loans repaid over 10-20 years, initial generating costs have been in the range $0.04-0.08/kWh. However once the loan has been repaid the costs drop dramatically. The typical range of generation costs is $0.01—0.04/kWh but may easily fall below $0.01/kWh. This is cheaper than any other source of electricity.

The cost of tidal power generation would be a $0.41/kWh. In this case the plant was intended to replace power generated using diesel engines, which is an expensive source. However, even with a renewable energy credit, the project was judged too expensive.

When electrical power generation from wind power is to be considered, the energy cost depends on the amount of wind available at a particular site. Generating costs, operating costs and some external costs will determine the total cost of electricity generated by the wind power.

Taking these factors into account, favourable estimates suggest that at the beginning of the twenty-first century modern onshore wind farms could generate electricity for €0.03/kWh at a wind speed of 10 m/s and €0.08/kWh at a wind speed of 5 m/s. Early commercial offshore wind farms generate power for between €0.05/kWh and €0.08/kWh.

In common with many renewable resources, geothermal power generation involves a high initial outlay but externally low fuel costs.

Some figures from the World Bank show that for the costs of development of geothermal projects for different qualities of geothermal resources, a good resource has a temperature above 250° C, and good permeability so providing good fluid flow. The World Bank estimates suggest that power can be produces from a large geothermal power plant (>30MW) exploring a good quality resources at between $0.025 and $0.050/kWh.

Solar thermal and solar photovoltaic power plants share a number of features such as short deployment times and additional benefits from dispersed deployment that affect the cost and value of both technologies. However the technologies themselves have different roots and the costs associated with them have to be considered separately.

The cost of solar thermal power to generate electricity at around \$0.11—0.12/kWh but for solar photovoltaic power generation, electricity probably costs around \$0.25/kWh. This can be competitive with the peak power costs in somewhere like California but is way above the cost of base-load power, \$0.025—0.050/kWh.

2.5 Factors effecting technology management (R&D, S&T, Policies, TNC, FDI, Innovation systems)

According to (Huq, 2004), the study included three countries (India, Nepal and Bangladesh), it indicates that the challenges facing technology policy in low-income developing countries. The three countries see the need for technology policy, but have failed, albeit in varying degrees, to establish an effective policy regime that would pave the way for sustainable development. However, the benefits of technology policy derive not merely from the statement of its need in plan and policy documents, as is apparent from the experiences of many developing countries, but rather from the appropriateness of policy design and the effectiveness of its implication.

The main points that emerge from the analysis of the state of technology development in Nepal, are the lack of indigenous industrial skills and inadequate, and uncoordinated infrastructure. The lack of consistent government policy coupled with inadequate information networks also created a serious constraint on the identification, selection and development of technologies. The lesson that can be drawn from Nepal's experience is that a conscious policy effort would be needed to improve the infrastructures that would enable the development of indigenous technological capability on the back of technologies transferred from elsewhere.

The significance of infrastructure provision for science and technology (S&T) development is illustrated by the experiences of India's successful industries in the atomic energy and space sectors. The difference between India's successful and lagging industries is that the successful ones, unlike the laggards, exhibit clarity of mandate of their goals and 'sustenance of their functions over a long period of time along with integration of R&D generation and its use. The Indian government has devised various initiatives to promote technological capability building. However, these efforts do not appear to have been effective because they represent a bureaucratic solution to the problem and consequently fall short of coordinating the various 'actors' involved in knowledge production and knowledge sharing.

In the case of Bangladesh, a serious commitment to technology promotion has been missing despite the declaration in the national plans of the need for promoting technological capability in the country. Where Bangladesh has failed miserably with respect to technological capability building is in the implementation of policy. But as in the two other countries considered in this study, technology policy in Bangladesh will also need to evolve within the broad framework of a national innovation system.

The experiences of developing countries show not only market failure when it comes to the task of building technological capability, but also government failure in providing relevant policies. This is apparent from the three cases discussed above. In exploring the way forward, developing countries are faced with the challenge of promoting the involvement of the private sector in R&D activities, while recognising the role of governments in coordinating the direction of research.

The experience of South Korea is particularly instructive in this respect. While the government has helped in building the training and skill base and in providing some useful S&T institutions, R&D development in the private sector has been actively promoted. The government of South Korea took the responsibility of promoting indigenous technological development by establishing the necessary S&D infrastructure, providing funds of R&D and at the same time strongly encouraging private firms to undertake R&D activities. Thus state participation is needed to correct shortfalls in the supply of investment funds for R&D activities; it does not follow that the state will necessarily have to engage itself in the operation and management of R&D projects. It is however essential that the S&T infrastructure is significantly strengthen by coordinating activities of the existing institutions and also by adding, as required, some new ones. This is the process in which the national system of innovation would be expected to evolve as a basis for capacity building and technological capability development in developing countries.

Technological policy that is destined to promote enterprise culture, R&D and innovation initiatives will ultimately enable developing countries to produce global competitive players in various areas of economic activity. On the other hand the failure of policy to address local problems in the context of development in the wider global economy will see low-income countries locked in to the vicious circle of poverty. It is in this light that the opportunities and threats of globalisation facing developing countries and the case of the technology policy and the role of the state in these countries- will need to be considered.

Villaschi (2004) mentioned that throughout the 1990's, Brazil followed economic policies enshrined in the virtues of market mechanism and considered by international organisations such as the international mechanism fund (IMF) and the World Bank.

This followed a period when the government played a crucial role in the industrial and leapfrogging of economy through the implementation of industrial and technological policies. The work had examined results of the shift from a strategy of economic development based on the role of the state to a strategy based on the role of the market. The evidence of improvement in industrial capabilities was particularly apparent in the performance of firms that faced foreign competition in the internal market.

However, there has been a little or no improvement in innovation capabilities. In most of the arrangements examined, product development occurred through imitation of international and local industries' leaders, and process improvements, through the acquisition of the new machinery. There was very little cooperation between industry and local universities or training organisations; nor between the entrepreneurs themselves. If a country were to embark on 'path creation' for its increased participation in the globalisation process, policies would need to promote activities in the knowledge and learning economy such as education, science, technology and industrial development. Factors that account for competitive advantages such as cheap labour, raw material and protected internal markets, which were important for late industrialisation under the Fordist techno-economic paradigm, might be helpful if the aim is to play a secondary role in global production networks. But they were irrelevant where the aim was increased participation of a country in the new economy and society based in cooperation, knowledge and learning.

According to Lall (2004), the strongest impression conveyed by this analysis was of growing diversity and divergence in manufacturing performance. The study showed how wide dispersion was in the industrial sector, how it had grown and how it reflected structural factors. Such factors notoriously difficult to alter in the short to medium term, and, because of cumulativeness, could not be left to reverse them selves by further liberalisation. Thus, they raised strong policy implications.

The other important lesson was that there were 'many roads to heaven'. Successful developing countries had used widely differing strategies to build capabilities. Some, but relatively few, had succeeded with 'autonomous' strategies, drawing in foreign technology largely at arm's length while building strong technological and innovative capabilities in local firms. Others, a large number, had gone some way by plugging into trans-national companies (TNC) production systems by becoming suppliers of labour-intensive products and components, without having strong domestic capabilities. Of these economies, a few had managed to combine their reliance on foreign direct investment (FDI) with strong industrial policy, targeting the activities they wish to enter and the functions they wish to upgrade into. The less successful developing countries had not followed any of these strategies effectively. Autonomous countries are opening up to FDI to access new and expensive technologies, while FDI-reliance countries were trying to build local R&D capabilities, often by inducing TNCs to upgrade technological activity. Local capabilities become more important to link with international resources and leverage them, and building capabilities was a difficult strategic challenge.

The industrial world also showed similar strategic differences in reliance on R&D and FDI. For advanced economies, the difference between the two strategies was of little practical significance today. FDI and domestic R&D were for them largely complementary: technological leaders draw upon foreign firm to provide specialised forms of technology and foreign firms draw upon the feed into domestic innovation. Technological followers were integrated into large systems; some establish independent areas of technological competence, while others remained as production bases.

At first sight, the best strategy for latecomers without strong technological capabilities appeared to battle their way into TNC production systems and let local capabilities develop slowly. This may not be true in the future. Industrial latecomers entering integrated production systems may found it difficult to sustain growth as wages rise unless they raised their skill and technological bases.

In general, developing countries need new, focused and 'intelligent' strategies for linking to global markets, leveraging foreign technologies and skills, and learning from their links. The value of strong linking and leveraging strategies was illustrated by the experience of the Asian newly industrialising economies; these could be adapted to the needs of the rest of the developing world. However, strategy also had to be industry-specific. Each industrial value chain differed in its organisational, technological, logistical and institutional needs. As local value chains became integrated into global chains, the nature, structure and strategies of the key player in each becomes important.

According to Malairaja (2004), the emergence of Malaysia from an agriculture-dominated economy to one based on high-tech manufacturing in the space of three decades owes its explanation largely to the country's increased participation in the global economy through the mechanisms of trade, investment and technology transfer. Foreign direct investment (FDI) by multinational corporation (MNCs) from the United States of America, Europe and Japan and international joint ventures (IJVs) had played a significant role in enabling the country to acquire capital and technologies and enhance its competitive performance to a level that would establish it as one of the world's leading manufacturers and exports of a wide range of electronic products.

The contemporary trend in the rapid globalisation in knowledge production and knowledge sharing had increased the significance of technology transfer to developing countries as a potential mechanism for learning and achieving innovative competitiveness.

Following the coming into effect of the new science and technology policy in 2002, there was a growing awareness in Malaysia about the importance of innovation as the key for the sustainable growth of the economy and for the international competitiveness of Malaysian firms. The new S&T policy regime would require existing technology transfer practices and mechanism to be reviewed within the framework of the Malaysian national innovation system (NIS). But the Malaysian NIS had itself yet to evolve as a robust basis for innovation and S&T initiatives. It was therefore important for policy to address questions about the demand for and supply of technologies and skills and also about options of capacity building to remove the constraint on innovation due to institutional and organisational fragmentation. In the developing world, policies should be directed at facilitate and strengthening links between institutions (government), research institutes and private firms in the context the Malaysian national innovation systems. The university-industry-government relationships should always be tight and improve mechanism and networks for effective implementation of technology transfer initiatives. This required the provision of adequate venture capital and infrastructure support like science parks, incubators and manpower training schemes to stimulate the development of technological capabilities at enterprise level.

According to Aubert (2004), the policies supporting technology development were known as "innovation policies". Although governments had a long such practice of promoting innovation by various measures of both direct and indirect nature, the explicit formulation of innovation policies began about 40 years ago in the 1960's.

Since then such policies had been expanded and improved, while new analytic concepts, such as the concept of "national innovation system", had been elaborated.

2.6 Conclusions and comments

People from developing country are always worried about the limitations of resources such as clean water, food to eat, clothes to wear and etc... As the author comes from a developing country with limited resources (Libya), this generated a conservative personality of me. After reading a lot of papers, books, magazines and articles (economic and technical) and specialised in the field of mechanical engineering for my first degree. A bell is always ringing in my mind and this question was always in mind 'can a man make a machine or engine without pollution and dark smoke'. When my care increased and the idea of optimising thoughts about economy and reading a lot about linking engineering and how knowledge can help human to control the surrounding environment around him. Technology management is found to be the answer to link limited resources, science and knowledge, engineering, economic aspects, health, employments and information, and communication technologies together. Man on earth can not live without electricity because the daily life of everybody depends on machines, lighting, heating, transports, communication with some others needs. All equipments mentioned above require electrical energy to operate. By looking back to the research work done in this field (power generation section), a little work is carried out regarding the optimisation and filtration of hard technologies in developing countries. The previous work focused on a single comparison of few technologies together of the same type such as coal with different grades of it. No doubt most of developing countries are short of resources (economic and financial). Due to the increase of population, more electrical energy is needed to satisfy this demand. Also some research is considering the hard technology alone and not paying attention to soft technologies. The integration of hard and soft technologies is important and crucial in the field of power generation and in previous work is always neglected.

Taking into account the above problems for developing countries, the short fall of most governments in developing countries to developing a successful technology policy and a conceptual framework for power generation, it is decided to focus on developing such framework to help decision makers and draw the guide lines to optimize and prioritise of a power generation hard technology option for developing countries and integrating them with soft technologies.

CHAPTER THREE

RESEARCH METHODOLOGY

3. Introduction

The main intention of this chapter is to outline the most common types of research methods available in literature survey and to discuss the research design and methodology. The chapter concentrates on the main methodologies that can be possible to use in business management research. The research approach and strategy, sample size, data collection method, data analysis, and tests for model validation is also discussed.

3.1 Understanding of research

Although research is central to both business and academic activities, there is no agreement in the literature on how it should be defined. One reason for the problem is that research means different things to different people and organisations. However from many different definitions offered, there appears to be agreement that:

- Research is a process of investigation and enquiry.
- It is systematic and methodological.
- Research increase knowledge.

The investigations must be thorough and rigorous at all stages of the research process. If the research is to be conducted in an efficient manner and make the best use of the opportunities and resources available, it must be well organised. If it is to provide a coherent and logical route to a reliable outcome, it must be conducted systematically using appropriate methods to collect and analyse data (Collis and Hussy, 2003).

3.1.1 Types of research

Choosing a research strategy is a significant role in business and management research. A research strategy could be viewed as providing the overall way of the research including the process by which the research is conducted (Remenyi et al., 1998). Different understanding of research by different people leads to different types of research. Table (3.1) below by Collis and Hussey (2003) classified the types of research fall into many parts, for example the purpose of the research (why are we doing the research), the process of research (the way in which data can be collected and analysed), the logic of the research (which can be moving from general to specific or vice versa) and the outcome of the research (whether can be trying to solve a particular problem or make a general contribution to knowledge).

Table (3.1) Classification of main types of research by Collis and Hussey (2003)

Types of research	**Basic of classification**
Exploratory, descriptive, analytic or predictive research	Purpose of the research
Quantitative and qualitative research	Process of the research
Deductive or inductive research	Logic of research
Applied or basic research	Outcome of the research

3.1.2 Purpose of the research

The normally asked question is the (why are you doing it?).

People in general and students in particular conduct research for different reasons such as ‘I love the subject, I want to be intellectual, I have a personal question I want to answer, I want to be a member of the research community, I haven’t been able to get a job, employers want people with this qualification, all my friends are do it, it's part of my course and I want to be creative and useful'.

3.1.2.1 Descriptive research

Descriptive research normally illustrates and describes phenomena as they exist. It is used to identify and provide information on the characteristics of a particular issue or problem. The collection of data is often quantitative and statistical techniques are usually used to summarise the information. Descriptive research tests problems in more depth than exploratory research (Collis and Hussey, 2003).

3.1.2.2 Analytical or exploratory research

It is a continuation of descriptive research where the researcher goes beyond merely describing the characteristics, to analysing and explaining why or how it is happening. Thus, analytic research aims to understand phenomena by discovering and measuring causal relations among them. For example, information maybe collected on the size of companies and levels of labour turnover. Analytic research attempts to answer such questions as:

- How can we reduce the number of complaints made by customers?
- How can we improve the delivery times of our products?
- How can we expand the range of our services?

An important element of explanatory research is identifying and, possibly controlling the variables in the research activities, since this permits the critical variables or the causal links between characteristics to be better explained. A variable is an attribute of an entity that can change and take different values which can be observed and/or measured.

3.1.2.3 Predictive research

It goes further than explanatory research and it aims to generalise from the analysis by predicting certain phenomena on the basis of hypothesised, general relationship. For example, predictive research attempts to answer such questions as:

- In which city would it be most profitable to open a new retail outlet?
- Will an introduction of an employee bonus scheme lead to higher levels of productivity?
- What type of packaging will improve the sales of our products?
- How would an increase in interest rates affect our profit margins?

Thus, the solution to a problem in a particular study will be applicable to similar problems elsewhere, if the predictive research can provide a valid, robust solution based on a clear understanding of relevant causes. Predictive research provides ‘how’, ‘why’ and ‘where’ answers to currents events and also to similar events in the future.

3.2 Process of research

Whatever the type of your research or approach is adopted, there are several fundamental stages in the research process are common to all scientifically based on investigations (the way the data can be collected and analysed).

3.2.1 Quantitative and qualitative research

Collis and Hussey (2003) indicated that quantitative research could be objective nature that focuses on assessing phenomena to provide measured results. It aims to collect and examine numerical data by using statistical methods. On the other hand, qualitative research can be more subjective in nature and can contain investigative and reflecting on perceptions to get an understanding of social and human actions.

"Qualitative data is in the form of descriptive accounts of observations or data that is classified by type. On the other hand, quantitative data is that data which can be expressed numerically of classified by some numerical value". Since quantitative data is in the form of numbers, it can frequently be examined using standard statistical methods, such as test validity (Lancaster, 2005). Techniques can be used to collect data in a case study consisting of documentary analysis, interviews and observations. In addition, it uses many methods for collecting data that could together be quantitative and qualitative. It is usually most excellent to merge data collection processes such as archive searching, interviews, questionnaires and observation. The proof might be qualitative (e.g. words), quantitative (e.g. numbers) or both (Collis and Hussey, 2003).

Therefore, the methodology used in this research was based mainly on quantitative and some qualitative data, which enables in depth of analysis of the research problem.

3.2.2 Choosing sample size

The first question new researchers tend to ask is "how many people should I speak to?" This obviously depends on the type of research. For large scale, quantitative surveys you will need to contact many more people than you would for a small, qualitative piece of research. The sample size will also depend on what you want to do with your results.

If you want to produce large amounts of tabulations, the more people you contact the better.

(Dawson, 2009) the rule tends to be general in quantitative research that the larger the sample the more accurate your results. However, you have to remember that you are restricted by time and money- you have to make sure that you construct a sample which will be manageable. Also, you need to account for non-response and you may need to choose a higher proportion of your research population as your sample to overcome this problem. In this research work, the author used the literature survey to collect data for all the criteria and sub criteria for all the nine hard power generation technologies. These data are in the form of quantitative data to help in developing the proposed framework for power generation in developing countries. Finding data for different criteria of hard technologies in developing countries was a difficult task to do and instead data were collected from developed countries and exposed to sensitivity study to conform requirement by developing countries in power generation sector. Regarding the validation of the proposed model, thirty envelops were sent containing sixty questionnaires to different power plants in the UK and another eighteen were distributed in Libya for different power plants. This large sample size of questionnaires was decided to avoid the problem of non- responding and its explained in details in chapter seven.

3.3 Logic of research

Whether you are moving from the general to the specific or vice versa? Research is normally conducted where there is really a problem to be studied and solved.

3.3.1 Deductive and inductive research

Deductive research is a study in which a conceptual and theoretical structure is developed and then tested by empirical observations; thus particular instances are deducted from general inferences. For this reason, the deductive method is referred as moving from general to the particular.

Inductive research is a study in which theory is developed from the observation of empirical reality; thus general inferences are induced from particular instances, which is the reverse of deductive method.

3.4 The research stages

The diagram illustrated in figure 3.1 below shows the traditional and highly structured view of the research process. This model also presents research as a neat, orderly process, with on stage leading on to the next. However, this is only a general for conducting research but in real life, research may be different according to the nature of the topic.

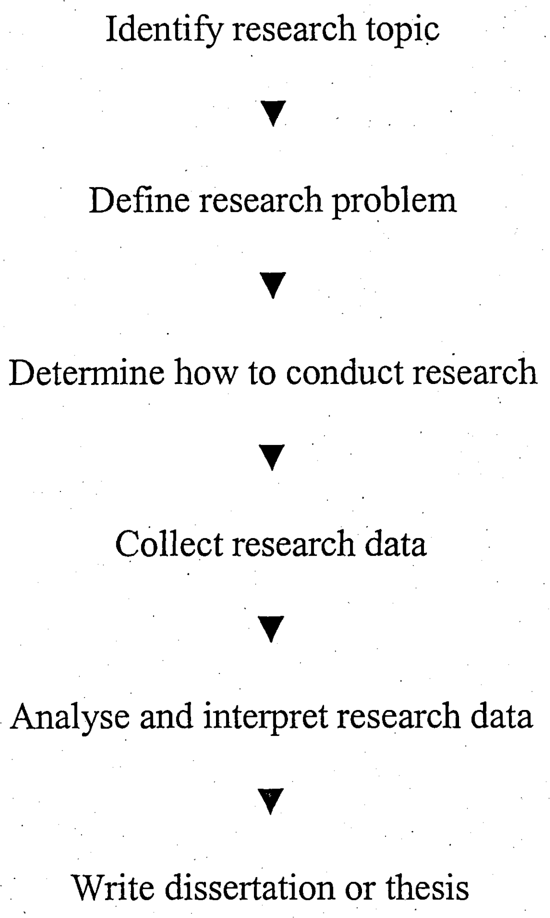


Figure (3.1) General stages in research life cycle, Collis and Hussey (2003)

3.5 The research methodology

After conducting the literature survey for developing countries for different sectors, it has become clear that resources are very limited in developing countries and mostly consumed in building new power generation facilities. There is a big gap between developed and developing countries in taking decisions of optimising and prioritising the selection of power generation technologies. Most of previous studies concentrated in comparing two or three hard technologies in isolation of the rest, and sometimes putting generation technologies from the same family under study and investigation (fossil fuels power generation technology or renewable power generation technologies). No body has before studied and developed a conceptual framework for power generation technologies in developing countries. Most sources of information (previous) did not consider the soft technologies as an important factor for power generation. The third criticism here the author wants to include is that, from literature survey there was not any mentioning of integration between hard and soft technologies in power generation sector. In addition to these reasons, the author sees that all international organisations try to help developing countries by giving general outlines advices and not specific and clear strategy to overcome the problem of selecting power generation technology.

3.5.1 Elements of proposed framework

Here in this work, the research has been divided into three main categories that are hard technology, soft technology and the integration of hard with soft technologies.

3.5.1.1 Hard technology selection

Based on the literature review for the sector of power generation (supply side), the hard technologies option is identified and discussed. These technologies are classified by means of the fuel used. These are coal fired power generation, oil fired power generation, gas fired power generation, hydropower generation, geothermal power generation, nuclear power generation, wind power generation, solar photovoltaic power generation and solar thermal power generation (Breeze, 2005). Some hard technologies are excluded and filtered as explained in section 4.10.2. According to Collis and Hussey (2003) the word literature refers to every source of published data.

The aim of literature research is to discover as many items of data as possible; he listed some sources of data:

- Books
- Articles in journals, magazines and newspapers
- Conference papers
- Reports
- Documents
- Published statistics
- Businesses, annual reports and accounts
- Newspapers
- Organisations, inside records
- Electronic database
- The Internet

3.5.1.2 Soft technology selection

Based on the literature review for the sector of power generation requirement, the soft technologies are identified related to different hard option. These soft technologies are classified according to their importance and the demand of hard technology selection. These soft technologies are communication and coordination, research and development, health and safety programs, information and communication technology (ICT), knowledge transfer to power sector, training programs, financial resources, local area network, county legal approvals, linking national planning council, management teams and power generation watchdog (Zhouying, 2005). These soft technologies are identified and explained in details in chapter six. Due to the shortage of information about soft technologies, technology indicators recognised and accepted by international bodies were used to help to identify the soft technologies for power generation sector.

3.5.1.3 Integration

After the selection of both hard and soft technologies took place, the limitation of hard technologies option was identified for different technologies. One of the technology management approaches is the integration of different main players such as hard and soft technologies (Linn, R. J, Zhang, W., and Li, Z, 2000). A matrix table for the priority of soft technologies was developed according to importance of soft technology for the hard option selection and its presented in table (6.8). The next step forward is the integration process between hard and soft technologies in order to get the hard technology working as can be seen by fig. (6.1).

3.6 Main criteria for power generation

Before any selection of hard technology can take place, it is based on some crucial criteria and sub-criteria affecting the selection of hard technology. From the literature review, the main criteria are the cost, plant life, the requirement, dependency, safety, pollution and development. There are some sub-criteria branched from the main criteria. These are capital cost, fuel cost, maintenance & operation cost, land used, water needed, people, foreign participation, local participation, noise level, physical discomfort, psychological discomfort, global warming, air pollution, thermal pollution, technology development and industrial development (Widiyanto, Kato, and Maruyama, 2004).

3.7 AHP model for power generation sector

Analytic Hierarchy Process AHP (Saaty, 1980) would be used to identify and prioritise the criteria and sub criteria and also to enhance and support the selection of the power generation hard technology in developing countries. The analytic hierarchy process (AHP) is very powerful multi-criteria tool for helping the decision makers to reach the right decision in many situations especially in power generation sector where the decision is so crucial. Before building the proposed model, the significant criteria and sub criteria are clearly identified and determined. The goal of the model should be clearly identified as well to be able to build this model. Sometimes this model is called the tree view of model. AHP software is based on pair-wise comparison between criteria and sub-criteria at the same level and they have got to be added to unity. The software can generate a block diagram connecting the goal with different criteria and sub-criteria together as shown in figure 4.2.

The AHP is a generic theory of measurement. It is a technique that can be employed to establish measures in both the physical and social fields (Saaty, 1988). The AHP method that was developed by Saaty (1980, 1990 and 1994) uses a process of pair-wise comparisons to determine the relative importance and thus the priority of alternatives in a multi-criteria decision making problem. It includes decomposing a complex and unstructured problem into a set of variables into another set that are organised into a hierarchy (Chow and Luk, 2005). Chin et al., (2002) illustrated that AHP is a powerful approach in solving fuzzy and complex decision problems. In addition, Saad and Grindy (2007) indicated that AHP could be useful for decision making process by allowing decision makers to evaluate the significance of objectives (criteria) and finding alternatives. For more than two decades, AHP may be studied as part of the curriculum includes techniques of decision making in the faculties of engineering and business.

AHP is a problem-solving framework and a systematic procedure for representing the elements of any problem (Shahin and Mahbod, 2007). Udo explained that the AHP technique has been adopted in many applications such as business performance evaluation, project selection, auditing, public policy, marketing, health care, transportation and many other areas (Udo, G., 2000).

The AHP approach is constructed generally from the three essential steps (Shahin and Mahbod, 2007).

These three steps are:

1- Start structuring top down and then determine first objective criteria and alternatives that affect the goal.

2- Comparison analysis, once the hierarchy has been structured, the second step is to identify the ratio of the priorities in the hierarchy.

3- Total local weights to the priorities of this compound is the last step, through the principal of the hierarchic composition that first multiplies local weights by the product of all higher level priorities. Within the hierarchy of this process turns local to global loads measured the importance of each held in a pyramid. Then, the alternative with the highest composite weight is selected.

3.7.1 Justification of using the AHP

According to Zanakis et al (1998) several have been found for solving multi-attribute decision making problems (Madm). Different methods might give different results when applied to the same problem. They examined the performance of eight methods: ELECTRE, TOPSIS, Multiplicative Exponential Weighting (MEW), Simple Additive Weighting (SAW), and four versions of Analytic Hierarchy Process (AHP). SAW was selected as the basis to compare the other methods, because of its simplicity makes it used a lot by practitioners. Generally, all AHP versions behave similarly and close to SAW than other methods. Mohanty and Venkataraman (1993) indicated that the advantages of AHP over other methods is that, it is designed to deal with tangible as well as non-tangible criteria, especially those in which the subjective judgements of persons constitute an important part of the decision process.

The author would like to point out and justify the following reasons for using the AHP in this research program:

1- The AHP model is a structured method to find the preferences of managers and decision makers in an easy and understandable way (Saaty, 2000., Yang, 1997).

2- The AHP model encourages the process of learning and database (Vries, 2006).

3- The hierarchical structure of the model provides decision makers with possibility to decide whether criteria at all levels of the same system (Yang, 1997).

4- Several commercial software packages based on the AHP approach is available (e.g. Expert Choice).

5- By means of using AHP model, it is possible to verify the model consistency options.

6- AHP model can be used to as a tool to reach group consensus (AL-Subhi and Al-Harbi, 2001).

7- The AHP model is a robust model compared to other multiple criteria decision models (Santana, in Salomon, 2001).

8- AHP can deal with different types of data in many ways, such as the merging of intangible with tangible data. (Vargas and Saaty, 1981; Calantone et al.,1999).

9- The AHP model combines together qualitative and quantitative factors in an included decision-making framework and can be considered as a helpful tool for difficult making processes. It reduces complex decisions to a series of one to one comparison (Vries, 2006).

10- AHP allows a number of persons and groups to share equally in the decision-making process. It can also provide an important link for developing trust and true group participation (Shahin and Mahbod, 2007).

3.8 The validation of model

After the AHP proposed model was developed that is linking the goal of the model with the criteria and sub criteria which determines the selection and prioritising of the hard power generation technology for developing countries. The results of the proposed model are discussed in chapter five and the results are shown in table (5.1) and fig. (5.1). The sensitivity analysis was conducted to check the impact of the changing the criteria and sub criteria on the final selection of the hard power generation technology and that is presented in tables in chapter five.

Also, the pair wise comparison is computed using the AHP software and the results are explained in details and presented in table (5.2) and fig.(5.2).

Now the moment was come to check the validity of the proposed model of power generation technology. Before we started the validation process, it was essential to collect a qualitative data to examine the model from the real world of power generation plants that will reflect the actual comparison of different criteria and sub criteria. A questionnaire technique was chosen to consult people working in power generation sector in the UK and Libya. This validation methodology and processing is explained in details in chapter seven.

CHAPTER FOUR

HARD TECHNOLOGY IDENTIFICATION AND CRITERIA FOR POWER GENERATION TECHNOLOGY

4.1 Introduction

In this chapter, it is focused on electricity generation industry in general and its importance for developing countries. Also here, the evolution of generating electricity methods is followed throughout the years and how different technologies are developed from simple reciprocating engine to nuclear power technology.

The aim of this chapter is to identify different hard technologies suitable for power electricity generation (appropriates) for developing countries and to build a model to select the hard technologies. Nine electricity generating technologies have been explained along with their costs and environmental effects. This chapter includes tables to show the size of different technologies around the world, some hard technologies are determined and some other technologies are eliminated from the model. Some important criteria are selected and some sub-criteria are chosen too to help to clarify and build the model.

4.2 Electricity generation

Electricity defines the modern world. Everything that we think about modern, from electric lambs, through radio and television to other home appliances, electronic devices, computers and all other of the information age equipment depend on electricity for their operation and working.

Today the people of developed countries take electricity for granted while those of under developed countries and regions yearn for it. The supply of electricity is both an expensive and complex process. Increasingly, electricity has become a security issue. While people apart from modernity can still live their lives without electricity, a modern industrial nation depends on its electricity supply.

This research work is primarily based on the ways of generating electricity. The transporting and delivering it to those who wish to use it. Nor does it treat, except obliquely, the political issues that attach them selves to the supply of electricity. What it does attempt, is to provide an explanation of some ways that man has devised to produce this most elusive of energy forms (Breeze, 2005).

4.3 The evolution of electricity generation technologies

The earliest power stations used reciprocating steam engines to generate power. These engines were not ideal for the purpose because they could not develop the high rotational speeds required to drive a generator effectively. This difficulty was eventually overcome with the invention of a steam turbine by Sir Charles Parson in 1884. Fuel for these plants was normally coal, which was used to generate steam in a boiler.

Hydropower also entered the power generation mix at an early stage in the development of the industry. Much of the key work of different turbine types using to capture power from flowing water was carried out in the second half of the nineteenth century.

By the beginning of the twentieth century both the spark ignition engine (petrol engine) and diesel engine had been developed. These two were used for generating electricity. Before World War II work had also begin in the use of wind turbines as a way of generating electrical power. But until the beginning of 1950's, steam turbine power stations burning coal, and sometimes other fossil fuels, together with the hydropower stations, provided the global power generation capacity.

In the 1950's the age of nuclear power technology was born. Once the principal was established, construction of nuclear power stations accelerated fast. It was widely thought was a modern source of energy for the modern new age; it was cheap, clean and technically exciting.

Nuclear power continued to expand quickly in the USA up to the late 1970's. In other parts of the world, uptake was slower but Great Britain, France and Germany invested heavily. In the Fare East, Japan, Taiwan and South Korea worked more slowly. Russia developed its own plants and India began a nuclear program, as did China.

From the end of 1970s the brightness of nuclear industry began to tarnish. Since then its progress has slowed practically in the west. In Asia, however, the dream remains alive for a longer time.

At the beginning of the same decade, in 1973 to be precise, the Arab-Israeli war caused a major increase in world oil prices rose dramatically. By then oil had also become a major fuel for power stations. Countries that were burning it extensively began to look for new ways of generating electricity and interest in renewable energy sources began to take place.

The stimulus of rising oil prices led to the investigation of a wide variety of different energy technologies such as wave power, hot-rock geothermal hot-rock power and the use of ethanol derived from crops instead of oil. However, the main winners among these technologies were solar and wind power.

Development took a long time but by the end of the century both solar and wind technologies had reached a stage where they were both technically and economically vital. There was considerable reason to hope that both would be able to contribute significantly to the electrical power generation mix in the twenty-first century.

One further legacy of the early 1970s that began to be taken into account in the electricity industry during the 1980s was a widespread concern for the environment. This imposes the industry to implement wide-ranging measures to reduce environmental emissions from fossil fueled power plants. Some other power generation technologies such as hydropower were also affected too.

The gas turbine began to make a big impact during the1980s as an engine for power stations. The machine was perfected during and after the Second World War as an aviation power unit but soon transferred to the power industry for use in electrical power plants supplying peak demand.

During the 1980s, the first large base-load power stations using both gas turbines and steam turbines, in a system known as combined cycle plant, were built. This configuration has become the main source of new base-load generating capacity in many countries where natural gas is available.

On the start of the twenty first century, it has seen renewed emphasis on new and renewable sources of electricity. Fuel cells are technically advanced but can be considered an expensive source of electricity, are approaching commercial viability. There is renewed interest in deriving energy from oceans, from waves and sea currents, and from the heat of tropical seas. Offshore wind farms have started to spread around the shores of Europe.

The story of the twenty-first century is likely to be the challenge between these new technologies and the old combustion technologies for dominance within the power generation industry (Breeze, 2005).

4.4 The size of the industry

How big is the electricity industry? Tables in this chapter provide the answer. The first table shows the amount of electricity generated across the global in 2000. Production is broken down in the table both by region and type.

Gross electricity generated in 2000 was 14,618 TWh. This is equivalent to roughly 1,670,000 MW power stations running continuously for a year. In fact, the actual global installed capacity in 2000 was over twice that, 3,666,000 MW.

When generation is broken down by type, thermal generation is seen to be biggest. This category refers to power generated from coal, oil or gas. These three fuels were responsible for 9318 TWh, 64% of electricity generated in 2000. Hydropower was the next most important source of generation, providing 2628 TWh (18%) with a nuclear power a close third (2434 TWh, 17%).

Table (4.1) World electricity production (TWh, 2000)

	Thermal power	Hydro	Nuclear & other	Geothermal	Total
North America	2997	658	830	99	4584
Central & South America	204	545	11	17	777
Western Europe	1365	558	849	75	2847
Eastern Europe & former USSR	1044	254	266	4	1568
Middle East	425	14	0	0	439
Africa	334	70	13	0	417
Asia and Oceana	2949	529	465	43	3986
Total	9318	2628	2434	238	14,618

Source: US Energy Information Administration,

Table (4.2) World electricity generating capacity (GW), 2000

	Thermal power	Hydro	Nuclear & other	Geothermal	Total
North America	662	176	110	17	965
Central & South America	68	115	3	3	189
Western Europe	360	147	128	14	648
Eastern Europe & Former USSR	299	80	49	0	428
Middle East	97	4	0	0	101
Africa	82	20	2	0	104
Asia and Oceana	684	171	70	5	930
Total	2252	713	362	39	3366

Source: US Energy Information Administration

By region, North America produced the largest amount of electricity in 2000, followed by Asia and Oceana. The most striking regional figure is that for African production, 417 TWh or less than one-tenth of North America. Central and South America also has low output, 777 TWh. If one wants to identify the poorest region of the world, one needs to look no further than table 4.1.

Table 4.2 provides values for the actual installed generating capacity which existed across the globe in 2000. The figures here broadly mirror those in first table, but there are one or two features to note.

Firstly, global nuclear capacity is only half that of global hydropower capacity but contributes almost as much electricity. This reflects the fact that hydropower plants can not run at 100% capacity throughout the year because they depend on a supply of water and rain fall and this will vary from season to season. Nuclear power plants, by contrast, work best if they are always operated flat out.

Secondly the gross capacity, 3366 GW has twice as much generating capacity as is required to generate the electricity in table 4.1, if every station was running flat out all the time. Clearly many plants are working at less than half capacity. There will be spare capacity in many regions of the world which is only called on during times of peak demand.

It might be seen that, as both tables indicate, Central and South America rely on renewable source, hydropower, for the majority of their electricity. In every other region of the world, thermal power plants are dominant. The composition of the world's power generating capacity is not likely to remain static. New types of generation technologies are becoming ever more competitive and these can be expected to prosper as the present century advances. Renewable technologies, in particular, will advance as environmental concerns and the cost of fossil fuels restrict the use of thermal power stations (Breeze, 2005) and (Zhang, et al., 2005)

4.5 The environmental considerations

The power generation industry, taken as a whole, is the biggest industry in the world. As such it has the largest effect of any industry on the conditions on earth. Some of the effects, particularly the ones associated with the combustion of fuels (fossil), are far-reaching both geographically and temporally (Neij, 2008).

Awareness of the dangers associated with this and other aspects of power generation has been slow to but since the 1997s a series of events have provided graphic evidence. Acid rain during the 1980s; nuclear disasters such as Chernobyl in 1986 in Ukraine; critical reviews of large hydropower projects in the 1980s and 1990s; the recognition of the dangers of global warming during the 1990s; the ever-present haze that has blighted many of the world's cities for 20 years and more: at the end of the twentieth century concerns for the environment were major international issues.

As a consequence of this, environmental concerns are beginning to shape and affect the power generation industry. This is an effect that will continue throughout the coming decades of the twenty-first century.

There are environmental considerations which relate to each different type of power generation technology. These are considered concerned in turn, in conjunction with the technologies, this work has taken into account the environmental factor which is so important in deciding the selection of the power generation technology (Breeze, 2005).

4.5.1 The evolution of environmental awareness

Man has always changed his or her surroundings. Some of those changes we no longer even recognised; the clearing of forests to create the agricultural farmlands of Europe for example.

Similar changes elsewhere are more obviously detrimental to local or global conditions. Tropical rain forests grow in the poorest of soils, and to clear them and the ground is of very little use. Not only this, but the removal of forest cover can lead to erosion, and flooding as well as the loss of ground-water. Most of these effects are negative.

Part of the problem is the increasing size of the human population. Where native tribes could survive in the rain forests in Brazil, the encroachment of outsiders has led to their erosion.

A similar effect is in power generation. When the demand for electricity was limited, the effect of the few power stations needed to supply that demand was small. But as demand has risen, so has the cumulative effect. Today that effect is of such a magnitude that it can not be ignored.

Consumption of fossil fuel is the first example. Consumption of coal has grown steadily since the industrial revolution. The first sign of trouble resulting from this practice was the ever-worsening pollution in some major big cities. In London the word smog was invented at the beginning of the twentieth century to describe the terrible clouds of fog and smoke that could last for days. Yet it was only in the 1950s that legislation was finally introduced to control the burning of coal in the UK capital.

Consumption of coal still increased but with the use of smokeless fuel in cities and tall stacks outside, problems associated with its combustion appeared to have been solved. That is until it was discovered that forests in parts of northern Europe and North America were dying and lacks were becoming lifeless. During the 1980s the cause was identified; acid rain resulting from coal combustion was to blame.

By the end of the 1980s scientists began to fear that the temperature on the surface of the earth was gradually rising. This has the potential to change conditions everywhere. Was this a natural change or manmade? Scientists did not know.

As studies continued, evidence suggested that the effect was, in part, at least, manmade. The rise in temperature followed a rise in the concentration of some gases in the atmosphere. Chief among these was carbon dioxide. One of the main sources of extra carbon dioxide was the combustion of fossil fuels such as coal.

If this is indeed the culprit, and it would appear prudent to assume that it is, the consumption of fossil fuel must fall, or measures must be introduced to remove and secure the carbon dioxide produced. Both are expensive. It has now become one of the main challenges for governments all over the world to reduce the amount of carbon dioxide being released into the atmosphere without harming their economies.

The way in which fossil fuel is used in power generation is gradually changing as a result of these discoveries and the legislation that has accompanied them. Other technologies also face challenges. Nuclear power is considered by some to be as threatening as fossil fuel combustion. Hydropower has attracted bad publicity in recent years, but should still have an important part to play in future power generation. Meanwhile there are individuals and groups prepared to go to almost any lengths to prevent the construction of wind farms which they consider unsightly (Neij, 2008).

4.5.2 The environmental effects of power generation

Most human activity has an effect on the environment and, as already mentioned above, power generation is no exception. Some of these effects are more seriously harming than others. The atmospheric pollutions resulting from coal, oil and gas combustion have had obvious effects. But combustion of fossil fuel releases a significant amount of heat into the environment, mostly as a result of inefficiency of the energy conversion process.

Power stations have a physical presence in the environment. Some people will consider this a visual intrusion and invasion. Most make noises, another source of irritation. There are electromagnetic fields associated with the passage of alternating currents through power cables. A power plant needs maintaining, servicing and often needs supplying with fuel. That will generate traffic and disturb.

Clearly some of these effects are more far-reaching than others. Even so, the local effects of a power station may be a significant issue for the immediately adjacent population. Deciding what and how much weight must be given to such considerations when planning future generating capacity can be a fearsomely difficult issue. It is the big issues, however, particularly global warming which may have the most significant effect of the future of power generation (Breeze, 2005).

4.5.3 The carbon cycle and atmospheric warming

The combustion of fossil fuels such as coal, oil and natural gas releases significant quantities of carbon dioxide into the atmosphere and environment. Since the industrial revolution the use of these fuels has accelerated. The consequence appears to have been a gradual increase in the concentration of carbon dioxide within the earth's atmosphere.

Before the industrial revolution, the concentration of carbon dioxide in the earth's atmosphere was around 270-280 ppm. Between 1700 and 1900 there was a gradual increase in atmospheric concentrations but from 1900 and onwards the concentration changed more rapidly as shown in the table (4.3).

From 1900 to 1940 atmospheric carbon dioxide increased by around 10 ppm, from 1940 to 1980, it increased by 32 ppm and by 2000 it had increased by a further 30 ppm. By then the total concentration was found to be 369 ppm, an increase of over 30% since 1700.

Table (4.3) The atmospheric carbon dioxide concentrations

Year	Carbon dioxide concentration (ppm)
1900	293
1940	307
1980	339
2000	369
2050	440--500
2100	500--700

If the increase in carbon dioxide concentration is a direct result of the combustion of fossil fuel then it will continue to rise until combustion is stopped or better treated. Estimates of future concentrations are at best speculative but the above table includes a range of estimates for both 2050 and 2100. The worst case in the table shows concentrations doubling in 100 years.

There is further warning. While the evidence of a fossil fuel concentration with the increase in concentration of carbon dioxide is compelling, the cycling of carbon between the atmosphere, the sea and the biosphere is so complex that it is impossible to be certain how significant the manmade changes are the main cause.

The atmospheric emissions of carbon from human activities such as the combustion of coal, oil and natural gas amount to a total of around 5.5 G tonnes each year. While this is a big figure, it is tiny compared to the total carbon content in the atmosphere of 750 G tonnes.

This atmospheric carbon is part of the global carbon cycle. There are roughly 2200 G tonnes of carbon contained in vegetation, soil and other organic material on the earth's surface, 1000 G tonnes in the ocean surfaces and 38,000 G tonnes in deep oceans.

The carbon in the atmosphere, primarily in the form of carbon dioxide, is not static. Plants absorb atmospheric carbon dioxide during photosynthesis, using the carbon as a building block for new molecules. Plant and animal respiration on the other hand, part of a natural process of changing fuel to energy, releases carbon dioxide into the atmosphere. As a result there are probably around 60 G tonnes of carbon cycled between vegetation and the atmosphere each year while a further 100 G tonnes is cycled between oceans and the atmosphere by a process of release and reabsorption. Thus the cycling of carbon between the atmosphere and the earth's surface is a complex exchange into which the human contribution is little.

The real significance of the additional release of carbon dioxide resulting from human activity depends on the interpretation of various scientific observations. The most serious of these relate to a slow increase in temperature at the earth's surface. This has been attributed to the greenhouse effect, whereby carbon dioxide and other gases in the atmosphere allow the sun's radiation to penetrate the atmosphere but prevent heat leaving, in effect acting as a global insulator.

If human activity is responsible for global warming, then unless carbon dioxide emissions are well controlled and eventually reduced, the temperature rise will continue and may accelerate. This will lead to a number of major changes to the global conditions. The polar ice caps will melt, leading to a rise to sea level which will flood many low lying areas of land. Climate conditions will change. Plants will grow more quickly in carbon dioxide rich surroundings.

Not all of scientists agree that changes in our practices can control the global changes. There have been large changes in atmospheric carbon dioxide concentrations in the past and large temperature fluctuations. It remains plausible that both carbon dioxide concentration changes and global temperature changes are part of a natural cycle and that the human contribution has no big influence.

It may be impossible to find absolute conclusive proof to support one argument over the other. If human activity is responsible, the change may become irreversible. Besides, it is clear that combustion of fossil fuels creates more carbon dioxide than would naturally have been available (Breeze, 2005).

4.6 Why power generation technology?

It is very well known that lack of access to clean water sanitation is a problem which affects a vast number of people. This issue is addressed in many ways. Firstly, by those focusing on local, simple technology and secondly by those who place technology within a wider context.

A water source normally ignored is municipal and industrial water. This has, as the name suggests, largely gone to waste until now.

According to R, Heeks, the technology alone is not enough. Long term strategies for operation and maintenance must be viable and this means that beneficiaries must participate in the introduction and use of technologies so that they accept responsibility and feel ownership of the projects. Where political objectives or power conflicts intervene-as they often do- the project may well fail, whatever the nature of the technology used.

The differentiation of approach between the purely technical and that with a wider agenda is also found in the decision of energy. Energy use in developing countries lies far below that for the industrial world- 63 kg of oil equivalent per capita in the least developed countries in 1990 compared with 4937 kg in the North countries. As a result, it is the Northern nations which make by far the greatest contribution to CO2 emissions (and some other environmentally damaging outputs). Nevertheless, energy use is growing faster in the South as well, and there is a desire that energy should be produced in a way that is sustainable (Heeks, 1995).

4.7 Different types of power generation technologies

There is no doubt that the essential need for human beings, is fresh drinking water, food and electricity to drive and provide all machines and equipment around him which are essential for human survival. In this research work, it is decided to concentrate on power generation technologies selection of the hard technology for developing countries. This work is going to take into account most of the significant criteria which may effect the electrical generation technology selection.

4.7.1 Coal fired power technology

Coal is the world's most vital and most widely used fuel for generating electricity. According to the World Energy Council, it provides 23% of total global primary energy demand and 38% of electricity production. Total world production of coal in 1999 was 4,343,151,000 tonnes and utilisation was 4,409,815,000 tonnes.

The importance of coal is reinforced by national statistics from the main global consumers. In the USA, coal fired plants produce 51% of the nation's power. This dominance is expected to maintain well into the twenty-first century. In China, coal fired stations were generating 65% of the electricity in 1988, and by the beginning of the twenty-first century 75% of the county's electricity came from fossil fuel, mostly coal. In India too, fossil fuel, once more primary coal, accounts for around 71% of installed capacity.

The major attraction of coal is its abundance and availability. Significant deposits can be found in most parts of the world, from USA to South Africa, across Europe, in many parts of Asia and in Australia. Exceptions exist, such as Japan and Taiwan, where resources are limited; these countries import huge quantities of coal. Among the continents, only South America and Africa-outside South Africa- have limited reserves.

According to the World Energy Council's 2001 Survey of Energy Resources, the proved recoverable world resources bituminous coal, sub-bituminous coals and lignites amounts to 984,453 M tonnes. (Anthracite, the hardest coal, is hardly ever used for power generation when alternatives are available). Figures for these reserves, broken down by coal type and by region, are shown in the table (4.4).

Figures for proved reserves, such these are in table (4.4), reflect the extent to which a resource has been surveyed rather than offering a measure of the real amounts of coal that exist. Potential reserves greatly exceed the identified reserves, and estimates of the latter are usually conservative. At current consumption levels, proved reserves of coal can continue to provide energy for at least 200 years..

Coal is the cheapest of fossil fuels, another reason why it is attractive to power generators. However it is costly to transport, so the best site for a coal-fired power plant is close to the mine that is supplying its fuel.

Coal is also the dirtiest of the fossil fuels, producing large quantities of ash, sulphurous emissions, nitrogen oxide (NOx) emissions and carbon dioxide, and releasing significant concentrations of trace metals. As a result the combustion of coal has been accountable for some of the worst environmental damage, barring accidents, created by heavy industry anywhere in the world.

In consequence, coal has developed an awful environmental image. But developments since the 1980s aimed at controlling emissions from coal-fired plants, combined with new coal burning technologies, mean that a modern coal-fired power plant can be built to meet the severe environmental regulations, anywhere in the world. Techniques for capturing sulphur, nitrogen emissions and ash are well established. The next challenge is to develop cost effective ways of removing and storing carbon dioxide, for of all fossil fuels, coal produces the major quantity of this greenhouse gas.

Recent coal-fired power plants, with emissions-control systems, are more expensive than the older style of plant common before the mid-1980s. Even so, coal remains the cheapest way of generating power in many parts of the globe. Whatever the environmental constrains, the fuel will continue to offer a substantial proportion of the world's electricity for much of the coming century (Rao.et.al., 2003) and (Breeze, 2005).

Table (4.4) The Proved global coal reserves

	Bituminous (M tonne)	Sub-bituminous (M tonnes)	Lignite (M tonnes)	Total
Africa	55,171	193	3	55,367
North America	120,222	102,375	35,369	257,966
South America	7738	13,890	124	21,752
Asia	179.040	38,688	34,580	252,308
Europe	112,596	119,109	80,981	312,686
Middle East	1710	--	--	1710
Oceania	42,585	2046	38,033	82,664
Total	519,062	276,301	189,090	984,453

Source: World Energy Council, Survey of Energy Resources 2001.

4.7.2 Gas turbine and combined cycle power plants

The gas turbine has seen a recent and dramatic rise in popularity within the power generation industry. Until the end of the 1960s gas turbines were almost entirely the preserve of the aviation industry. During the 1970s and 1980s they began to find favour as standby and peak power units because of their facility for quick start-up. It was during the 1990s, however, that they became established, so that by the twentieth century the gas turbine had turned out to be one of the most widely used prime movers for new power generation applications-both base load and require following-virtually everywhere. It has been suggested that gas turbines could account, for example, for 90% of new capacity in the USA in the next few years.

A number of factors contributed to this change in fashion. Deregulation of gas supplies, particularly in Europe and the USA, and the fast expansion of the natural gas networks have increased the availability of gas while conspiring to keep prices of natural gas low. More and more severe emission-control regulations have pushed up the cost of coal-fired power plants making relatively pollutant-free natural gas look more attractive. Power sector deregulation has also contributed, by attracting a new type of generating company seeking quick returns. Gas turbine based power stations can be built and commissioned tremendously rapidly because they are based around standardised and often packaged units and the capital cost of gas turbines has fallen steadily, making it cost-effectively attractive to these companies.

The most important factor, however, has been the development of the combined cycle power plant. This configuration, which combines gas and steam turbines in one unit power station, can provide a cheap, high capacity, high efficiency power generation unit with low environmental emissions. With net conversion efficiencies of the largest plants now around 50 %, and with manufacturers claiming potential efficiencies of 55% or more in plants incorporating their latest machines, the combined cycle plant provides power generating companies with a product that seems to promise the best economic and environmental performance that technology can currently offer.

This unreserved popularity has occasionally led power generating companies into difficulties. In the UK, for example, there was a significant move towards gas fired combined cycle power plants during the 1990s. New market regulations introduced at the end of the decade led to market fall in electricity cost and meant that combined cycle plants could no longer generate power economically.

Gas turbines are cheap to make but the fuel they burn, normally natural gas, is relatively expensive. The economics of gas-based generation is therefore extremely sensitive to both electricity and to gas prices. Gas turbines can burn other fuels distillate or coal bed methane for example. However, the modern one is based on natural gas and it is upon this their continued progress will rest (Stopatto, 2008) and (Breeze, 2005).

4.7.2.1 Natural gas

The switch from coal-and oil fired power plants to natural gas-fired plants has become a global event. This can be seen in gas production and consumption statistics. World Energy Council Figures indicate that the production of natural gas grew by 4.1% between 1996 and 1999. In China gas use increased by 10% in 1999 and in the Asia Pacific region the increase was 6.5 %. Africa consumption has increased by 9.1%.

Globally the USA was the largest consumer of natural gas in 2001 according to the US Energy Information Administration (EIA) followed by Russia, Germany, the UK and Canada respectively. Russia and the USA, meanwhile, were the main producers, sharing between them 44% of annual production in 2001. They were followed by Canada, the UK and Algeria as the fifth producer.

In Europe gas usage is expected to increase significantly during the next twenty years. According to Euro gas, consumption will rise from 332 million tonnes of oil equivalent (mtoe) in 2000 to 471 mtoe in 2020, a rise of 42%. Europe's principle users in 2000 were the UK, Germany, Italy, France and the Netherlands. Of these only the UK and the Netherlands produce a significant quantity of gas. The other countries import the majority of the gas they consume.

Of course not all of this gas is consumed in power stations, but a significant proportion of it is. In the USA, for example, power generation along with their costs and environmental effects a along with their costs and environmental effects accounted for around 20% of natural gas in 2001. As already noted, the driving forces behind the increasing popularity of the fuel gas within the power industry are economic. Natural gas produces lower levels of atmospheric pollution than either coal or oil when it is burnt. That includes sulphur dioxide, nitrogen oxide (NOx), hydrocarbon particulates and carbon dioxide. Thus it is easier to meet emission regulations with a gas-fired power plant if compared with a plant burning either coal or oil.

The gas industry is keen to promote the idea of gas as a clean fuel, but critics would argue that its use is at best a sto-gap. A sustainable energy future should rely on renewable sources of energy and gas is not renewable. More importantly, the supply of gas available in the world is limited and will run out.

Table (4.5) The proved recoverable natural gas resources

	Reserve (billion m3)	Estimated reserve life (years)
Africa	11,400	69
North America	7943	9
South America	6299	63
Asia	17,101	52
Europe	53,552	58
Middle East	53,263	>100
Oceana	1939	46
Total	151,502	58

* The Russian federation contributes 47,730 billion m3 to this total.

Source: World Energy Council

The above table (4.5) shows that current proven reserves are expected to last for around 60 years at current levels of consumption.

It also shows the estimated recoverable natural gas reserves from different regions of the world, based on numbers collected by the World Energy Council for its 2001 Survey of Energy Resources. As these figures illustrate, Europe and the Middle East have the largest proven recoverable reserves of gas. (Note: however, that most of the European reserves are located in the Russian Federation.)

North America and Western Europe are taxing their known reserves highly. At 1999 rate of gas production, proved reserves in the USA would be exhausted in 9 years. However, the estimated reserves remain enormous so this is no immediate cause for concern. Western Europe, the Netherlands and Norway all have extensive reserves remaining. Other countries proven reserves are in a similar or worse situation to that in the USA. Indeed Western Europe is to rely increasingly on imports from Russia and Algeria, to maintain its supplies of gas. From an energy security perspective, this could become a risky situation in the future (Wong, 2006) and (Breeze, 2005).

4.7.2.2 Natural gas costs

The use of natural gas to produce electricity depends crucially on the cost of the gas. Natural gas is a more expensive fuel than coal, the other major fossil fuel used for power generation. However the capital cost of a coal fired power plant is significantly higher than that of a gas-fired power station. Hence the total fuel bill over the lifetime of each plant determines whether coal or gas can produce the cheapest electricity.

Utility gas prices are often closely related to the price of oil, though deregulation of the gas industry has weakened the link in some countries such as the UK. One reason for this link is that many gas-fired power plants can easily be fired with oil and would switch to oil if natural gas became more expensive. This fixes an upper limit on the cost of natural gas. (It is worth noting, however, that while some gas-fired steam plants can burn oil, gas turbine require distillate which is more expensive. Even so, most gas turbine plants are designed for dual fuel using gas or oil.)

Table (4.6) The global gas prices for power generation ($/GJ)

	1997	1998	1999	2000	2001	2002
Finland	3.06	2.87	2.58	2.7	2.61	2.61
Germany	3.78	3.51	3.35	3.66	--	--
Taiwan	6.10	5.23	4.83	5.88	5.86	--
UK	2.94	3.01	2.75	2.51	2.65	1.94
USA	2.63	2.25	2.44	4.11	4.42	3.42

Source: US Energy Information Administration.

Table (4.6) collects annual prices of gas for power generation from a handful of countries between the years 1997 and 2002. These give abroad indication of how costs differ across the globe. The finished prices in the above table are remarkably stable over the 6 year period, whereas in the UK, prices fluctuate much more. However, the USA showed the largest range of prices, with the cost of gas for power generation soaring in 2000 and 2001. Such volatility can play havoc with power generation economics.

Where gas supplies are narrow or non-existent the possibility exists to import liquefied natural gas (LNG). LNG costs more than piped gas when the cost of liquefaction, transportation and regasification are taken into account. This is illustrated in the above table (4.6) with gas prices for Taiwan which are consistently the highest quoted. Even at such a high price, LNG has proved attractive to countries like Japan, Taiwan and South Korea. In 1999, a 25% of exported natural gas was in the type of LNG. Of this 75% was transported to the Asia Pacific region (Beer, 2007) and (Breeze, 2005).

4.7.2.3 Gas turbine technology

A gas turbine is a machine which harnesses the energy contained within a working fluid - either kinetic energy of motion or the potential energy of a gas under pressure - to generate a rotary motion. In the case of gas turbine this fluid is usually, but not necessarily, air. The earliest manmade device for harnessing the energy of moving air was the windmill, described by Hero of Alexandria in the first century AD.

The early windmill was a near comparative of today's wind turbine. Closer in concept to the gas turbine was the smoke jack, developed in the middle of the second millennium. As described in the seventeenth century by John Wilkins, later Bishop of Chester, the smoke jack used hot air rising through a chimney to move windmill vanes and drive a shaft which could be used to turn a spit for roasting meat.

The principle of harnessing moving air to create rotary motion for driving machinery was developed further during the industrial revolution. Following this principle, the nineteenth century saw a number of predecessors to the gas turbine. These used some form of compressor to generate a flow of pressurised air which was fed into a turbine.

The direct ancestor of the recent gas turbine was first outlined in a patent granted to German engineer F. Stolze in 1872. In Stolze's design, as in that of all modern gas turbines, an axial compressor was used to generate a flow of high pressure air. This air was then mixed with fuel and ignited (combustion), creating of flow of hot, high-pressure gas fed into a turbine. Significantly the compressor and the turbine were mounted on the same shaft.

Whereas the gas turbine supplied with pressurised gas from a separate compressor must inevitably rotate provided it has been designed correctly, the arrangement patented by Stolze need not necessarily do so. This is because the energy to operate the compressor which provides the pressurised air to drive the turbine is produced by the turbine itself. Thus unless the turbine can generate additional work than is required to turn the compressor, the energy for this being provided by the combustion of fuel that produce the hot gas flow to drive the turbine - the machine will not work. This demands extremely efficient compressors and turbines. Both need to operate at high efficiency of around 80%. In addition, the turbine must be able to accommodate very hot inlet gases in order to derive enough energy from the expansion of flow gases. Only if these conditions are met, the turbine will operate in a continuous manner.

The first machine, which could run in a continued fashion, was built in Paris in 1903. This, though, did not have a rotary compressor on the same axis as the turbine. That honour fell to a machine built by Aegidus Elling in Norway and operated later in 1903. In Elling's machine the inlet temperature of gas was 400° C.

Development of the gas turbine continued throughout the early years of the twentieth century, the aim remaining to generate either compressed air, rotary motion for industrial usage. Then, around the 1930s, the potential of the gas turbine to provide the motive force to flight was re-organised and aircraft with jet engines based on the gas turbine were developed in Germany, the UK and in the USA. This led, in turn, to modern aircraft engines that power and support the world's airline fleets.

During the 1970s and early 1980s gas turbines began to find a limited application in power generation because of their ability to start up quickly. This made them valuable as reserve capacity, brought into service only when grid demand came close to available capacity. These units were based on the aero-engines from which they were derived but by the late 1980s bigger, heavy gas turbines were under development. These were proposed solely for power generation (Fetescu, 2003) and (Breeze, 2005).

4.7.2.4 Environmental impact of gas turbine

One of the primary advantages of gas turbines is they produce relatively low pollution, at least compared with coal fired power plants. In the developed countries of the world where emission control became a high profile issue, this has had a significant effect on the choice of technology for novel generation capacity.

Most gas turbine power plants burnt natural gas which is a clean fuel. Gas turbines are extremely sensitive to levels of impurities in the fuel, so fuel derived from other sources, such as gasification of coal or biomass, must be widely cleaned before it can be burnt in a gas turbine.

Even so, gas turbines are not entirely benign. They can produce considerable quantities of NOx, some carbon monoxide and small amounts of hydrocarbons. Of these, NOx is generally considered the biggest problem.

4.7.2.5 Cost of the gas turbine power stations

In 1994 a report commissioned by the Centre for Energy and Economic Development set the capital cost of a new combined cycle power plant to be built in the USA after the year 2000 at US$ 800/KW. In 2003 the US, EIA estimated the overnight cost of a US combined cycle plant in 2001 which would commence generating power in 2005 to be US$ 500 to 550 /KW. The simple cycle combustion turbine cost US$ 389/KW, the EIA estimated.

It is difficult to obtain actual gas turbine costs because competition is severe and manufacturers are loath to release prices. The only real basis of data, therefore, is the available contract prices for actual projects (Neij, 2008).

Table (4.7) The combined cycle power plant costs

	Capacity (MW)	Cost (US$ million)	Cost/KW (US$)	Start up
UK (Teesside)	1875	1200	640	1993
Bangladesh	90	100	1110	1995
India (Jagurupadu)	235	195	830	1996/97
Malaysia (Lumet)	1300	1000	770	1996/97
Indonesia (Muar)	1090	733	670	1997
UK (Sutton Bridge)	790	540	680	1990
Vietnam (Phu My3)	715	360	500	2002
USA (Possum)	550	370	670	2003
Algeria	723	428	590	2006
Pakistan	775	543	700	----

Source: Modern Power System

Depending on location, other estimates suggest that infrastructure costs and land prices could double this number. Even so, the cost is normally significantly lower than that of a coal fired power plant.

In fact combined cycle power plants are the cheapest of most fossil fuel fired electricity generating stations to build. This makes them particularly attractive for countries with limited resources for power plant construction. They provide a cheap and fast addition to generating capacity, and they will be economical too, provided the cost charged for the power generated is high to cover generating costs and loan repayments.

Operational and maintenance (O&M) costs for the gas turbine plants are highly competitive in relation to coal. The EIA estimated that the variable O&M costs for combined cycle plant (in 1996 prices) 2.0 mills/kWh and the fixed O&M costs15.0 mills/kWh. This compares with 3.25 and 22.5mills/kWh for a conventional coal-fired power station.

Unlike a coal fired power station, where much of the plant can be manufactured in the country where it is being built, a gas turbine is a highly technical and complex machine which can only be made by a narrow number of manufactures. This means that most countries need to import all the gas turbines they use in electricity generating stations. Depending on the type of finance, this could make gas-turbine-based power plants less attractive than the coal fired alternative.

Such considerations have declined the use of gas turbines in developing countries that have not embraced private power production.

With a gas turbine power station, capital cost shows a small part of the total economic picture. More important is the cost of the fuel, which is higher than the cost of the fuel for the competitive coal-fired power station.

There are situations where power from a gas turbine plant can command a higher price than that from a coal fired plant. Gas turbines can be fired and stopped more easily, so they can be used to follow the demand curve, supplying peak power when demand is high. This is more highly valued than base-load power.

Thus the economics of the gas turbine plant are so complex. Even so, many planners assume that is currently the cheapest option, quoting a generating cost of around $0.03/kWh. A current challenge to conventional thinking put the generating cost in the range of $0.05 to $0.07/kWh. This would make some renewable sources cheaper. Even so, there is no evidence yet for a waning in popularity of the gas turbine for power generation issue (Breeze, 2005) and (Fetescu, 2003).

4.7.3 Diesel engine power generation technology

Piston engines or reciprocating engines (the two terms are often used interchangeably to describe these engines) are used throughout the world in applications ranging from grass mowers to cars, trucks, locomotives, ships and for power and combined heat, and power generation. The in use is massive; the US alone produces 35 millions each year.

Engines differ in size from less than 1kW to 65 MW. They burn and use a wide range of fuels including natural gas, biogas, LPG, gasoline, diesel, bio-diesel, heavy fuel oil and even coal.

The power generation applications of piston engines are extremely varied too. Small units can be used for emergency power or for combined heat, and power in homes and offices. Larger stand-by units are often used in situations where a continuous supply of power is short and critical; e.g. hospitals or to support highly sensitive computer installations such as air traffic control. Many commercial and industrial facilities use medium-sized piston-engine-based combined heat and power units for base-load power generation. Large engines mean it can be used for base-load, grid connected power generation, while smaller units are used as one of the main sources of base-load power to isolated communities with no access to electricity grid.

Smaller units are normally based on car or truck engines while the larger engines are based on locomotive or marine engines. Performance of these engines varies. Smaller engine are usually cheap because of they are mass produced but they have relatively low efficiencies and short lives. Larger engines tend to be more expensive but they will operate for much longer. Large megawatt scale engines are probably the most efficient prime movers available, with simple cycle efficiencies approaching 50%.

There are two principle types of reciprocating engines, the spark-ignition engine and the compression ignition engine. The latter was traditionally the most popular for power generation applications because of high efficiency. However, it also produces high level of atmospheric pollution, particularly nitrogen oxides. As a result spark-ignition engines burning gas have become the more popular units for power generation, at least with developed nations. A third type of piston engine, called the Stirling engine, is also been developed for some power generation applications (Silveira and Carvalho, 2004) and (Breeze, 2005).

4.7.3.1 Engine size and speed

The speed at which a piston engine runs will depend on its size. In general small units can operate at high speed and large units at low speed. However since in most situations a piston-engine-based power unit will have to be synchronised to an electricity grid operating at 50 or 60 Hz and the engine speed must be a function of one or other of these rates. Thus a 50 Hz high speed engine will operate at 1000, 1500 or 3000 rpm while a 60 Hz machine will operate at 1200, 1800 or 3600 (rpm).

Engines are usually divided into three categories, high, medium and slow speed-engines when classified to speed.

Engine performance changes with speed. High-speed engines give the greatest power output as a function of cylinder size, and hence the greatest power density. However the larger, slower engines are more efficient and can last longer.

In addition, standby service or continuous output base-load operation, piston engine power plants are good at load following. Internal combustion engines operate well under partial load conditions. For a gas fired spark-ignition engine, output at 50 % load is roughly 8 to10 % lower than full load. The diesel engine performs better, with output hardly changing when load drops from 100% to 50%.

4.7.3.2 Compression engines

Compression ignition engines or diesel engines use no spark plugs. Instead they use a high-compression ratio to heat air within the cylinder to high temperature so that when fuel is finally admitted towards the end of the compression stroke, it ignites spontaneously. The compression ration is normally in the range of 12:1- -17:1.

The efficiency of diesel engine ranges from 30% (high heating value, HHV) for small engines to 84% (HHV) for the largest engines. Research must push this to 52% (HHV) within the next few years. Diesel engines can be made to larger sizes than spark ignition engines, with high-speed diesel available in sizes up to 4 MW and slow-speed diesel up to 65 MW. Large, slow speed engines can have huge cylinders. For example, nine cylinders, 24 MW engine used in a power station in Macau has cylinders with a diameter as large as 800 mm.

The combustion temperature inside a compression ignition engine cylinder is much greater than within a spark ignition engine cylinder. As an outcome, nitrogen oxide emissions can be 5—20 times greater than from an engine burning natural gas. This can prove a problem and emission reduction measures may be required to comply with atmospheric emission regulations set (Breeze, 2005) and (Rao and Rubin, 2002).

4.7.3.3 Environmental considerations

Piston engine power units generally burn fossil fuels and the environmental considerations that need to be taken into account are exactly the same considerations that affect all coal, oil, and gas fired power plants; the emissions resulting from fuel combustion. In the case of internal combustion engines, the main emissions are nitrogen oxide, carbon monoxide and volatile organic compounds (VOCs). Diesel engines particularly those burning heavy diesel fuels will also create particulate matter and some sulphur dioxide.

Nitrogen oxide is formed primarily during combustion by a reaction between nitrogen and oxygen in the air mixed with fuel. This reaction takes place more quickly at higher temperatures. In lean burn gas engines where the fuel is burnt with an access air, temperatures can be kept low enough to maintain low nitrogen oxide emissions. The diesel cycle depends on relatively high pressure and temperatures and as a consequence of this produces a high levels of nitrogen oxides

4.7.3.4 Costs of engines

The capital cost of a piston engine power plant generally depends on the unit size. Small engines are generally mass produced and cheaper than their larger relatives. However, this is often compensating by higher installation costs.

Thus typical total plant costs for 100 KW generator units is $1515/KW while a 5000 KW installation costs $919/KW.

While plants in the 100 to 5000 KW capacity range are based on standard components, large piston engine power plants generally has a cost structure more like a gas turbine power plant. The Table (4.8) shows the costs of a number of large diesel engine based power stations. These plants are built in different countries, using different engine configurations, and yet the unit costs of the plants all fall within a remarkably narrow range of $1100 to 1300/KW.

Table (4.8) The typical large diesel power plant costs

Project	Capacity (MW)	Cost ($million)	Cost/KW ($)	Start-up
Kohinoor Energy, Pakistan	120	140	1167	1997
Gul Ahmed Energy Co,	125	138	1104	1997
Pakistan, Jamaica Energy Partners	76	96	1263	---
APPL, Sri Lanka	51	63	1235	1998
IP, Tanzania	100	114	1140	1998
Kipevu 2, Kenya	74	84	1135	2002

Source: Modern Power System

Maintenance costs do vary with engine size and type. Small, high-speed engines generally require the most frequent maintenance while larger engines can run for much longer periods without any attention. Engine oil monitoring systems are often required, particularly in large engines, to examine wear rates. The US EPA found that maintenance costs varied between $0.007 and $0.02/KW for engines in the 100 to 5000/KW range, with smallest engines incurring the highest costs.

Capital cost is a significant factor in the cost of electricity from a piston engine power plant but the fuel cost is normally more important. On a cost per kWh basis, gas engines up to 5 MW will normally compete with gas turbine units of similar size, the higher efficiency of the reciprocating engine in simple cycle model providing a slight edge in many cases. The advantage of reciprocating engines may extend to engines of up to 50 MW under certain conditions. For example where the power plant is required to load follow, or at high altitude, the reciprocating engine has a significant advantage.

Diesel engines have a large use in supplying power to remote communities or isolated commercial facilities. Generation costs under these circumstances can be high if the fuel has to be shipped to the site, adding different transport costs. Often, the diesel unit is the only viable source of power.

Renewable energy systems such as wind, solar and small hydropower now offer an alternative to diesel in some cases. US orders for stationary engines grew by 68% to June 2001, with natural gas-fired engine orders up by 95%. This is a trend expected to go on in the near future (Breeze, 2005).

4.7.4 Nuclear power generation technology

Nuclear power is the most contentious of the forms of power generation. To evaluate its significance involves political, strategic, environmental, economic and safety factors which attract partisan views far more loudly that any other method of electricity generation.

After World War II, nuclear power generation grew and by the beginning of the 1970s had grown into the big hope for unlimited global power. In 1974, the US power industry alone had ordered 200 nuclear reactors and in 1974 the US Energy Research and Development Administration estimated that the US nuclear generating capacity could reach 1200 GW by 2000. (Total US generating capacity in 2002 from all sources were 980GW). The UK, Germany, France and Japan began to build substantial nuclear generating capacity too.

However, as orders were being placed, the nuclear industry was reaching a watershed. A combination of economic, regulatory and environmental factors conspired to bring the development of nuclear power to stop the progress in the USA. Similar effects spread to all countries.

There were already environmental and safety concerns during the 1970s but two dangerous accidents, one in Three Mile Island in the USA in 1979 and the other at Chernobyl in the Ukraine in 1986, turned public opinion powerfully against nuclear power. In response, new safety regulations were introduced, making construction times longer and increasing costs. By 1980s, 100 nuclear projects in the USA alone had been cancelled. To make situations worse, nuclear waste disposal had become a political issue that needed to be resolved. As of 2004, no new nuclear reactor had been ordered in the USA since 1978.

The US still retains a large fleet of nuclear power stations. Some countries in Europe and Scandinavia decided to cancel the option completely. In 1978 Austrian people voted to ban nuclear power. Sweden voted in 1980 to phase out nuclear power by 2010, although this timetable may yet be abandoned.

Other Western countries such as France, Belgium and Finland remain positive about nuclear power generation.

There are a big number of nuclear power plants in Eastern Europe which are Russian-design reactors. The safety of Russian designs has been a matter of worry since the Chernobyl accident in 1986. When the Cold War ended, efforts were made to improve the safety of Eastern European reactors or demand their closure.

Also in Asia, a nuclear generation evolution has followed a different course. Japan has continued to develop its installed nuclear base as South Korea did, though Japanese nuclear industry began to face great criticism at the end of the twentieth century. India has a local nuclear industry. And in the middle of1990s, China started to develop what promises to be a strong nuclear base. These nations, but primarily China, are keeping the nuclear construction industry a live (Yildirim et al., 2005).

4.7.4.1 Global nuclear capacity

By the end of 1990, according to figures compiled by the World Energy Council, there were around 430 operating nuclear reactors worldwide. (There were 437 operating in 1995.). These had a total generating capacity of 349GW. A further 41 units were under construction; these had a total capacity of 33GW.

The global figures are broken down in table (4.9) to show a distribution of current nuclear generating capacity by region. In Europe, 215 units with 171GW, has the greatest capacity. North America has 120 operating units with an aggregate generating capacity of 109GW and Asia has 90 units of the continents, only Australia and Antarctica have none.

Nationally, France produces around 75% of its electricity from nuclear power plants. Lithuania generates 73% from nuclear sources and Belgium 58%.

Table (4.9) The global nuclear generating capacity

	Number of unit	Total capacity (MW)
Africa	2	1800
North America	120	108,919
South America	3	1552
Asia	90	65,884
Europe	215	170,854
Middle East	1	1000
Total	431	350,009

Source: World Energy Council

4.7.4.2 Fundamentals of nuclear power

A nuclear power station generates electricity by utilising energy released when the nuclei of a large atom such as uranium, split into smaller components, a process called nuclear fission. The amount of energy released by the fission process is enormous. One kilogram of naturally occurring uranium could, in theory, release 140GWh of energy. (140GWh represents the output of a 1000MW coal-fired plant operating a full power for nearly 6 days.)

There is another method of nuclear energy, which is nuclear fusion, this involves the reverse of the fission reaction. In this case, small atoms are encouraged to fuse at astonishingly high temperatures to form large atoms. Like nuclear fission, fusion releases huge amounts of energy. However, it will only take place under very extreme conditions. Fusion of hydrogen atom is the main source of energy in the Sun.

The reason why both fission and fusion can release energy lies in their relative stability (Yildirm, et al, 2005) and (Breeze, 2005).

4.7.4.3 The future of nuclear generating technology

For the reasons already given above, the nuclear power industry looked declining at the end of the twentieth century in all but a handful of Asian countries. The twenty-first century has brought a new wish. Against all expectations, nuclear power plants in the USA are often fairing well in the deregulated electricity market and their value is growing. This may encourage a more positive attitude towards nuclear plants within the financial sector there.

The development of new reactors that are cheaper, quicker to build, and safer may help to improve perceptions. Meanwhile global warming offers the nuclear industry a good opportunity to sell their product as a zero greenhouse emissions technology. This debate has not won support with environmental groups which still perceives nuclear power as a pariah. The industry has, however, been successful in lobbying for support in the US government which wants to build a new generation of nuclear power plants. The UK government appears to hold the option of nuclear capacity open.

Major issues still remain if nuclear power is to be rehabilitated. The disposal of nuclear waste is a major problem and one that appears no nearer a satisfactory solution than it did in 1980s or 1990s. Nuclear proliferation renders nuclear power suspect as it is a source of fissile weapons material. The danger of terrorism has seriously raised the safety stakes as far as the nuclear industry is concerned. If concerns relating to them can be overcome, the nuclear industry may see the renaissance it desperately seeks (Yildirim et al., 2005).

4.7.4.4 Environmental considerations of nuclear

The use of nuclear power raises important environmental questions. It is the apparent failure to tackle these satisfactorily that has led too much of the popular disapprobation that the nuclear industry attractive. There are two adjuncts to nuclear generation that cause great concern; nuclear weapons and nuclear waste.

While the nuclear industry may claim that civilian use of nuclear power is a separate issue to atomic weapons, the situation is not that clear. Nuclear reactors are the source of Plutonium which is the primary ingredient of modern nuclear weapons. Plutonium creation depends on the reactor design; a breeder reactor can produce large quantities while a PWR produces very small amounts. Nevertheless all reactors producing Plutonium do contain dangerous fissile material.

The danger is widely recognised. Part of the role of the international Atomic Energy Agency is to monitor nuclear reactors and track their inventories of nuclear material to ensure that none is being diverted into nuclear weapons construction. Unfortunately, this system can never be foolproof. It seems that only if all nations can be persuaded to abandon nuclear weapons can this danger, or at least the popular fear of it, be removed.

The contents of a nuclear reactor core include significant quantities of extremely radioactive nuclei. If these were released during a nuclear accident they would inevitably find there way to humans, animal and plants.

Large doses of radioactivity or exposure to large quantities of radioactive material kills relatively rapidly. Smaller quantities of radioactive material are lethal too, but over a longer time scale.

The industry has gone to extreme lengths to tackle this worry, by building even more sophisticated safety features and strong restrictions into their power plants (Breeze, 2005).

4.7.4.5 Radioactive waste

As the uranium fuel in a nuclear reactor undergoes fission, it generates a blend of radioactive atoms within the fuel pellets. Eventually the fissile uranium becomes of too low a concentration to maintain a nuclear reaction. At this point the fuel rod will be removed from the reactor and must now be disposed in a safe manner. However, after more than 50 years, no safe method of disposal has been developed.

Radioactive waste disposal has become one of the environmental battlegrounds over which the future of nuclear power has been fought. Environmentalists dispute that no system of waste disposal can be absolutely safe, either now or in the future. And since some radio-nucleides will remain a danger for thousands of years, the future is an important factor to consider.

Governments and the nuclear industry have tried to find acceptable solutions. But in countries where popular opinion is taken into consideration, no mutually acceptable solution has been reached. As a result, most spent fuel has been stored in the nuclear power plants where it was produced. This is now causing its own problems as storage ponds designed to store a few years' waste become filled, or overflowing.

One possibility that has been explored, is the reprocessing of spent fuel to remove the active ingredients. Some of the recovered material can be recycled as fuel. The remainder must be stored safely until it becomes inactive. But reprocessing has proved expensive and can worsen the problem of disposal rather than assisting it. As a result it appears unaccepted publicly.

The primary alternative is to bury waste deep underground in a manner that will prevent it ever being released. This requires both a means to encapsulate the waste and a place to store the waste after encapsulation. Encapsulation techniques include sealing the waste in a glass similar to matrix.

Finding a site for such encapsulated waste has proved problematical. An underground site must be in stable rock formation and in a region not subjected to seismic disturbance. Sites in the USA and Europe have been studied but none have been acceptable

Other solutions have been proposed for nuclear waste disposal. One involves loading the fuel into a rocket and shooting it into the sun. Another utilises particle accelerators to destroy the radioactive material generated during fission.

Environmentalists maintain that the problem of nuclear waste is insoluble and represents an ever-growing problem for future generations. The industry disputes this but in the absence of a persuasive solution its arguments lack weight. Unless a solution is found, the industry will continue to suffer and seem unsafe (Yildirim, 2005) and (Breeze, 2005).

4.7.4.6 The cost of nuclear power

Nuclear power is capital exhaustive and costs have escalated since the early days of its development. This is partly as a result of higher material costs and high interest rates, but is also a result of the need to utilise specialised construction materials and techniques to ensure plant safely. In the USA, in the early 1970s, nuclear plants were being built for units costs of $150- -300/KW. By the late 1980s, the figures rose to $1000--3000/KW.

The Taiwan Power Company carried out a study, published in 1991, which examined the cost of building a fourth nuclear plant in Taiwan. The study found that the cost of the two unit plant would be US$ 3.6 billion, a unit cost of around $3150/KW. The estimate was based on end dates of 2001 and 2002 for the two units. Orders were actually placed in 1996, with construction scheduled for completion in 2004 to 2005.

Nuclear construction costs do not take into account decommissioning. This can cost 9% to 15% of the primary capital cost of the plant. However, nuclear proponents argue that when this is discounted it adds only a small percent to the investment cost.

The fuel costs for nuclear power are much lower than that for fossil fuel-fired plants, even the cost of reprocessing or disposal of the spent fuel is taken into account. Thus, levelised costs of electricity provide a more meaningful picture of economics of nuclear power generation.

Taiwan has to import all its fuel, so costs of fossil-fuel-fired generation are clearly higher. Where cheap sources of fossil fuel are available locally, the situation will be dissimilar. Australia, for example, estimates that coal fired power generated pithead plants is cheaper than nuclear power.

A 1997 European study compared the cost of nuclear, coal and gas based power plants for base load generation. For a plant to be commissioned in 2005, nuclear power was cheaper than all but the lowest priced gas-fired scenario based on a discount rate of 5%. When the discount rate increased to 10%, nuclear power was virtually the most expensive option. Other studies have confirmed this assessment.

Coal is generally the source of new generating capacity with which nuclear investment is compared. But the cost of coal-fired electricity depends heavily on transportation costs. These can be considered as much as 50% of the fuel cost. Given this sensitivity, the local availability of coal will have a strong determinant of the economic viability of nuclear power. Gas-fired base-load generation in combined cycle power plants is also cheap but similarly sensitive to fuel prices.

While the cost of new nuclear generating capacity might be prohibitive for some parts of the world, but may be acceptable in others, the cost of power from existing nuclear power plants is extremely competitive. This is true even where coal and gas are available. Thus the Nuclear Energy Institute claims that 2002 was the fourth year for which nuclear-generated electricity was the cheapest in America, undercutting power from coal, oil and gas-fired power plants. (Hydropower from old plants may well be cheaper still.) In support of this, a number of companies are now making a successful business of running US nuclear power stations sold by utilities when the US industry was deregulated. In France, nuclear power is on average the cheapest source of electricity (Breeze, 2005).

4.7.5 Solar power

Solar energy is the most significant source of energy available to the earth and its inhabitants. Without it there would be no life at all. It is the energy source that drives the photosynthesis reaction. As such, it is responsible for all the biomass on the surface of the earth and is also the origin of fossil fuels, the products of photosynthesis millions of years ago and now hidden beneath the earth's surface. Solar energy creates the world's winds; it evaporates the water which is responsible for rain; waves and marine thermal powers are both a consequence of insulation. In fact, apart from nuclear energy, geothermal energy and tidal power, the sun is responsible for all the forms of energy which are exploited by man.

All these different sources of energy, each derived from the sun, can be used to generate electrical power. However solar energy can also be used directly to produce electricity.

This can be achieved most simply by exploiting the heat contained in the radiation of the sun, but electricity can also be generated directly from light using an electronic device called a solar cell. Both methods are valuable renewable sources of electricity generation (Breeze, 2005) and (Neij, 2008).

4.7.5.1 Sites for solar power generation

In principle solar power can be generated anywhere on earth but some regions are better than others. Places where the sun shines frequently and regularly are preferable to regions where cloud cover is common. The brighter the sunlight, the greater the output and the more advantageous the economics of generating plant. Many of the world's developing countries, where demand for electricity is growing rapidly, offer good conditions for solar electricity generation.

Solar generating stations do not take massive amounts of land but they do require many times the space of a similarly sized fossil fuel power plant. But solar power does not necessarily require large nearby areas of land in order to generate electricity. Solar panels can be made in small modular units which can be incorporated into buildings so that power generation can share space used for other purposes.

Distributed generation of this type has many advantages. In California, and elsewhere, there is a major daytime grid demand peak resulting from the use of air conditioning systems. As the air conditioning systems are used to combat heat generated by the sun, distributed solar electricity generation matches this demand perfectly. Recent experience has shown that domestic solar panels virtually remove this additional demand from the houses to which they are fitted.

4.7.5.2 Solar technology

There are two ways of changing the energy contained in sunlight into electricity. The first called solar thermal generation, involves using the sun simply as a source of heat. This heat is caught, concentrated and used to drive a heat engine. The heat engine may be a conventional steam turbine, in which case the heat will be used to generate steam in a boiler, but it could be a gas turbine or a sterling engine.

The second way of capturing solar and converting it into electricity involves use of photovoltaic or solar cell. The solar cell is a solid-state device similar to a transistor or a microchip. It uses the physical characteristics of a semiconductor such as silicon to turn the sunlight directly into electricity.

The ease of the solar cell makes it an extremely attractive method of generating electricity. However the manufacture of the silicon required for solar cell is energy intensive. The solar thermal plant, although more complex, is currently cheaper and uses more conventional power station technology.

Whatever its type, a solar power plant has a major weakness. It can only generate electricity when the sun is shining. During the night there is no light and so no electricity. In order to avoid this problem, a solar power station must either have some form of conventional fuel back-up, or it must incorporate energy storage. Solar cells are frequently joined with rechargeable batteries in order to provide non stop power in remote locations. Solar thermal power plants can also be designed with heat storage systems which permit them to supply power in the absence of the sun (Hall and Bain, 2008) and (Carrasco et al., 2006).

4.7.5.3 Environmental considerations of solar power

Solar power is considered to be one of the most environmentally benign methods of electricity generation. Neither solar thermal nor solar photovoltaic power plants produce any atmospheric emissions during operation. A photovoltaic installation makes no noise either, and a solar thermal plant very little. Nevertheless both types of plant do have an environmental impact.

On a benefit scale, both types of solar power plant require a significant amount of space, more than that required by a fossil fuel power plant. However the best sites for such plants are likely to be arid areas where this should not pose a problem. Construction of a huge plant is likely to involve some local environmental disruption. Once in operation there maybe some benefits locally from the shade created by the array of solar collectors.

When solar panels are installed on rooftops or incorporated into new buildings they share space used for other purposes. Retrofit of solar panels can be unsightly, but where a building has been planned to incorporate solar panels, there is no excuse for any negative visual impact.

This type of development has environmental benefits because it decreases the need for central power station capacity, it reduces the need to reinforce transmission and distribution systems, and it provides electricity at the point of use, so energy losses should be much less than power transmitted many kilometres.

Solar thermal power plants depend on conventional mechanical and electrical components. There may be spillages of heat transfer fluid but these should be easy to manage. Otherwise their construction, operation and decommissioning should be easily managed without affects on the local environment.

Solar photovoltaic devices use less common place materials. The predominant material for solar cells today is silicon. This is energy intensive to produce in its pure form. Lifetime analysis of photovoltaic systems illustrate a relatively high level of emissions of carbon dioxide and other atmospheric emissions as a result of the emissions from the predominantly fossil-fuel-fired power plants generating the electricity used in the production of the silicon.

Lifetime analysis of photovoltaic generation suggests that such a plant will release between 100 and 170g of carbon dioxide for every kilowatt hour of electricity generated. This is much higher than from a solar thermal power plant for which the equivalent facts are 30 to 40 g/KWh. It is nevertheless much lower than the gas-fired power station (430 g/kWh) or a coal-fired power station (960 g/kWh). In future this impact should be decreased as global renewable capacity grows and with it a wider availability of cleaner electricity (Breeze, 2005).

4.7.5.4 The cost of solar power

Solar thermal and solar photovoltaic power plants have common features such as short deployment times and additional benefits from dispersed use that affects the cost and value of the two technologies.

However the technologies themselves have different essential roots and the costs associated with them have to be considered.

4.7.5.5 Solar thermal costs

The following table (4.10) lists the costs for solar thermal power plants estimated by the Sandia National Laboratory and the National Renewable Energy Laboratory, both run under the sponsorship of the US Department of Energy.

Table (4.10) The solar thermal costs

	Capital cost ($/KW)	O&M costs ($/KW)	Levelised energy costs ($/KW) 2000	2010
Solar trough	2900	1	0.11	0.09
Solar tower	2400--2900	0.7	0.09	0.05
Solar dish	2900	2.0	0.13	0.06

Note: The levelised energy cost is for private financing.

Source: US Department of Energy

4.7.6 Solar photovoltaic costs

The most important market for solar photovoltaic technology in 2003 was grid-connected residual and home installations. These accounted for 365 MW of total annual production of 744MW and roughly 50%.

The cost of a grid connected solar photovoltaic system based on silicon can be separated roughly into thirds. One-third is for the actual silicon to make the cell (the module), a further one-third for the construct of the solar cell and panel of module, and one third for installation and ancillary tools.

In the USA in 2003, the cost of an installed rooftop system of this kind was $6500 to $8000 /KW as shown by table (4.11). This compares with $7000 to $9000 /KW in 2001 and $12000 /KW in 1993. Even so, this makes solar photovoltaic technology one of the most costly available today for generating electricity.

Table (4.11) The solar photovoltaic costs

	Photovoltaic module ($/KW)	Installed AC system ($/KW)
1993	4250	12,000
1995	3750	11,000--12,000
1997	4150	10,000--12,000
1999	3500	9,000--11,000
2001	3500	7000--9000
2003	3000	6000--8000

Source: Renewable energy world

The price of the solar cell accounts for a major part of the overall cost. In the above table (4.11) this is between one-third and one-half of the total cost. New technologies may offer ways of reducing costs. Amorphous silicon and cadmium telluride modules were selling for $2000/KW to $3000/KW in 2003. The manufacture of silicon designed specially for solar cell applications may also decrease costs of silicon further.

The cost of electricity from solar photovoltaic power plants remains high. At an installed cost of $5000/KW, electricity most likely costs around $0.025/KWh. This can be competitive with the peak power costs in somewhere like California where the cost of base-load power, $0.025 to $0.050/KWh, in market with well developed infrastructures. Nevertheless the price has reduced to a point where widespread installation is feasible (Breeze, 2005) and (Carrasco, at el., 2006).

4.7.7 Wind power technology

Wind is the motion of air in response to pressure difference within the atmosphere. Pressure difference exerts a force which makes air masses to move from a region of high pressure to one of a lower pressure zone. That movement is called wind. Such pressure differences are caused primarily by differential heating of the sun on the face of the earth. Thus wind energy may be considered to be a form of solar energy.

Annually, over the earth land mass, around 1.7 million TWh of energy is generated by wind power. Over the globe as a whole, the figure is higher. Even so, only a small portion of wind energy can be harnessed to generate positive energy.

One of the limiting factors in the exploitation of wind power onshore is competing land use. Taking this into account, a 1991 estimate put the realisable comprehensive wind power potential at 53,000 TWh/year. This figure is broken down by regions in the table (4.12). As the table shows, wind resources are wide spread and available in most parts of the world.

The figures in the table are probably conservative because modern wind turbines are more efficient than those available when the survey was conducted. Even in this conservative estimate the resource is much larger than world demand for electricity. This is expected to reach 26,000TWh.

Table (4.12) The regional wind resources

	Available resource (TWh/year)
Western Europe	4800
North America	14,000
Australia	3000
Africa	10,600
Latin America	5400
Eastern Europe and former Soviet Union	10,600
Asia	4600
Total	53,000

And,

Table (4.13) The European wind energy resources

	Annual resources (TWh)	Potential capacity (MW)
Austria	3	1500
Belgium	5	2500
Denmark	10	4500
Finland	7	3500
France	85	42,500
Germany	24	12,000
Great Britain	114	57,000
Greece	44	22,000
Ireland	44	22,000
Italy	69	34,500
Luxembourg	--	--
Holland	7	--
Norway	76	38,000
Portugal	15	7500
Spain	86	43,000
Sweden	41	20,500

Source: The figures in this table are taken from Windforce.

4.7.7.1 Wind sites

The economics of wind power depend largely on wind speed. The actual energy contained in the wind varies with the third power of the wind speed. Double the wind speed, and the energy it carries increases eightfold.

A 1.5 MW wind turbine at a site with a wind speed of 5.5 m/s will generate around 1000 MWh/year. At a wind speed of 8.5 m/s the production rises to 4500 MWh and at 10.5 m/s, the yearly output will be 8000 MWh. This is close to the theoretical unit. Other factors will come into participation at very high speed, limiting turbine output. However these figures indicate quite clearly that the selection of a good wind farm site is vitally important for the economics of a project.

The starting point for any wind development must be a windy site. But other factors come into play too. Wind speed varies with height; the higher the turbine is raised above the ground the better the wind regime it will produce. This will benefit larger wind turbines which are placed on upper towers, but larger turbines tend to be more efficient anyway, so further advantages accrue.

Depending on the efficiency of a wind turbine, there is a decrease wind speed below which a wind power generation is not considered economical. This number depends on the efficiency of wind turbine considered, as well as on the turbine cost. With the turbines existing at the beginning of twenty first century, a wind speed as low as 5 to 5.5 m/s is considered economically exploitable at an onshore site. Since offshore costs are higher, an offshore wind speed of 6.5 m/s is needed to make a site economically attractive (Breeze, 2005) (Hall and Bain, 2008).

4.7.7.2 Environmental considerations

The principle environmental advantage of wind power is that it is a renewable resource. This means that its exploitation does not lead to a depletion of a global natural resource in the way that the burning of coal or gas grades in reduced reserves. As a consequence, wind power can contribute to a sustainable global energy future.

Wind power is also considered a clean source of energy. Its use does not lead to important environmental or atmospheric emissions.

Table (4.14) presents estimations for the lifetime of carbon dioxide emissions from a wind plant and from coal and gas-fired power stations. The life-time assessment looks at emissions that take place during the manufacture of the components of a power plant, as well as the emissions that take place during the whole of its operational service. As a result of the former, a wind plant releases 7 tonnes of carbon dioxide for each GWh of power it generates.

Table (4.14) The lifetime missions of carbon dioxide for various power generation technologies

	Carbon dioxide emissions (tonnes/GWh)
Coal	964
Gas	484
Wind	7

Source: Concerted action for offshore wind energy in Europe, Delft University, 2001.

The table (4.14) shows, a coal plant releases well over 100 times more and a gas plant close to 70 times the amount than from the wind plant.

A side from carbon dioxide, wind power produces fewer sulphur dioxides, less nitrogen oxides and less of the other atmospheric pollutants that are emitted by coal fired power plants and to a lesser extent by gas fired plants. However, wind power plants are not completely benign. The use of wind power does have harmful consequences for the environment. Key among these is visual impact and noise.

Visual impact generally attracts the most serious criticism. Wind farms cover a large area and they are impossible to hide. While actual land utilisation is low and the area occupied by a wind farm can be used for other purposes too, the vision of an array of wind turbines, often in otherwise undeveloped rural areas, is considered by many to be visual offensive.

The other key effect of a wind turbine is to generate noise. The noise, a low-frequency whirring, has been compared to the sound of wind in the branches of a tree but the constant is likely to make it more intrusive than the sound of the wind. To this rotor noise must be added the mechanical noise emanating from the gearbox and generator and occasionally some electrical noise.

The blade noise is the most serious of these. Turbine noise is generally more intrusive when wind speeds are low, but it will be masked by background noise provided the machine is far enough away from human habitation. This again will limit the feasible sites for wind development.

Under certain circumstances wind turbine can also cause electromagnetic interference, affecting television reception or microwave transmission. This can normally be mitigated by simple remedial measures and by careful site selection (Beer, 2007).

4.7.7.3 The cost of wind power

Ever since the recent wind power industry began to develop, the main question always to be answered is the question of cost. Can wind power battle with conventional forms of power generation?

Early development in California during the 1980s was stimulated by government financial incentives; when these were dropped, the development of the task declined too. The California wind development program was also affected by the fall in the cost of oil that started in the late 1980s. Real oil prices fell by 75% between 1980 and 1992, according to the World Bank statistics.

Continuous development since the early 1980s has led to the cost of wind turbine installations falling rapidly during the 1980s and early 1990s. World Bank estimated that wind technology costs went down by between 60% and 70% between 1985 and 1994. While prices are still falling, the rates are not as dramatic as they were. Current installation costs for an onshore wind farm are between €700/KW and €1000/KW. Offshore wind farms still cost around €1500/KW but this could drop to €1000/KW by 2010.

The installation cost is the main up-front cost of a wind farm. However energy costs also depend on the quantity of wind available at a particular site. To this must be added the cost of financing the project. Operating costs must also be included before a final form for the final cost of each KWh of electricity can be established.

When these factors are taken into account, favourable estimates suggest that at the beginning of the twenty first century modern onshore wind farms could generate electricity for €0.03/KWh, at a wind speed of 10 m/s and €0.08/KWh at a wind speed of 5 m/s. Early commercial offshore wind farms can generate power for between €0.05/KWh and €0.08/KWh. Generating costs have been predicted to drop by 36% between 2002 and 2010 and a further 24% between 2010 and 2020, predictions which if borne out will make wind power still more competitive.

These figures imply that onshore wind is currently broadly competitive with coal fired power generation but not with gas-fired generation. Less favourable reviews of wind power state that it generates power for two to three times the cost of coal plants.

While arguments about its cost effectiveness continue, in practice the future of wind power is likely to be determined by political decisions. Environmental concerns are increasingly leading to legislation which demands the introduction of renewable electricity generation. Aside from hydropower, wind power is the best placed renewable source to meet that need. If renewable energy is required, in many situations that renewable energy will be wind energy (Shata, et al, 2006) and (Breeze, 2005).

4.7.8 Geothermal power technology

Geothermal energy is the heat contained within the body of the earth. The origins of this heat are originated in the formation of the earth from the consolidation of stellar gas and dust some billion years ago. Radioactive decay within the earth continually generates supplementary heat which augments that already present.

The distance between the earth surfaces to its core is 6500 km. Here the temperature may be as high as 7000°C. As a result of temperature difference between the centre and the much cooler outer regions, heat flows continuously towards the outer surface. As estimated 100x10^15 W of energy reaches the outer surface each year. Most of this heat cannot be exploited, but in some places a geothermal anomaly creates a region far above the ground temperature close to the surface. In such cases it may be possible to utilise the energy, either for heating or in some cases to generate electricity.

The region of the earth at the earth's surface is known as the crust. The earth's crust is generally 5 to 55 km thick. The temperature within the crust increases on average by 17 to 30°C for each kilometre below the surface. Below the crust is the mantle, a viscous semi-molten rock which has a temperature of 650°C to 1250°C. Inside the mantle is the core. The earth's core consists of a liquid external core and a solid inner core where the highest temperatures exist.

Geothermal temperature anomalies take place where the molten magma in the mantle comes closer than usual to the surface. In such regions, the temperature gradient within the rock maybe 100°C per km, or more. Sometimes water can travel down through fractured rock and carry heat back to the surface. Plumes of magma may rise to within 1 to 5km of the surface and at the sites of volcanoes; it actually reaches the surface from sometimes. The magma also intrudes into the crust at the boundaries between tectonic plates which make up the surface of the earth. Theses boundaries can be recognised by earthquake regions such as the Pacific basin 'ring of fire'.

The most apparent signs of exploitable geothermal resources are hot springs and geysers. These have been used by man for 10,000 years. Both the Romans and ancient

Chinese used hot springs for bathing and therapeutic medical treatments. Such use happens in several parts of the world, mainly in Iceland and Japan. A district heating system based on geothermal heat was inaugurated in Chaude-Aigues, France, in the fourteenth century; this system may still be in existence.

Table (4.15) The main geothermal users, worldwide

	Capacity (MW)
USA	2850
Philippines	1850
Italy	770
Mexico	740
Indonesia	590
New Zealand	345
Iceland	140

Source: US Geothermal education office.

Industrial exploitation of hot springs dates from the discovery of boric acid in spring waters at Larderello in Italy in 770. This allowed the development of a chemical industry based on the springs. It was here that the first experiment to generate electricity based on geothermal heat took place in 1904. This led, in 1915, to a 250 KW power plant which exported power to the neighbouring region. Exploitation elsewhere had to wait until 1958 when a plant at Wairkei in New Zealand and the Geysers development in the USA began in 1960.

Geothermal generating capacity has grown gradually since then. By the beginning of the twenty first century there was roughly 8000 MW of the installed geothermal capacity internationally. The largest user is the USA with around 2850MW of installed capacity. The Philippines has 1850MW, while Italy has 770MW, Mexico has 740MW and Indonesia has 590MW as shown in table (4.15). In total 23 countries have exploited geothermal power but two of them, Greece and Argentina, no longer have operating capacity.

Geothermal energy is attractive for power generation because it is simple and relatively cheap to exploit. In the simplest case vapour can be extracted from a borehole and used directly to steer a steam turbine. Such easy geothermal resources are rare but others can be used with little more difficulty. The virtual absence of atmospheric emissions means that geothermal energy is clean compared to fossil fuel fired power. The US Department of Energy identified geothermal energy as a renewable one (Breeze, 2005).

4.7.8.1 Geothermal fields

Geothermal fields are formed when water from rain or snow is able to seep through faults or cracks within rock, sometimes for several kilometres, to reach beneath the surface. As the water heats up it rises naturally back towards the surface by a process of exchange and may appear there in the form of hot springs, geysers, fumaroles or hot sludge holes.

Sometimes the way of the ascending water is blocked by an impermeable layer of rock. Under these conditions, the hot water collects underground in the cracks and pores of the rock beneath the impermeable barrier. This water may be capable of reaching a much higher temperature than the water which emerges at the surface naturally. Temperatures as high as 350°C have been found. Such geothermal reservoirs can be accessed by drilling through the impermeable rock. Steam and hot water will then flow upwards under pressure and can be used at the surface.

Most of the geothermal fields known today have been identified by the presence of hot springs. In California, Italy, New Zealand and some other countries, the presence of these springs led to prospecting usage of drilled holes deep into the earth to locate underground reservoirs of hot water and steam. More recently geothermal exploration techniques have been used to try and locate underground geothermal fields where no hot springs exist. Sites in Imperial Valley in southern California use this method.

Some geothermal fields produce only steam, but these are rare. More often the field will produce either a mixture of steam and hot water or hot water alone, regularly under high pressure. All three may be used to generate electricity.

Deep geothermal reservoirs may be 2 km or deeper below the surface. These can produce water with a temperature of 120 to 350°C. High temperature reservoirs are best for electricity generation. Shallow reservoirs may be as little as 100m below the surface and are cheaper and easier to access, but the water they produce is cooler, often less than 150°C. This can still be used to generate electricity but more likely used for heating.

Geothermal reservoirs are not limitless. They contain a finite amount of water and energy. As a consequence both can become depleted if over exploited. If this happens, either the pressure or the temperature, or both, of the fluid from the reservoir declines.

In theory the heat within the deep reservoir will be continuously replenished by the heat flow from below. This rate of replenishment may be as high as 1000 MW, but is usually smaller. In practice geothermal plants have normally extracted the heat faster than it is replenished. Under these circumstances, the temperature of the geothermal fluid falls and the practical life of the reservoir are limited.

Estimates for the practical life of a geothermal of a reservoir vary. This is partly because it is extremely difficult to gauge the size of the reservoir. While some may become virtually exhausted over the lifetime of a power plant, around 30 years, others appear able to continue to supply energy for 100 years or more. Better understanding of the nature of the reservoirs and improved management will help maintain them for longer (Kitz et al., 2005).

4.7.8.2 Geothermal energy conversion technology

There are three ways of converting geothermal energy into electricity. Each is designed to exploit a specific kind of geothermal resource. The simplest situation occurs where a geothermal reservoir produces high temperature dry steam alone. Under these circumstances, it is possible to employ a direct-steam power plant which analogous to the power train of a steam turbine power station but with the container replaced with the geothermal steam source.

Most high-temperature geothermal fields produce not dry steam, but a steam and a hot water mixture. This is most effectively exploited using a flash steam geothermal plant. The flash process converts part of the hot, high-pressure water to steam and this steam, with any extracted fluid directly from the borehole, is used to rotate the steam turbine. Where the geothermal resource is of a relatively small temperature a third system called a binary plant may be more appropriate. This uses the lower-temperature geothermal fluid to vaporise a second low boiling point fluid contained in a separate, closed system. The vapour expands and then drives a turbine which turns a generator to produce electricity.

4.7.8.3 Environmental considerations

Geothermal power generation is commonly classed among the renewable energies technologies. Strictly this is incorrect, geothermal heat is mined from the earth and the heat removed to generate electricity is not replaced. However, the amount of heat contained within the earth is virtually limitless in human terms. As already noted above, this is the place of the US Department of Energy which classifies geothermal energy as renewable.

The construction of a geothermal power plant involves the same nature of disruption that many civil engineering project encounter. However, this adds to the disruption associated with the drilling of wells to remove geothermal fluid from an underground reservoir and the re-injection wells to organise the fluid once it is exhausted of heat. Drilling needs significant quantities of water and this must be taken from local water courses. To decrease environmental effects, this should be taken from high flow streams and rivers, preferable during the rainy season.

Geothermal resources are often linked with natural features such as fumaroles, geysers, hot springs and mud holes. These features will normally be protected by environmental legislation, so drilling directly into a reservoir that feeds such features will often not be possible. These features may have social and religious significance which must be respected.

Management of underground geothermal reservoir forms a vital part of any geothermal project both on environmental and economic grounds. Continuous depletion of reservoirs will lead to a lowering of the local water table and may lead to subsidence as well as to a decrease in the quality of fluid from the boreholes. The quality of the fluid should be maintained by re-injection as much as possible of the extracted fluid. However, re-injection can lead to a cooling of reservoir. This can be avoided by carefully mapping the local flows and re-injection some distance from the extraction location. Induced seismic movement has also been liked with re-injection, but a casual link is difficult to prove since most geothermal projects are in regions of high or regular seismic motion.

The emissions from a well-managed geothermal plant should be very small when compared with a conventional steam plant. Any carbon dioxide contained in the fluid from the subterranean reservoir will be released and there maybe traces of hydrogen sulphide. However, the latter can be treated chemically to prevent release. The saline brine can cause severe groundwater pollution, as experienced in New Zealand where the Wairakei power plant released 3500 tonnes/h of brine into the Waikato River. To avoid such pollution, modern geothermal plants re-inject all the extracted brine once used (Breeze, 2005) and (Neij, 2008).

4.7.8.4 The cost of geothermal power

In common with many renewable resources, geothermal power generation includes a high initial outlay but extremely low cost fuel. In the case of geothermal plant there are three primary areas of outlay, prospecting and exploration of the geothermal resource, development of the steam field and the cost of the power plant itself.

Prospecting and exploration may cost as much as $1 million. This will weight more heavily on little geothermal projects than on larger schemes. Steam field development will depends on plant size, as will the cost of the power plant itself, even if small plants tend to be more expensive than larger plants.

Table (4.16) shows facts from the World Bank for the costs to develop a good resource has a temperature above 250°C, and good permeability in condition that good fluid flow. It will provide either dry steam or a mixture of steam and brine with low gas content and the brine will be relatively non corrosive; a poor resource may have a temperature of below 150°C, but it could provide fluid at higher temperatures with some other defect such as a corrosive brine or poor fluid flow.

Table (4.16) Direct capital costs ($/kW) for geothermal power plants.

Plant size (MW)	Resource		
	Good	Medium	Poor
Less than 5	1600—2300	1800—3000	2000—3700
From 5 to 30	1300—2100	1600—2500	--
Bigger than 30	1150—1750	1350—2200	--

Source: World Bank.

As the figures in the table (4.16) show, costs for a good resource vary between $1150 and $2300/kw depending on plant size. Where the resource is poor, large plants are not normally economically viable. Costs for tiny power plants under these circumstances vary between $2000 and $ 3700/kw.

Further indirect costs will be incurred, depending on the location and ease of access to the site. These will vary from 5% for an easily accessible site and a local skilled workforce, to 60% of the direct cost in remote regions where skilled labour is limited. An alternative cost estimate from the US Energy Information Administration put the cost of a 50 MW geothermal power plant entering service in the USA in 2006 at $1700 to $1800/kw.

These costs will all be accounted for in the initial investment required to construct a plant. Electricity generation costs will depend partly on this, partly on financial arrangements such as loan repayments and partly continual operation and maintenance costs. World Bank estimates suggest power can be produced from a large geothermal power plant (bigger than 30MW) exploiting a good quality resource of between $0.025 and $0.05 kWh. A plant of less than 5MW could generate power from a similar source for $0.05-$0.07/kWh. With a poor quality resource, a small geothermal plant can generate for $0.06 to $0.15/kWh.

Based on these estimations, a large geothermal power plant can hope to compete with gas-fired power plants. Small plants are less economical but they can still offer exceptionally competitive power in remote rural areas where the alternative is a diesel-fired power plant. Power from the latter will cost at least $0.10kWh or much higher (Breeze, 2005).

4.7.9 Hydropower technology

Hydropower is the oldest and most likely under-rated renewable energy resource in the world. The original known reference is found in a Greek poem of 85 BC. At the end of 1999, hydropower provided 2650 TWh of electricity, 19% of total global output. Yet when renewable energy is discussed, hydropower is normally mentioned.

Part of the reason for this is the disapprobation that huge hydropower has attracted over the past 10 to 15 years. Concerns for the environmental effects of large projects which wipe out wildlife habitant, displace indigenous peoples and upset sensitive downstream ecologies, coupled with often heavy handed and insensitive scheduling and approval procedures, have resulted in the image of hydropower becoming extremely tarnished.

Some of this condemnation is deserved. Large hydropower projects have been built around the world without taking their effects into account. Schemes are often completed late and over budget. And when they are completed they sometimes do not function as proposed.

There are many hydropower projects that perform well. With proper planning, environmental effects can be decreased. When accounted for properly, hydropower is one of the cheapest sources of electricity generation. And while the countries in Western Europe and North America have developed most of their hydropower sites in a manner that attracts relatively little criticism, today the developing world has massive hydropower potential which remains untapped and if developed sensitively, could provide a major improvement in the life quality.

The World Commission on Dams has addressed these problems in 'Dams and Development, a new framework for decision making'. This report proposes a complete reassessment of the criteria and methods used to determine whether a large hydropower project should be constructed. It lays out an approach to decision-making which takes account of all the environmental and human rights issues that critics have raised, an approach which should filter out bad projects but allow successful projects to proceed.

Large dams, however, form only a fraction of hydropower. Small hydropower, generally defined as projects with generating capacities under 10MW, can provide a valuable source of electricity. Small projects are normally suited to remote regions where grid power is not possible to deliver. They may have detrimental environmental effects but well-designed schemes should have lesser or no impact.

While large projects have been displaced from the renewable arena, small hydropower is still permitted through the door. This partition is politically motivated and not logical, since both large and small hydropower are renewable sources of energy. If the World Commission of Dams proposals are executed then perhaps the image of large hydropower can be rescued. But that may take several years to happen (Breeze, 2005) and (Roth and Ambs, 2004).

4.7.9.1 The hydropower resource

Table (4.17) presents some figures for global hydropower potential, broken down by geographical region. The gross theoretical capability, shown in column one, represent the amount of electricity that can be generated if the total amount of rain that falls over a region could be used to generate power at sea level (hence utilising the maximum head of water and extracting most energy). This number is of little practical use but the second column in the table is more functional. This shows how much of the theoretical capability could be exploited using technology today available.

As the table presents, hydropower potential is to be found in all parts of the world. While every region has a significant resource, the largest capability available is in Asia where there is 4875TWh of technically exploitable energy. At the other end of the scale, the Middle East has 218TWh.

Not all of the technically exploitable capability in any region could be cost effectively utilised. That can be termed the economically exploitable capability. Of the total technical exploitable listed in the table, 14,379TWh, just over 8000TWh is considered to be economically exploitable. This is three times greater than 2650TWh of electricity generated by the hydropower plants operating around the world today. Consequently two-thirds of the global resource remains unexploited.

Table (4.17) The Regional hydropower potential

	Gross theoretical Capability (TWh/year)	Technically exploitable capability (TWh/year)
Africa	>3876	> 1888
North America	6818	> 1668
South America	6891	> 2792
Asia	16,443	> 4875
Europe	5392	> 2706
Middle East	688	< 218
Oceania	596	> 232
Total	> 40,704	> 14,379

Source: World Energy Council

And,

Table (4.18) The regional installed hydropower capacity

	Capacity (MW)
Africa	20,170
North America	160,133
South America	106,277
Asia	174,076
Europe	214,368
Middle East	4185
Oceania	13,231
Total	692,420

Source: World Energy Council

The real level of exploitation varies widely from region to region. The World Energy Council estimates that in the 1990s 65% of the economically feasible hydropower potential has been developed in Europe and 55% in North America. In Asia, by contrast the level of exploitation was 18% while in Africa it was as small as 6%.

So, as noted, the developed world has the advantage of much of its hydropower resource, although the resource in the developing world remains largely unexploited. Africa, in particular, has some major hydropower sites that could sensitively and correctly be developed; providing significantly greater prosperity to regions of that continent.

Today the gross global installed hydropower capacity is just under 700GW, with another 100GW under construction. Current global hydropower capacity is broken down by region in table (4.18). In gross, Europe has the biggest installed capacity, followed by Asia and North America. The Middle East, probably the world's most dry region, has the smallest capacity. Comparing the numbers in the table (4.18) with those in the first table (4.17) confirms that Africa has exploited relatively less of its capability than any other region.

If all the outstanding economically exploitable capacity in the world was utilised with the same efficiency as that of existing capacity, an additional 1400GW could be constructed. This would roughly triple hydropower capacity. Exploitation would engage an additional 14,000 power plants with an average size of 100MW, at a cost of $1500 billion (Breeze, 2005).

4.7.9.2 Hydropower sites

The first stage in building a hydropower plant is to find a suitable site. This may appear obvious, but its important to realise that hydropower is site specific. Not only does it depend on a suitable site being available but the nature of the project will depend on the topography of the site. You cannot have a hydropower plant without a suitable place to construct it. In the case of large hydro projects (□10 MW in capacity), sites will often be along way from the place where the power is to be used, necessitating a major transmission project too.

A hydropower project requires a river. The energy that can be taken from the river will depend on two factors, the volume flowing and the drop in riverbed level, normally known as the head of water, that can be used. A steeply flowing river will yield more electricity than a sluggish one of similar size.

This does not mean that slow-flowing rivers are not suitable for hydropower development. They often provide sites that are cheap and easy to exploit. In contrast, steeply flowing rivers are often in inaccessible regions where exploitation is difficult.

Some sites offer the potential for the generation of thousands of megawatts of power. Properly, the largest of these in on the Congo river, where a multiple barrage development capable of supporting up to 35,000MW could be installed. This is exceptionally large; most are smaller. Even so, such sites are likely to be extremely expensive to develop and in the current climate, extremely sensitive. They are also to be multipurpose projects involving flood control, irrigation, fisheries and recreational usage as well as electricity generation.

How does one set about locating a hydropower site? Many countries have carried out at least cursory surveys of the hydropower potential within their territory and provisional details of suitable sites are available from the water of power ministries. Sometimes much more detailed information is available but this cannot replace on-site surveys. Indeed surveys carried out as part of a feasibility study form an integral of hydropower scheme (Breeze, 2005).

4.7.9.3 Small hydropower

Small hydropower projects are those under 10MW in size, though this classification can vary for different countries. (In India, for example, any project under 25MW is considered to be small.) While small projects operate on fundamentally the same principles as large projects and use similar equipments, there are some differences that need to be considered separately.

There are three types of small hydropower project, designated small, mini and micro ones. According to the United Nations Development Program (UNIDO) and the World Bank definition, a project in the range 1 to 100KW is classified as a micro project while 100 KW to 1MW is a mini project. The small project range will stretch from 1MW to between 5 and may be 30MW depending on who it is defining.

Small hydropower potential is regularly assessed separately from large scale hydro-potential. A 1996 estimate put the global small hydro capacity at 47,000MW with a further 180,000MW remaining to be exploited. In Europe there is around 9,000MW of installed small hydropower capacity and sites available for 18,000MW more. China claims an exploitable potential for sites with capacities under 25MW of 70,000MW. Madagascar maintains has a gross theoretical small hydro potential of 20,000GWh each year. Clearly there is huge potential for future development in many corners of the world.

Small hydropower projects may be developed anywhere, mountainous terrain often offers the best potential. Thus Austria and Switzerland are both big users of small hydropower in Europe. This represents a valuable resource since communities are located in mountainous territory often cannot be integrated to a national grid.

Small hydropower plants are theoretically similar to large siblings but the level of investment involved will affect the way a small project is developed. The turbines used in small plants are the same types as those employed in large projects but whereas the big plants will use turbines designed particularly for the site being developed, a small plant will generally have to use off-the-shelf turbine designed and generators in order to keep costs low.

In addition to the standard Pelton, Frances and propeller turbines, there are a number of special small hydropower turbines. These include Mitchell Banki turbines, Turgo impulse turbines, Osberger cross flow turbines and Gorlov turbines. Energy efficiency tends often to be lower for small hydro projects.

A study by the United Nations Developing Program (UNDP) and the World Bank in Ecuador found that systems under 50KW had a maximum efficiency of 66% rising to 70% for units in the 50 to 500KW range and 74% for units between 5KW and 500MW.

Head height is an important factor in determining small hydro economics with higher head sites normally to develop. An impulse turbine is the best option where the head height is above 30m, a reaction turbine below for lower heads is recommended. A head height of less than 2.5m is difficult to exploit.

Dams and barrage structure are also similar in small and large projects but many small schemes can use simpler designs. Run of river are popular since they involve the minimum of civil works. Novel designs, such as inflatable and rubber barrages have also been in use.

A key cost factor in a small hydro project is the feasibility study. Any hydropower project must involve a pre-feasibility study to determine if the site is suitable for development and a feasibility study to prepare design details. The studies will look at the hydrological and geological conditions at the site. For large schemes, the feasibility study accounts for 1 to 2% of the whole cost. In a small scheme it has been identified to consume 50% of the budget.

Small hydropower budgets are squeezed from other directions too, because capital costs are not necessarily in proportion to the size of the scheme. Control system costs, for example, escalate as the project size falls. The cost of grid connection may also make smaller projects un-economical as grid-connected public power providers, although they can still provide an economic supply to a small isolated village or hamlet (Breeze, 2005) and (Jacobsson and Son, 2000).

4.7.9.4 The environment

The environmental effects of a hydropower project, particularly one involving a dam and reservoir, are significant and should be taken into account when the project is under consideration. What is going to be submerged when a reservoir is created? What effect will the dam or barrage have on sedimentary flow in the river? What are the greenhouse gas implications? Whose interests are affected? All these issues must be addressed carefully.

In order to make a case study for such a project, a thorough environmental assessment will usually be necessary and in most cases it will be compulsory. Such a study should include proposals for the improvement of any negative effects of the development. In many cases, particularly where international lending agencies are involved, a project will not be permitted to proceed unless the environmental assessment is favourable. This is true of both public sector and private sector projects.

4.7.9.5 Greenhouse gases

While of the effects of a hydropower project are negative, the effect on greenhouse emissions should, on the face of it, be positive. The generation of hydropower does not involve creation of carbon dioxide. Unfortunately, the situation is not that simple because a reservoir can become the source of methane and this gas is an even more efficient greenhouse gas than carbon dioxide. (It is roughly eleven times more potent.)

A reservoir would become a source of methane if it contains a great deal of organic material – a tropical rain forest would be ideal and conditions are right for anaerobic fermentation. In the worst case, a hydropower plant can produce more greenhouse emissions over its lifetime, than a similarly sized fossil fuel power plant.

Fortunately that is not normally the case. If the site is chosen carefully, and trees are cleared before inundation, the project should produce total greenhouse emissions equivalent to as little as 10% of the emissions in one year from a similarly sized fossil fuel plant. Most of it will be carbon dioxide, generated as a result of the construction of the equipment of the plant.

4.7.9.6 The cost of hydropower

As with most renewable sources of energy, most of the costs associated with a hydropower plant are up-front costs required for its construction. Under most circumstances the actual source of energy, the water, will cost nothing.

In the case of hydropower, the up-front costs can be high making hydropower plants difficult to fund using standard lending arrangements. Project financing in particular, where a loan is made in the expectation of payback being covered by revenue from the power plant, has proved particularly difficult in latest years. The interest payments required force the cost of electricity too high for it to be economical.

And up to now, realistic costs mean that hydropower is certainly competitive. Some would argue that it is the cheapest source of electricity available. The problem for hydropower is that while commercial loans for power plants are generally over 10 to 20 years, a hydropower plant will continue to generate power for perhaps 50 years; with relatively small further investment to rehabilitate the power house, this can be extended to 100 years or longer. There are some dams still functioning in Spain that were built by the Romans – though not to generate power.

The cost of hydropower varies from country to country and project to project. The Table (4.19) presents some plants built in the last two decades (the Fiji plant was actually completed around 1982). As the table shows, the cost of construction of a project can range from $700/kw to $3500/kw.

The Chinese government has invested heavily in hydropower over the last decade. Their experience indicates that medium and large scale projects can be built for an average cost of around $740/kw. In general, smaller projects are relatively more costly, as the table indicates. Remote sites such those in Nepal are also more costly to develop than simply accessible sites. Project costs will also depend on the kind of hydropower plant being built. Turbines for low-head pressure plants tend to be more expensive than those for high head projects. Bulb turbines, of any size, are inherently costly.

Table (4.19) The typical hydropower project costs

	Capacity (MW)	Cost (US$ millions)	Unit cost (US$/KW)
Upper Bhote Koshi (Nepal)	36	98	2722
Manasavu-Wailoa (Fiji)	40	114	2850
Kimti (Nepal)	60	140	2333
Bakun (Philippines)	70	147	2100
Mtera (Tanzania)	80	139	1738
Casecnan (Philippines)	140	495	3536
Theun Hinboun	210	317	1510
San Roque (Philippines)	345	580	1681
Birecik (Turkey)	672	1236	1839
Ita (Brazil)	1450	1070	738
Katakana (Turkey)	1800	1496	831
Three Gorges (China)	18,200	15,000	824

Source: World Bank, Statkraft, Modern Power System, The international Journal of Hydropower and Dams, Montgomery Watson Harza.

The price of electricity from hydropower plant will depend on the cost of building and financing the project and on the amount of electricity it generates when operating. For recent hydropower projects built by the private sector with loans repaid over 10 to 20 years, preliminary generating costs have been in the range $0.04 to $0.08/kwh. However once the loan has been repaid the costs drop dramatically. The typical range of generation costs is $0.01/kWh to $0.04/kWh but may easily fall below 0.01/kWh. This is cheaper than any other source of electricity when compared.

Small hydropower projects can range from $800/KW to over $6000/KW depending on the site and the size of the project. According to the Indian Renewable Energy Development Agency, the capital cost of small hydro in India is between $800/KW and $1300/KW and the generating cost is $0.03—$0.05/kWh. Similar numbers from the

Energy Technology Support Unit for a typical UK project, but the capital cost at around $1500/KW (Breeze, 2005) and (Roth and Ambs, 2004).

4.10 Power generation technology identification

Power generation technology is the methodology to using certain technique to abstract the energy stored in a certain fuel and somehow transferring it to useful electrical energy. There are so many methods to do so but not all of them are suitable for developing countries for one reason or another.

Here are some common methods to generate electrical power or in other words, power generating technologies. These technologies are classified according to fuel used:

1- Coal fired power generation

2- Oil fired power generation

3- Gas fired power generation

4- Diesel power generation (piston engine)

5- Fuel cells power generation

6- Hydropower generation

7- Tidal power generation

8- Geothermal power generation

9- Biomass based power generation (bio fuel)

10- Nuclear power generation

11- Wind power generation

12- Solar power generation

4.10.1 Power generation technology selection

In this research work, the most commonly used technologies in developing countries and may be feasible for the group. Amongst these there are some technologies more appropriate than others for developing countries.

1- Coal fried power generation

2- Oil fired power generation

3- Gas fired power generation

4- Hydropower power generation

5- Geothermal power generation

6- Nuclear power generation

7- Wind power generation

8- Solar photovoltaic power generation

9- Thermal power generation (solar)

4.10.2 Power generation technology filtration

The goal of this study is to select a power generation technology for developing countries at strategic level. Therefore, some of these power technologies are excluded from this study for some reasons.

1- Diesel engines have a long history of use in supplying power to remote communities or isolated commercial facilities. It is commonly very well known that diesel engines are most likely to be used in emergency conditions where the supply of power is crucial, such as in hospitals, some computer facilities for control purpose, military radars to watch the enemy and some governmental sites.

2- Fuel cells power generation technology cannot compete with its high installation costs at $4500/kw compared with other generating technologies. With the exception of the PAFC (Phosphoric Acid Fuel Cell), fuel cells are unproven commercially. It seems unlikely that they will ever be able to achieve the near-term industry cost target of $1500/kw or the long-term target of $400/kw by 2015.

3- Tidal power generation is excluded from the study when it applies to developing countries where a lot of them are far from the sea or oceans. The second major problem where a country cannot rely on a tidal power generation technology alone is that where the two levels of sea water and the basin water are the same. In this condition the plant will not rotate and drive the turbine and therefore no electrical power is generated. For the above reasons, this technology is excluded from this study.

4- Biomass based power generation is also excluded from the study because this technology is basically dependant on the burning of grains produced by agriculture to feed human beings and animals. In developing countries there is a big shortage of food for humans and animals; therefore there is no logic to burn the grains to produce power. The second reason is that this technology is still under development.

5- Waste Power generation is excluded from this study because of the capital cost of equipment to generate electricity from waste is generally much higher than for conventional power generation equipment to burn fossil fuel. The cost of a typical municipal waste combustion plant is $5000 to $10,000/kw, at least three times the cost of a coal-fired power plant of the same generating capacity. According to US government estimates, such plans generate electricity at between $0.02 and $0.14/kWh.

4.11 Selection of some criteria

There are some common criteria for the electrical power generation technologies, these criteria are used to help in evaluating and appropratising these technologies to fill full the increasing demand in the developing countries. These are as follow:

1- Cost to generate power and it's measured in US Dollars ($) or Cents.

2- Plant life, it is measured in years.

3- Requirement, there are different kinds of these requirements.

4- Dependency, this criterion shows how much a developing country can rely on itself or others and it is measured as a percentage.

5- Safety, this criterion shows how much a selected generating technology is safe to humans when it is put to work.

6- Pollution, this criterion presents how much a selected technology can harm the surroundings such as humans, animals and planet, and it is measured in more than one unit.

7- Development, this criterion shows how much a developing country can benefit from implementing a selected generating technology.

4.11.1 Some important sub-criteria

As mentioned above, there are some common criteria to evaluate the different types of available generating technologies for generating electrical power. These criteria have some sub-criteria to be able to illustrate the situation and make the analysis clear and understandable.

1- Cost,

    1.1- Capital cost (US$ cents/kWh).
    1.2- Fuel cost (US$ cents/kWh).
    1.3- Operating & Maintenance (US$ cents/kWh).

2- Plant Life (years), has no sub-criteria.

3- Requirements,

  3.1- Land used (Hectares/kWh).

  3.2- Water needed (m3/kW).

  3.3- Employment (persons/GWh)

4- Dependency,

  4.1- Foreign participation, percentage (%).

  5.1- Local participation, percentage (%).

5- Safety,

  5.1- Noise level, decibels (dB)

  5.2- Physical discomfort, percentage (%)

  5.3- Psychological discomfort, percentage (%)

6- Pollution,

  6.1- Global warming, grams of carbon dioxide (g.CO2/kWh)

  6.2- Air pollution, percentage (%)

  6.3- Thermal pollution, amount of heat released (GJ/GWe)

7- Development,

  7.1- Technology, percentage (%)

  7.2- Industrial, percentage (%)

4.12 Selecting a suitable software for analysis

This research work is considered to be a decision making process. From the goal of this research, it is clear that the hard technology is chosen to be in the field of power generation for reasons already noted.

There are other methods used in the multi-criteria decision making process (MCDM), such as distance based approach (DBA), data envelopment analysis (DEA) and operational competitiveness rating analysis (OCRA). The last method is mainly used in financial situations (Parkan and Wu, 2000).

For future research, the analytic network process (ANP) may be recommended.

Our present complex environment calls for a new logic, a new way to cope with the myriad of factors that affect the goals and the consistency of the judgement we use to draw valid conclusions. This approach should not be so complex that only the educated can use it, but should serve as a unifying tool for thoughts in general.

The Expert Choice using the Advanced Decision Support Software named as the Analytic Hierarchy Process (AHP) is chosen to be used as a tool. The AHP has some advantages over some other methods.

4.13 Using data from literature

Finding data for developing countries was a difficult task, where it is found, most of the time, it is short and does not satisfy the various types of technologies or criteria.

Here, some data is listed to help to develop some conclusions which may help to clarify and bring the research work steps forward. So to determine the intensity of impact of the various components of a system, we must perform some type of measurement on a scale with units such as pounds, mills, and dollars. But these scales limit the nature of the ideas we can deal with.

To measure priorities, we compare one element against another. The old adage that one cannot compare apples and oranges is false. Apples and oranges have many properties in common: size, shape, taste, aroma, colour, seediness, juiciness, and so on. We may prefer an orange for some properties and an apple for others; moreover, the strength of our preference may vary. We may be indifferent to size and colour, but have a strong preference for taste, which again may change with the time of day. It is this sort of complicated comparison which occurs in real life over and over, and some kind of mathematical approach is required to help us determine priorities and make trade-offs. The analytic hierarchy process is such an approach (Saaty, 1995/1996).

The AHP has some advantages; some of theses are listed as follows:

1- Unity: the AHP provides a single, easily understood, flexible model for a wide range of unstructured problems.

2- Complexity, the AHP integrates deductive and systems approaches in solving complex problems.

3- Interdependence, the AHP can deal with the interdependence of elements in a system and does not insist on linear thinking.

4- Hierarchic Structuring, the AHP reflects the natural tendency of the mind to sort elements of a system into different levels and to group like elements in each level.

5- Measurement, the AHP provides a scale for measuring intangibles and a method for establishing priorities.

6- Consistency, the AHP tracks the logical consistency of judgements used in determining priorities.

7- Synthesis, the AHP leads to an overall estimate of the desirability of each alternative.

8- Trade-offs, the AHP take into consideration the relative priorities of factors in a system and enables people to select the best alternative based on their goals.

9- Judgement and Consensus, the AHP does not insist on consensus but synthesises a representative outcome from diverse judgements.

10- Process Repetition, the AHP enables people to refine their definition of a problem and to improve their judgement and understanding through repetition.

Table (4.20) The main data collected from the literature for the nine technologies considered in this study and their criteria.

	oil fired	natural gas	coal fired	hydro-power	geothermal	nuclear power	solar photo-voltaic	wind power	solar thermal
cost/capital	1.3	1.2	1.8	2.9	2.2	2.1	29.2	5.7	5.8
cost/fuel	2.4	2.3	1.6	0	0	0.7	0	0	0.8
cost/O&M	0.5	0.4	1.1	0.3	1.3	1.2	0.6	1.3	1.25
plant life	35	35	40	50	30	30	10	20	20
requirement land	80	80	220	3000	650	400	1600	6000	1000
requirement water	0.7	0.7	0.8	7	1.1	0.8	0	0	0.4
requirement employment	4500	4500	4700	200	800	5000	500	500	700
dependency foreign	70	65	60	20	20	60	20	20	20
dependency local	25	25	35	60	15	4	20	15	25
safety-noise	30	30	30	15	70	20	10	20	20
safety-physical	30	25	45	20	50	35	20	40	30
safety psychological	10	10	15	15	40	90	10	20	10
pollution, global warming	733	650	990	18	22	22	59	37	180
pollution air	30	25	55	0	40	20	0	0	15
pollution thermal	40	40	45	0	75	60	81	0	40
development technology	15	25	35	65	40	55	65	50	50
development industrial	30	30	30	15	15	35	8	8	10

Source: JSME International Journal Series B, 2004, Volume 47; part 2, Widiyanto, A; Kato, S; Maruyama, N.

Note: The top three rows have been converted from Yens to Dollars ($1 = 120 yens). Using the Analytic Hierarchy Process (AHP), methodology based on the judgement between the criteria such as cost, plant life, requirements, pollution, safety and other criteria noted above.

4.14 Building the model using the AHP

Now after determining the nine power generation technologies, the significant criteria and the sub-criteria, the AHP software can build the general model or the tree view of the model.

Model Name: POWER GENERATION TECHNOLOGY SELECTION

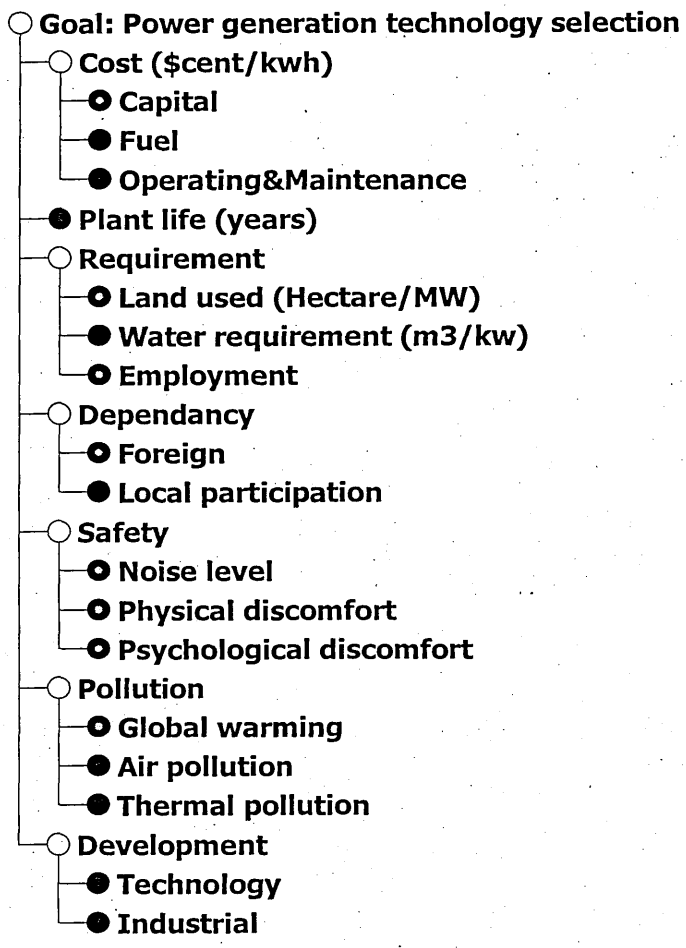


Fig. (4.1) The model of the power generation technology

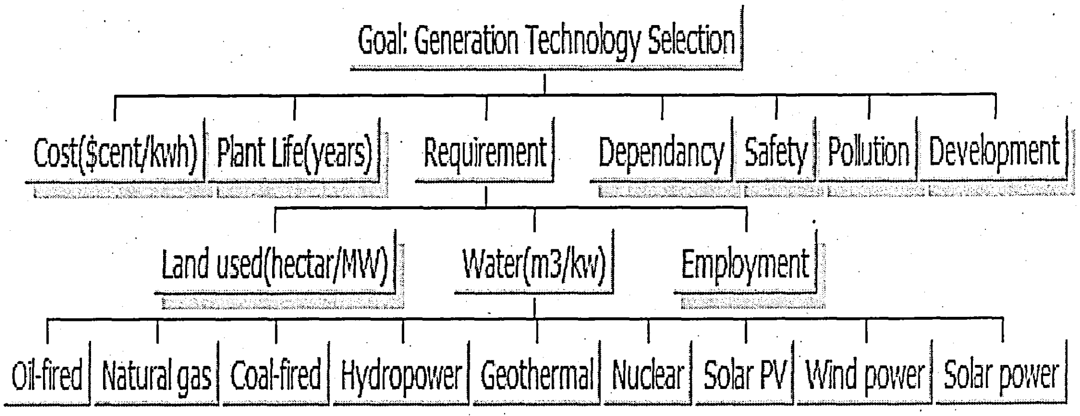


Fig. (4.2) The hierarchy block diagram of the power generation technology (produced by AHP).

The above hierarchy block diagram is the outcome result from the AHP software used for analysis. The above block diagram represents the four layers of the model and these are:

The goal, the criteria, the sub criteria and the alternatives represented by the different hard technologies option.

4.15 Conclusion

In this chapter, the power generation technologies are explained and identified. The size of this industry is illustrated by means of tables around the world. The hard technologies are classified by means of fuel type. In every section the cost of the technology is explained and also the fuel as well. The environmental considerations and the effect on the hard technology on the environment of hard technologies are presented.

The power generation section in developing countries is especially because of its significant, importance and share of lifting other sectors to develop.

Nine hard technologies are identified to be included. These are coal fired, gas fired, nuclear, solar photovoltaic, solar thermal, wind power, geothermal power and hydropower generating hard technologies. Some hard technologies are excluded from the study for some explained reasons.

Some important criteria and sub criteria are identified which have significant effect on the selection of power generation technology.

Using data from literature for different criteria and some criteria for hard technologies to achieve the goal of the study and presented in table 4.20.

There is a full explanation why the AHP software is chosen here as a multi criteria decision making tool and also the advantages of this model over some other methods.

The proposed model is presented in fig. 4.1 including the goal and all different criteria and sub criteria.

The hierarchy block diagram is shown to clarify the different levels of the proposed model.

CHAPTER FIVE

HARD TECHNOLOGY SELECTION RESULTS AND THE SENSITIVITY ANALYSIS

5.1 Introduction

This research work is considered as a decision making process. From the goal of this research, it is clear that the hard technology is chosen to be in the field of power generation for some reasons already noted.

Our present complex environment calls for a new logic, a new way to cope with the myriad factors that effect of goals and the consistency of the judgement we use to draw valid conclusions. This approach should not be so complex that only the educated can use it, but should serve as a unifying tool for thought in general.

The Expert Choice using the Advanced Decision Support Software named as the Analytic Hierarchy Process (AHP) is used to take the appropriate decision of hard technology selection to generate electrical power.

5.2 Results

After building the model and entering the data to the AHP software (Analytic Hierarchy Process), the following diagram was produced by the (AHP) showing the results.

The results show that the hydropower technology is the most significant power generation technology for developing countries where compared with the other eight technologies which have different values with respect to goal as listed in table (5.1):

Table (5.1) The output results of the AHP for hard technology priorities

Hard technology	Priority
Hydropower	0.19
Wind power	0.177
Solar photovoltaic	0.164
Geothermal power	0.104
Natural gas	0.077
Nuclear power	0.076
Oil fired	0.075
Solar thermal	0.073
Coal fired	0.064

The Hydropower generation technology has a value of 0.19, the highest. The Wind power generation has a value of 0.177, the second highest. The Solar Photovoltaic has a value of 0.164, the third highest. The Geothermal power generation technology has a value of 0.104, which makes it the forth. The natural gas technology has a value of 0.077 which makes it the fifth power generation technology. The nuclear power technology has a value of 0.076 which makes it the sixth power generation technology to meet the goal.

The second group of power generation technologies are, oil fired, solar thermal and coal fired power generation technologies.

The oil fired technology has a value of 0.075, which makes it the seventh generation technology with respect to the goal.

The solar thermal power generation technology has a value of 0.073 which makes it the eight generation technology with respect to the goal. The coal-fired technology is the last of all with respect to the goal with a value of 0.064.

It is very clear that renewable alternative technologies which have the lowest effect and friendly impact on the environment that means they will not pollute the environment and do not need any fuel to operate are the most significant technologies with respect to the goal which make them the best power generation technologies to build and use to generate electrical power in developing countries as it can be seen by fig. 5.1.

Graph (5.1) The results of the power generation technologies selection by the (AHP)

5.3 Introduction to sensitivity analysis

Sensitivity analysis is to be carried out for the future work to make this model copping with any possible changes in the input criteria such as fuel prices we see today that is oil, gas and coal are increasing very sharply. The second reason to carry sensitivity analysis is to make this model compatible for developing counties.

Sensitivity analysis is identified as one of the principal quantitative techniques used for risk management in the United Kingdom. Also it is indicated that sensitivity analysis can provide the basis for planning adaptation measures to mitigate the risk of climate change. Sensitivity analysis can be used as an aid in identifying the important uncertainties for the purpose of prioritizing additional data collection or research. Furthermore, sensitivity analysis can play an important role in model verification and validation throughout the course of model development and refinement. Sensitivity analysis can be used to provide insight into the robustness of model results when making decisions. Sensitivity analysis methods have been applied in various fields, including complex engineering systems, economics, physics, social sciences, medical decision making and others (Frey and Patil, 2002).

5.4 Methods of sensitivity analysis

This section identifies sensitivity analysis methods used across various disciplines. Different methods and specific applications of each method are given. Strengths and limitations of the methods are noted in brief.

5.4.1 Nominal range sensitivity

This method is also known as local sensitivity analysis. This method is applicable to deterministic models. It is usually not used for probabilistic analysis. One use of nominal sensitivity analysis is as a screening analysis to identify the most important inputs to propagate through a model in a probabilistic framework. It is described as it can evaluate the effect on model outputs exerted by individually varying only one of the model inputs across its entire range of plausible values, while holding all other inputs at their nominal or base-case values. The difference in the model output due to the change in the input variable is referred to as the sensitivity or swing weight of the model to that particular input variable.

The results of the nominal range sensitivity are most valid when applied to a linear model.

Its advantage is a relatively simple method that is easily applied. It works well with linear models and when the analyst has a good idea of plausible ranges that can be assigned to each selected input. The results of this approach can be used to rank order key inputs only if there are no significant interactions among the inputs, and if ranges are properly specified for each input.

The disadvantage of this method is that it addresses only a potentially small portion of the possible space of input values because interactions among inputs are difficult to capture.

5.4.2 Difference in log-odds ratio (ΔLOR)

The difference in log-odds ratio (ΔLOR) method is a specification of nominal range sensitivity methodology. The ΔLOR is used when the output is a probability. It is described as the odds or odds ratio of an event is a ratio of the probability that the event occurs to the probability that the event does not occurs. If the event has a probability of occurrence as P, then the odd ratio is $P/ (1-P)$.The log of odds ratio or legit is just another convenient way of rescaling probabilities.

If the ΔLOR is positive, changes in one or more inputs enhance the probability of the specified event. If ΔLOR is negative, then the changes in the outputs cause a reduction in the probability of the event not occurring. The greater the magnitude of ΔLOR, the greater is the influence of the input (Frey and Patil, 2002).

The ΔLOR method was used by Stiber to identify key inputs to a model of ground water decontamination via reductive de-chlorination. The model inputs, referred to as "evidence," include site parameters such as temperature, pH, and whether various specific chemicals are found to be present, such as oxygen, hydrogen, chloride, dichloroethene (DCA), methane, and others.

The advantage of ΔLOR method is a useful measure of sensitivity when the model output is a probability.

The disadvantages of this method, it can be used only when the output is in terms of probability. It suffers from drawbacks similar to nominal range sensitivity analysis. It is similar to nominal range sensitivity analysis, ΔLOR cannot account for nonlinear interactions between or among inputs. Similar to nominal range sensitivity analysis, the significance of differences among the sensitivities can be difficult to determine for nonlinear models and correlated inputs, making it potentially difficult to rank order key inputs.

5.4.3 Break-even analysis

Break-even analysis is more of a concept than specific method. Broadly speaking, the purpose of break-even analysis is to evaluate the robustness of a decision to changes in inputs.

Break-even analysis involves finding values of inputs that provide a model output for which a decision maker would be indifferent among the two or more risk management options. The combinations of values of inputs for which a decision maker is indifferent to the decision options are known as switch-over or break-even values. Then, in order to assess the robustness of a choice between the options, one can evaluate whether the possible range of values of the model inputs corresponds with only one of the two choices.

The break-even analysis is often used in economics for purposes such as budget planning. Break-even analysis has also found applications in several other fields, such as health care.

The advantages of the switch-over or break-even point guides further modelling and elicitation. If the range of uncertainty regarding an input encloses the break-even point, then that input will be important in making a decision; that is, there will be uncertainty regarding which decision to take. In such a situation, further research can be directed so as to help the decision maker narrow the range of uncertainty and make a decision with more confidence.

The disadvantage of this method is that, it is not a straightforward method to apply. It is a useful concept, but its application is increasingly complex as the number of sensitive inputs increases. There also is not a clear ranking method to distinguish the relative importance of the sensitive inputs.

5.4.4 Automatic differentiation technique

The automatic differentiation (AD) technique is an automated procedure of calculating local sensitivities for large models. In AD, a computer code automatically evaluates first-order partial derivatives of outputs with respect to small changes in the inputs. The values of partial derivatives are a measure of local sensitivity.

Most of existing sensitivity analysis methods based on differentiation, such as numerical differential methods has one or more of the following limitations: inaccuracy in the results, high cost in human effort and time, and difficulty in mathematical formulation and computer program implementation. To overcome these limitations, AD techniques were developed. AD is a technique to perform local sensitivity analysis and not a new method in itself. In AD, the local sensitivity is calculated at one or more points in the parameter space of the model. At each point, the partial derivatives of the model output with respect to a selected number of inputs are evaluated.

Automatic differentiation finds application in models that involve complex numerical differentiation calculations, such as partial derivatives, integral equations, and mathematical series. It is used in fields such as air quality, aerodynamics, mechanical structures, and others. AD can be used for verification of part of a model.

The advantages of AD are that, AD techniques, such as ADIFOR, can be applied without having detailed knowledge of the algorithm implemented in the model. ADIFOR does everything automatically once it is appended with the main code. AD is superior to finite difference approximations of the derivatives because numerical values of the computed derivatives are more accurate and computational effort is significantly lower. It is observed that a CPU time saving of 57% by using AD for sensitive analysis as compared to using a traditional method.

The disadvantage of the AD technique made be limited to specific computer languages, such as FORTRAN in the case of ADIFOR, requiring the user to provide FORTRAN code for the model. Because AD is a local technique, it suffers from the limitations of nominal range sensitivity analysis. Furthermore, unlike nominal range sensitivity analysis, the possible range of values is not considered. The accuracy for sensitivity results is conditioned on the numerical method used in the AD software. Also, for nonlinear models, the significance of differences in sensitivity between inputs is difficult to determine, making the rank ordering of key inputs potentially difficult. This method cannot be used if partial derivatives cannot be evaluated locally.

5.4.5 Regression analysis

Regression analysis can be employed as a probabilistic sensitivity analysis technique. Regression analysis serves three major purposes: (1) description of the relation between variables; (2) control of predictor variables for a given value of a response variable; and (3) prediction of a response based predictor variables. A relation between inputs and output should be identified prior to regression analysis, based on techniques such as scatter plots or on understanding the functional form of the model. Methods such as stepwise regression can be used to automatically exclude statistically insignificant inputs. The regression model may not be useful when extrapolating beyond the range of values used for each input when fitting the model. Regression analysis is most properly performed on an independent random sample of data. The effect of inputs on the output can be studied using regression coefficients, standard errors of regression coefficients, and the level of significance of the regression coefficients.

Regression analysis as a sensitivity analysis method applied in various fields such as veterinary science, social science, food sciences, and food safety. It is also used logistic regression for sensitivity analysis of a stochastic population model.

The advantages of the regression techniques allow evaluation of sensitivity of individual model inputs, taking into account the simultaneous impact of other model inputs on the result. Other regression techniques, such as those based on the use of partial correlation coefficients, can evaluate the unique contribution of a model input with respect to variation in a selected model output. Rank regression can capture any monotonic relationship between an input and the output, even if the relationship is nonlinear.

The disadvantage of this method is that the key potential drawbacks of regression analysis include: possible lack of robustness if key assumptions of regression are not met, the need to assume a functional form for the relationship between an output and selected inputs, and potential ambiguities in interpretation.

5.4.6 Analysis of variance

Analysis of variance (ANOVA) is model independent probabilistic sensitivity method used for determining whether there is a statistical association between an output and one or more inputs. ANOVA differs from regression analysis in that no assumption is needed regarding the functional form relationships between inputs and the outputs. Furthermore, categorical inputs and groups of inputs can be addressed. Inputs are referred to as "factors" and values of factors are referred to as factor levels in ANOVA. An output is referred to as a "response variables." Single factor ANOVA is used to study the effect of one factor on the response variable. Multifactor ANOVA deals with two or more factors and it is used to determine the effect of interactions between factors. A qualitative factor is one where the levels differ by some qualitative attribute, such as a type of pathogen or geographic regions. ANOVA is a nonparametric method used to determine if values of the output vary in statistically significant manner associated with variation in values for one or more inputs. If the output does not have a significant association with variation in the output is random. The exact nature of the relationship between the inputs and the output is not determined by ANOVA. Although the F-test is generally used to evaluate the significance of the response of the output to variation in the inputs, additional tests, such as the Tukey test and Scheffe test, can also be used to evaluate. For example, the effect of different input value ranges. In ANOVA, it is assumed that the output is normally distributed. Diagnostics checks are important to determine the assumptions of ANOVA are violated. If any key assumptions are violated, corrective measures can be taken to address the problem.

ANOVA finds broad application across various fields, including health risk assessment, material testing, food quality, microbiology, and microbial risk assessment.

The advantage of this method is that no assumption is needed regarding the type of underlying model and both continuous and discrete inputs can be analysed using ANOVA. The results of ANOVA can be robust to departures from key assumptions, and additional techniques can be employed to deal with issues such as multicollinearity.

The disadvantage of this method is that ANOVA can become computationally intensive if there are a large number of inputs. If this becomes a problem, a suggestion is to try to reduce the number of inputs analysed by using some less computationally intensive method, such as nominal range sensitivity analysis, to screen out intensive inputs. If there is a significant departure of the response variable from the assumption of normality, then the results may not be robust.

5.4.7 Response surface method (RSM)

The response surface method (RSM) can be used to represent the relation between a response variable (output) or one or more explanatory inputs. The RSM can be used in a probabilistic analysis and it can identify curvatures in the response surface by accounting for higher-order effects. The RMS is generally complex and, therefore, used in a situation when a limited number of factors are under investigation. A Response Surface (RS) can be linear or nonlinear and is typically classified as first order or second order. The second-order structure is used when there are interaction terms between inputs. The amount of time and effort to develop a RS is typically a function of the number of inputs included and the type of RS structure required. It is always advantageous to limit the number of inputs that are included in the RS to those are identified as most important by using screening sensitivity analysis method, such as nominal range sensitivity analysis. Monte Carlo simulation methods are typically used to generate multiple values of each model input and to calculate corresponding values of the model output.

The RSM is often employed for optimization and product quality studies. It is sometimes demonstrated, the use of RSM to optimize properties of cereals to maximize consumer acceptance. The RSM can be applied for reliability analysis of an aluminium-extrusion process.

A key advantage of the RSM approach is that a potentially computationally intensive model can be reduced to a simplified form that enables much faster model run times. Therefore, it will be easier to apply iterative numerical procedures to the RS, such as optimization or Monte Carlo simulation, compared to the original model. Furthermore, the functional form of the RS model and the values of its coefficients may provide a useful indication of key sensitivities. Nominal range sensitivity or other methods can be applied to the RS model to elucidate sensitivities, with faster run times.

The disadvantage is that because the RS is calibrated to the data generated from the original model, the valid domain of applicability of the RS model will be limited to the range of values used to generate the calibration data set. Most RS studies are based on fewer inputs than the original model. Therefore, the effect of all original inputs on the sensitivities can not be evaluated by the RSM.

5.4.8 Fourier amplitude sensitivity test

The Fourier Amplitude Sensitivity Test (FAST) method is a procedure that can be used for both uncertainty and sensitivity analysis. The FAST method is used to estimate the expected value and variance of the output, and the contribution of individual inputs to the variance of the output. The FAST method is independent of any assumptions about the model structure, and works for monotonic and non monotonic models. The effect of only on input (local sensitivity) or the effect of all inputs varying together can be assessed by FAST.

The main feature of the FAST method is a pattern search method that selects points in the input parameter space and is reported to be faster than the Monte Carlo method. The classic FAST method is not efficient to use for high-order interaction terms. However, the extended FAST method developed by Saltelli (1999) can address higher-order interactions between the inputs. A transformation function is used to convert values of each model input to values along a search curve. As part of the transformation, a frequency must be specified for each input.

The advantage of this method is that the FAST method is superior to local sensitivity analysis method because it can apportion the output variance to the variance in the inputs. It also can be used for local sensitivity analysis with little modification. Its model independent and works for monotonic and non monotonic models. Furthermore, it can allow arbitrarily large variations in input parameters. Therefore, the effects of extreme events can be analysed. The FAST method can be used to determine the difference in sensitivities in terms of the differing amount of variance in the explained by each input and thus can be used to rank order key inputs.

The disadvantage is that the FAST method suffers from computational complexity for a large number of inputs. The classical FAST method is applicable to models with no important or significant interactions among inputs. However, the extended FAST method developed by Saltelli (1999) can account for high-order interactions. The reliability of the FAST method can be poor for discrete inputs.

5.4.9 Mutual information index

The objective of the mutual information index (MII) sensitivity analysis method is to produce a measure of the information about the output that is provided by a particular input. The sensitivity measure is calculated based on conditional probabilistic analysis. The magnitude of the measure can be compared for different inputs to determine which inputs provide useful information about the output. MII is a computationally intensive method that takes into account the joint effects of variation in all inputs with respect to the output. MII is typically used for models with dichotomous outputs, although it can also be used for outputs that are continuous. The MII method typically involves three general steps: (1) generating an overall confidence measure of the output value; (2) obtaining a conditional confidence measure for a given value of an input; and (3) calculating sensitivity indices. The overall confidence in the output is estimated from CDF of the output. Confidence is the probability for the outcome of interest. For example, if the dichotomous output is whether risk is acceptable, the confidence is the probability that the risk is less than or equal to an acceptable level.

The MII method was devised by Critchfield and Willards (1986), who demonstrated its application on a decision tree model. A dichotomous model was used to decide between two options to treat the disease of deep vein thrombosis (DVT): anticoagulation and observation. Each of these options had a relative importance to the decision maker and they were valued in terms of utility.

The advantage of MII includes the joint effects of all the inputs when evaluating sensitivities of an input. The mutual information is a more direct of the probabilistic relatedness of two random variables than other measures, such as correlation coefficients. For example, the correlation coefficient of two random variables examines the degree of linear relatedness of the variable. Although two uncorrelated variables may not be independent, two variables with zero mutual information are statistically independent. Therefore, the MII is a more informative method. The results can be presented graphically, thus facilitating their comprehension.

The disadvantage of this method is that the calculation of the MII Monte Carlo techniques suffers from computational complexity, making practical application difficult. Another approach has been suggested using symbolic algebra, which is reported to be less computationally intensive. Because of the simplifying approximation that may be used in MII, the robustness of ranking based on the sensitivity measure can be difficult to evaluate.

5.4.10 Scatter plots

A scatter plot is a graphical sensitivity analysis method. Scatter plots are used for visual assessment of the influence of individual inputs on an output. A scatter plot is a method often used after a probabilistic simulation of the model. Scatter plots are also often used as a first step in other analyses, such as regression analysis and RS methods.

Each realization in a probabilistic simulation, such as a Monte Carlo simulation, generates one pair of an input value and the corresponding output value. These simulated pairs can be plotted as points on a scatter plot. Scatter plots depict the possible dependence between an input and the output. Dependence may be linear or nonlinear. The range of variation of the output may be constant regardless of the specific value of the input, or it may be non constant. Scatter plots may be based on sample values or based on the ranks of the values. Because scatter plots can help visualize and identify potentially complex dependencies between input and output, they can be used to guide the selection of appropriate sensitivity analysis methods. For example, if the relationship is nonlinear, then a nonlinear regression model, or a transformation of the data, may be required.

Scatter plots have been used as an aid to sensitivity analysis in various fields, including behavioural studies, environmental pollution, plant safety, medical science, and veterinary science. As an example, Moskowitz, 1997, used consumer-based product evaluation to identify optimal product formulations for ready-to-eat cereal. Several physical attributes of the cereal, such as appearance, colour, flavour, and quality, which depend on parameters (or inputs) such as the amount of sweeteners and starch, die size, and roasting time, have an impact on how much the customer likes the cereal.

The advantage of this method is that Scatter Plots are often recommended as a first step in sensitivity analysis of a statistical sample of data, whether it is an empirical sample or the result of a probabilistic simulation. A key advantage of scatter plots is that they allow for the identification of potentially complex dependencies. An understanding of the nature of the dependencies between inputs and an output can guide the selection of other appropriate sensitivity analysis methods.

A potential disadvantage of scatter plots is that they can be tedious to generate if one must evaluate a large number of inputs and outputs unless commercial software to automatically generate multiple scatter plots. Although not necessarily a disadvantage, the interpretation of scatter plots can be qualitative and may rely on judgement. Whatever the sensitivities of two inputs differ significantly from each other cannot be judged from their scatter plots.

5.5 Sensitivity analysis using AHP

It is often desirable to test the responsiveness or sensitivity of the outcome of a decision to changes in the priorities of the major criteria of that problem. What one does is to change the priority of that criterion keeping the proportions of the priorities for the other criteria the same so again they all, including the changed criterion, add to one. The software Expert Choice has at least five ways to display the result of such sensitivity changes.

5.5.1 Performance sensitivity

All information about how alternatives behave on each of the criteria is put in a single graph. Each criterion is represented by a vertical line and the points at which the lines representing the alternatives cross that line indicate the values the alternatives have for that criterion, as measured on the right hand scale. The vertical line next to the right hand scale, labelled overall, show that the composite weight for each alternative as do the intersections with the scale itself. The priority of a criterion is shown by the height of its rectangle as read from the left scale (Saaty, 1995).

5.5.2 Dynamic sensitivity

Both criteria and alternatives are represented by horizontal bars on the left and on the right respectively. Varying the length of the criteria bars gives rise on the appropriate variations in the lengths of the bars representing the priorities of the alternatives. When one criterion bar is moved outward for example the others automatically and proportionately move inward (Saaty, 1995).

5.5.3 Gradient sensitivity

It shows the variation of the priorities of alternatives corresponding to variations in the priority in single criteria. The intersection of the vertical line with the horizontal scale shows the actual values of the criterion as it arises in the problem. The intersection of the alternatives' lines with the left hand vertical scale, represent the alternatives' priorities. Moving this line to the left or to the right shows how the alternatives' priorities change as the priority of the criterion changes (Saaty, 1995) and (Chang, at el., 2007).

5.5.4 Two dimension plot

It shows how well the alternatives (represented by cycles) perform with respect to pairs of criteria one on the x-axis and the other on the y-axis. The figure here shows their projection on the diagonal of the rectangle. The farther out on this composite line the projection of a point falls, the better that the alternative rates on the two criteria.

5.5.5 Weight differences sensitivity

The lengths of the horizontal bars show the difference of each pair of alternatives, here given for the alternative1 priority and the alternative2, on each of the criteria. If it is positive it is in favour of the alternative1 (represented on the right), if it is negative it is in favour of alternative2 (represented on the left). The overall difference scale is the bottom line in the figure. All pairs of alternatives may be examined in this way.

5.6 Sensitivity analysis of power generation technology selection

Before selecting and choosing any of the nine input factors, it is important to see the output of the model and most important factors effecting this decision (factor weight) and the factor significance.

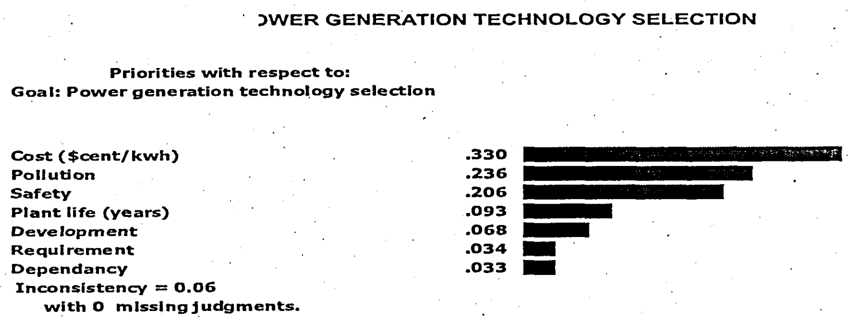
From graph (5.2), it is clear that the importance of these determine factors are as follows respectively:

Table 5.2 The weight of different criteria determining goal

Criteria name	**Weight %**
Cost	33
Pollution	23.6
Safety	20.6
Plant life	9.3
Development	6.8
Requirement	3.4
Dependency	3.3
Inconsistency = 0.06	

As it can be clearly seen from graph (5.2) that cost has the highest effect and weight among these criteria, it is more logical to vary the criteria and sub criteria according to their weight and with higher importance.

The cost is the combination of the three sub-criteria namely as, capital cost, fuel cost and operation & maintenance cost.



Graph (5.2) The priorities of different criteria with respect to power generation technologies

The first criterion is the cost of the power generation which has the highest significant weight affecting the output decision of this research work.

The first sensitivity analysis calculation to be conducted is the capital cost,

From the AHP software, the total of the three above sub-criteria should be added to 1 (unity).

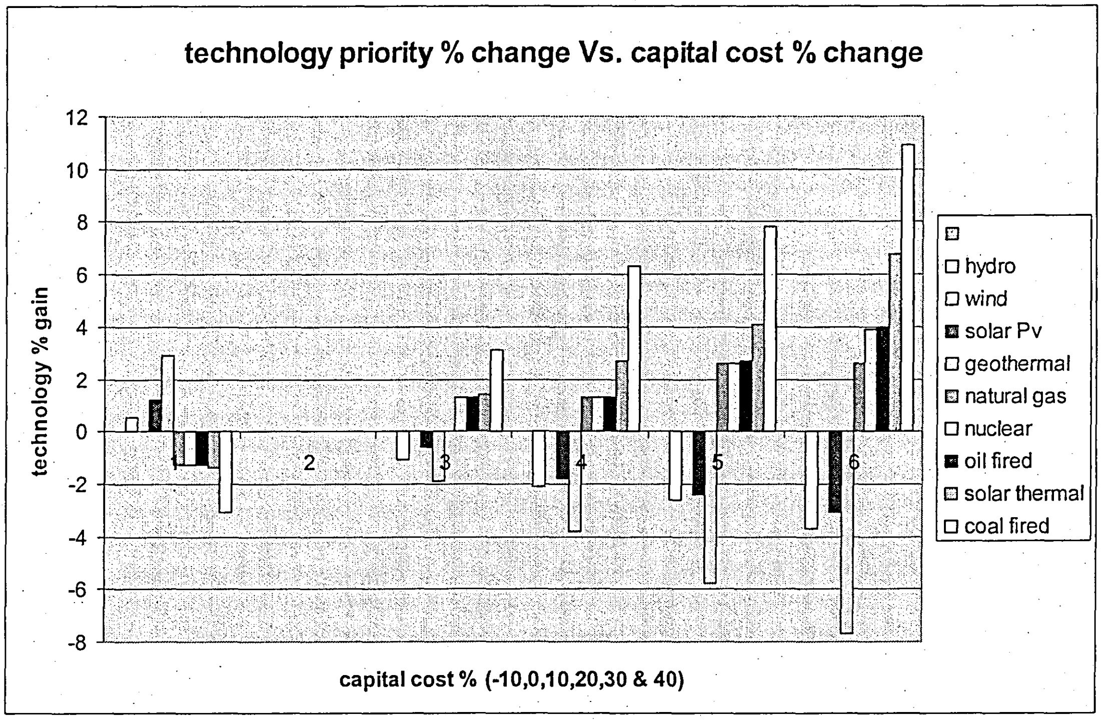
And hence, we can look to the AHP results before analysing the sensitivity analysis.

The percentage of the capital cost participation of the total cost is 49.7%, the fuel cost percentage is 36.9% and the operation and maintenance percentage is 13.4%.

The first criterion to be varied is the capital cost and what impact has it got on different technologies priorities gain of loss is given in table 5.3.

Table (5.3) The capital cost change and the percentage priority technology gain

Capital cost %	Hydro	Wind	Solar PV	Geothermal	Natural gas	Nuclear	Oil fired	Solar thermal	Coal fired
-10	0.53	0	1.22	2.9	-1.3	-1.3	-1.3	-1.4	-3.1
0	0	0	0	0	0	0	0	0	0
10	-1.1	0	-0.6	-1.9	0	1.3	1.3	1.4	3.1
20	-2.1	0	-1.8	-3.8	1.3	1.3	1.3	2.7	6.3
30	-2.6	0	-2.4	-5.8	2.6	2.6	2.7	4.1	7.8
40	-3.7	0	-3.1	-7.7	2.6	3.9	4	6.8	10.9



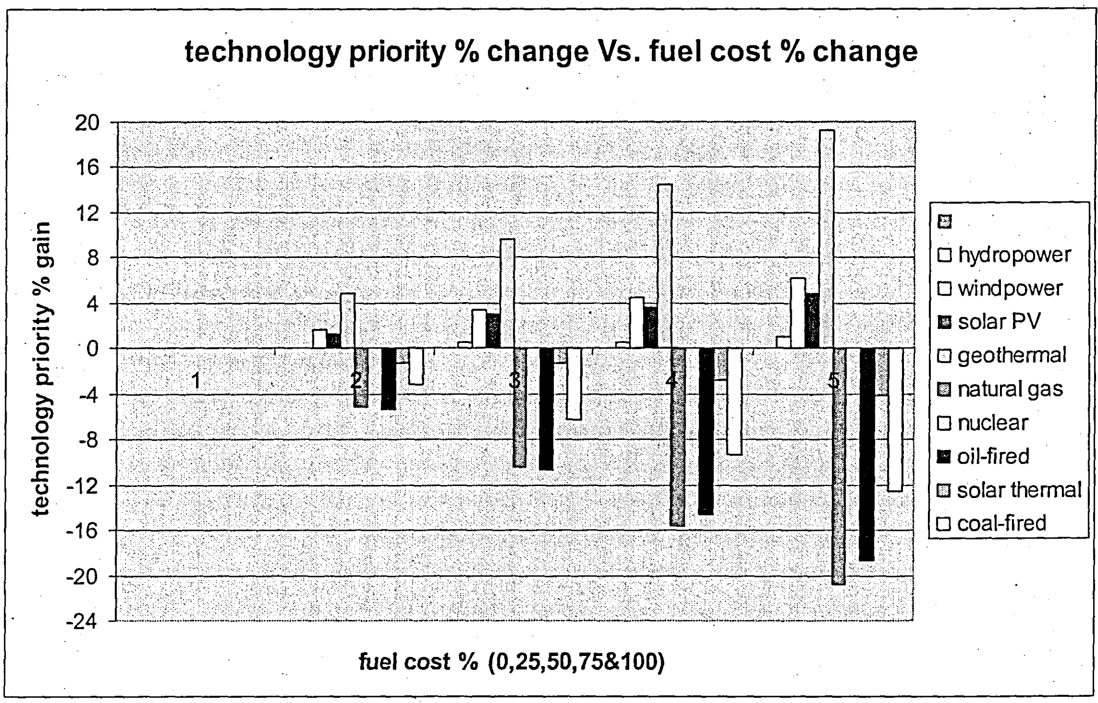
Graph (5.3) The technology percentage gain with a change in the capital cost.

From table (5.3) and the graph (5.3), it can be seen and concluded that the coal fired technology has the highest priority percentage gain when the capital cost is varied from -10, 0, 10, 20, 30 and 40%. The second significant criterion is the solar thermal technology has the second priority percentage gain when the capital cost is changed. It can be explained that the technologies which depend on fossil fuels have made the largest gain among other technologies results.

The second important criterion is the fuel cost and how different technologies priority percentage change when the fuel cost varies from the core value to 100%.

Table (5.4) The impact of fuel cost varying on different technologies percentage gain.

Fuel cost %	Hydro	Wind	Solar PV	Geothermal	Natural gas	Nuclear	Oil fired	Solar thermal	Coal fired
25	0	1.695	1.22	4.808	-5.195	0	-5.3	-1.37	-3.13
50	0.53	3.39	3.049	9.615	-10.39	0	-10.67	-1.37	-6.25
75	0.53	4.52	3.659	14.423	-15.58	0	-14.67	-2.74	-9.38
100	1.05	6.512	4.878	19.2	-20.78	0	-18.67	-4.11	-12.5



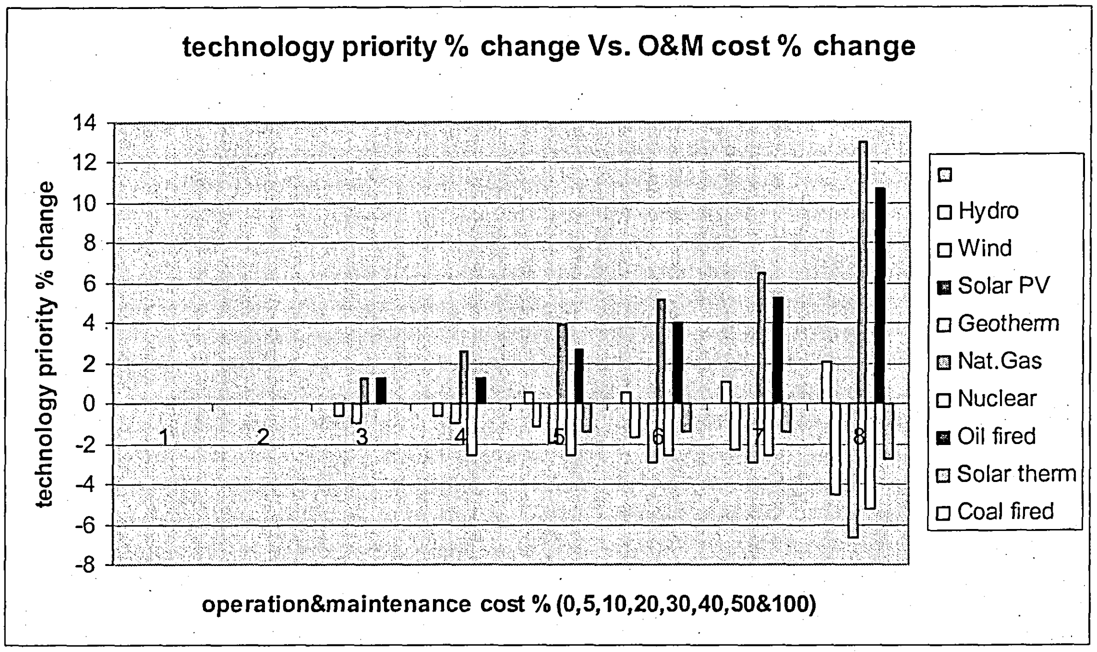
Graph (5.4) The technology priority percentage change with the fuel cost varying

From table (5.4) and graph (5.4), it can be seen and concluded that the priority percentage of the geothermal technology has the highest significant gain. And the second significant priority technology percentage gain is the wind power technology.

The third criterion is the operation and maintenance (O&M) and different priority technologies percentage change when the operation and maintenance varies.

Table (5.5) The operation and maintenance cost and different technologies change.

O &M cost %	Hydro	Wind	Solar PV	Geothermal	Natural gas	Nucle ar	Oil fired	Solar thermal	Coal fired
5	0	0	0	0	0	0	0	0	0
10	0	-0.57	0	-0.96	1.3	0	1.3	0	0
20	0	-0.57	0	-0.96	2.6	-2.58	1.3	0	0
30	0.526	-1.13	0	-1.90	3.9	-2.58	2.67	-1.4	0
40	0.526	-1.69	0	-2.88	5.2	-2.58	4	-1.4	0
50	1.05	-2.26	0	-2.88	6.5	-2.58	5.3	-1.4	0
100	2.10	-4.52	0	-6.70	13	-5.20	10.7	-2.74	0



Graph (5.5) The effect of operation & maintenance cost on technologies priority percentage gain

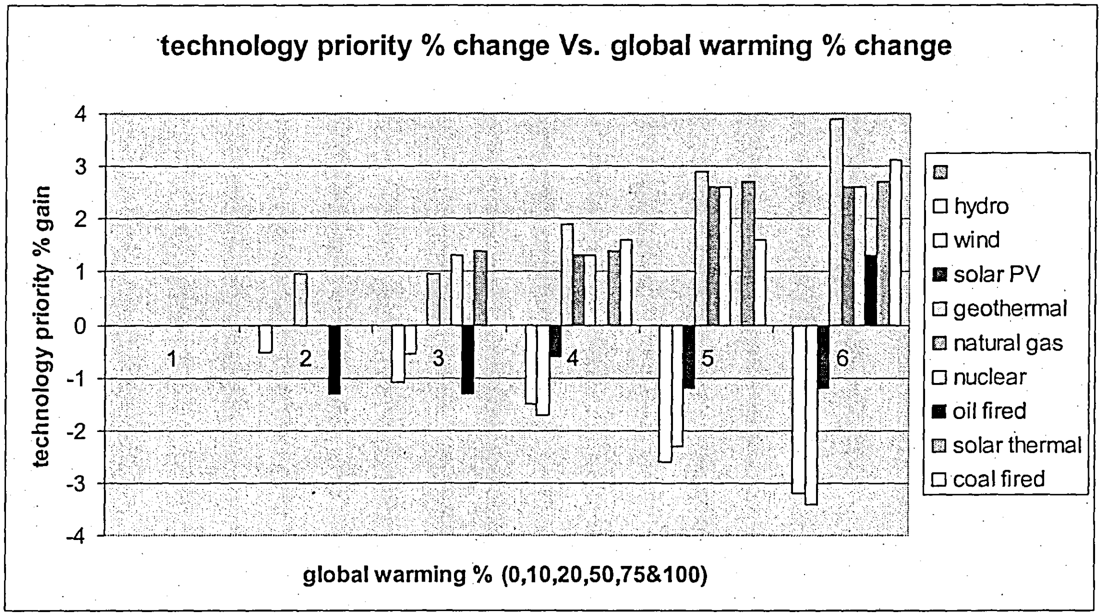
From table (5.5) and graph (5.5), it can be seen and concluded very clear that the highest significant technology priority gain is the natural gas power generating technology. The second significant technology priority gain is the oil fired power generating technology.

The second criterion which has the second significant effect by looking to table (2.2) and graph (2.2) is the pollution and its three sub-criteria are global warming, air pollution and thermal pollution.

The first of the mentioned three to execute and to check its sensitivity and its effect on the output decision is the global warming.

Table (5.6) The global warming percentage change and its impact on different technologies percentage change.

Global warming	Hydro	Wind	Solar PV	Geothermal	Natural gas	Nuclear	Oil fired	Solar thermal	Coal fired
0	0	0	0	0	0	0	0	0	0
10	-0.53	0	0	0.96	0	0	-1.3	0	0
20	-1.1	-0.56	0	0.96	0	1.3	-1.3	1.4	0
50	-1.5	-1.7	-0.6	1.9	1.3	1.3	0	1.4	1.6
75	-2.6	-2.3	-1.2	2.9	2.6	2.6	0	2.7	1.6
100	-3.2	-3.3	-1.2	3.9	2.6	2.6	1.3	2.7	3.1



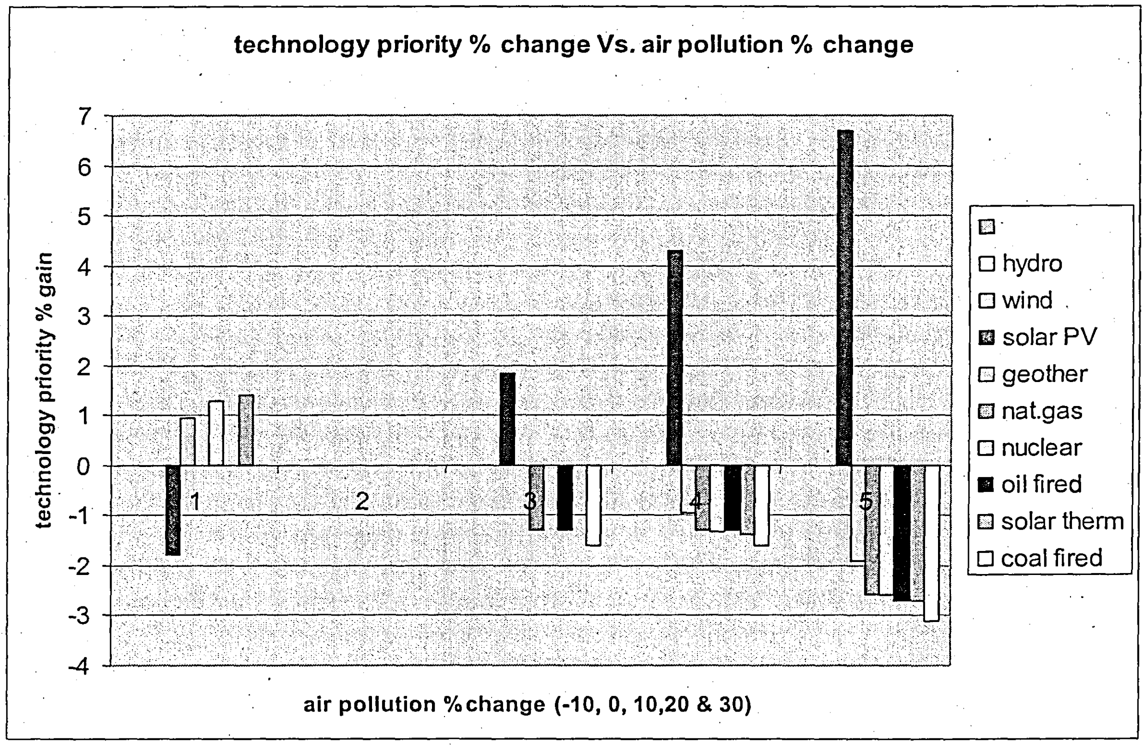
Graph (5.6) The global warming percentage change verses different technologies priority percentage gain.

From table (5.6) and the graph (5.6), it can be seen and concluded that the geothermal power generation technology has the highest priority percentage gain. The second priority percentage gain is the coal fired technology and the third priority percentage gain is the solar thermal power technology.

The second sub-criteria is the air pollution to be examined and how it is effecting the output decision.

Air pollution	Hydro	Wind	Solar PV	Geothermal	Natural gas	Nuclear	Oil fired	Solar thermal	Coal fired
-10	0	0	-1.8	0.96	0	1.3	0	1.4	0
0	0	0	0	0	0	0	0	0	0
10	0	0	1.83	0	-1.3	0	-1.3	0	-1.6
20	0	0	4.3	-0.96	-1.3	-1.32	-1.3	-1.4	-1.6
30	0	0	6.7	-1.9	-2.6	-2.6	-2.7	-2.7	-3.1

Table (5.7) The air pollution percentage change and the change in different technologies percentage change.



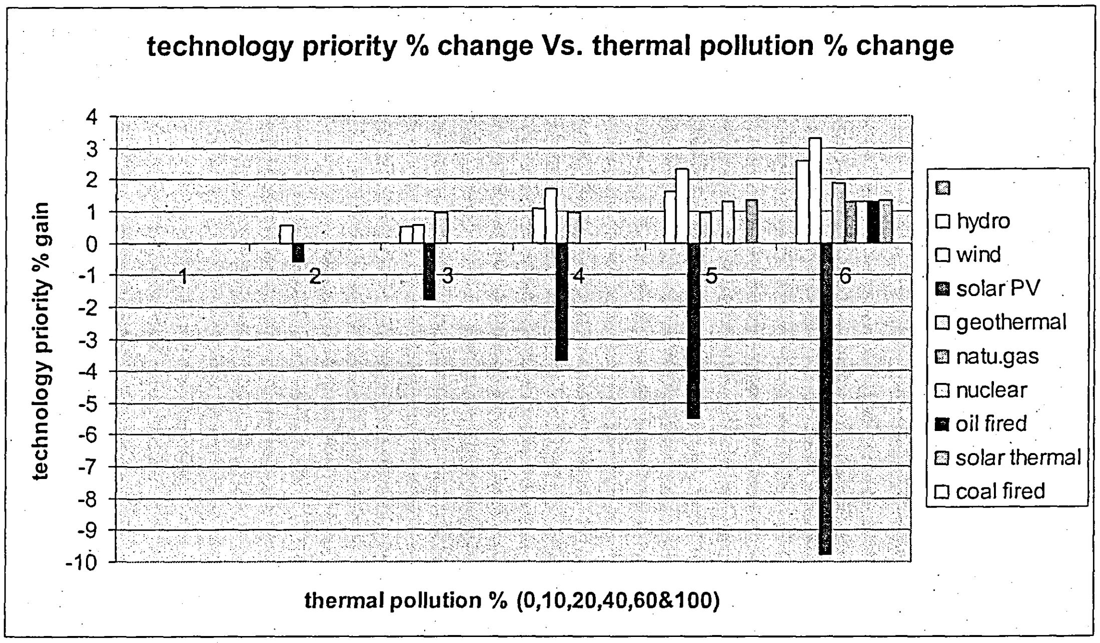
Graph (5.7) The air pollution effect on different technologies priority percentage gain.

From table (5.7) and the graph (5.7), it can be seen and concluded that the sensitivity analysis shows that the possible change from -10 to 30 % of air pollution results the highest technology priority percentage gain is the solar photovoltaic.

The third sub-criteria to be sensitivity analysed is the thermal pollution and how it is effecting the output decision of hard technology priority.

Table 5.8 The effect of thermal pollution change on the different hard technology.

Thermal pollution	Hydro	Wind	Solar PV	Geothermal	Natural gas	Nuclear	Oil fired	Solar thermal	Coal fired
0	0	0	0	0	0	0	0	0	0
10	0	0.56	-0.61	0	0	0	0	0	0
20	0.53	0.56	-1.8	0.96	0	0	0	0	0
40	1.1	1.7	-3.7	0.96	0	0	0	0	0
60	1.6	2.3	-5.5	0.96	0	1.3	0	1.37	0
100	2.6	3.3	-9.8	1.9	1.3	1.3	1.3	1.37	0



Graph (5.8) The thermal pollution change and effect on different technologies priority.

Table (5.8) and graph (5.8) show that the highest technology priority percentage change is the wind power technology and the second power technology is the hydropower technology when the thermal pollution varies up to 100%.

The rest of the criteria varying have no significant effect on the final output decision whatsoever.

5.7 Conclusions on results and sensitivity analysis

After the data is analysed using the AHP (Analytic Hierarchy Process) software to reach the decision and the goal of this research work. The goal is to select appropriate power generation technology of generating electricity for developing countries. The second part is conducting the sensitivity analysis of this decision.

Nine different power generation technologies have been included in this study they are hydropower technology, wind power technology, solar photovoltaic power technology, geothermal power technology, natural gas technology, nuclear power technology, oil fired power technology, solar thermal power technology and coal fired power technology.

Using the AHP software, the results were obtained as illustrated in table (5.1) and graph (5.1).

It is very clear that renewable alternative technologies which have the lowest effect on the environment that means less polluting the environment and do not need any fuel to operate are the most significant technologies with respect to the goal which make them the best power generation technologies to build and use to generate electrical power for developing countries.

The second part of the conclusion is the sensitivity analysis and varying the input sub-criteria and seeing their effect on the decision and from the tables and the graphs, some results were obtained.

From table (5.1) and graph (5.1), it can be seen and concluded that the coal fired technology has the highest priority gain when the capital cost is varied from -10, 0, 10, 20, 30 and 40%. The second significant is the solar thermal technology has the second priority gain when the capital cost is changed.

From table (5.2) and graph (5.2), it can be seen and concluded that when the fuel cost is under sensitivity analysed that the priority percentage of the geothermal technology has the highest significant gain. And the second significant priority percentage technology gain is the wind power technology.

From table (5.3) and graph (5.3), it can be seen and concluded that when the operation and maintenance cost is varied the highest significant technology priority gain is the natural gas electrical generating technology. The second significant technology priority gain is the oil fired electrical generating technology.

From table (5.4) and graph (5.4), it can be seen and concluded when the global warming criterion is varied that the geothermal power generation technology has the highest priority percentage gain. The second priority percentage gain is the coal fired and the third priority percentage gain is the solar thermal power technology.

From table (5.5) and graph (5.5), it can be seen and concluded when the air pollution is varied that the sensitivity analysis shows that the possible change from -10 to 30 % results that the highest technology priority percentage gain is the solar photo voltaic.

From table (5.6) and graph (5.6), it can be seen and concluded that when the thermal pollution criterion is varied, the highest technology priority percentage change is the wind power technology and the second power technology is the hydropower technology when the thermal pollution varies up to 100%.

The rest of criteria have no effect when varied on the output hard technology selection power generation technologies.

CHAPTER SIX

TECHNOLOGY INDICATORS, SOFT TECHNOLOGY IDENTIFICATION AND INTEGRATION OF TECHNOLOGIES FOR POWER GENERATION

6.1 Introduction

Literature on "soft technologies" is limited, particularly in power generation. Therefore, the internationally accepted indicators were looked up to identify critical soft technologies applied to power generation.

This chapter is divided into two main parts. The first part is focused on internationally accepted technology indicators. The second part of it is concerned with the identification of relevant soft technologies in power generation. The limitations of the hard technologies for power generation are determined. And also the soft technologies matrix is included related to the hard technology options. Finally in the chapter, the integration process between hard and soft technologies is explained in details.

6.2 Technology indicators

Indicators can provide crucial guidance for decision-making in a variety of ways. They can translate physical and social science knowledge into manageable units of information that can facilitate the decision making-process. They can help to measure and calibrate progress towards sustainable development goals. They can provide an early warning, sounding the alarm in time to prevent economic, social and environmental damage. They are also important tools to communicate ideas, thoughts and values because as one authority said, "We measure what we value, and value what we measure (United Nations, 2001).

Science and technology (S&T) indicators can also measure the technological capabilities at a country level if they are based on actual statistical data that reflect the real life of the technological process.

The African Ministerial Conference on science and technology, November, 2003 regarding the new partnership for African development (NEPAD) endorsed the compilation of indicators for scientific research, technological development and innovation activities. It also stressed that it is a priority for all African countries to have comprehensive national science, technology and innovation policies with emphasis on the development of effective National System of Innovation. The document draws on the advice of the experts working group to provide a conceptual framework and guide lines for developing indicators of science and technology and innovation activities and the existence of related national policies.

6.3 Indicators (why)

An indicator is a statistic measure, such as gross domestic product (GDP), or population, or combination of statistics, such as GDP per capita, which tells the public and the policy maker about the state of the economy and the society. Indicators can be used by public to participate in public policy debate and policy makers can use them to support the design and monitoring of evidence-based policy.

African countries recognise the importance of science, technology and innovation in economic and social changes and sustainable development. These activities are also a key to attaining the goals of the New Partnership for African Development (NEPAD), and the United Nations Millennium Development Goals (MDGs).

For African countries there is also a need to develop African science and technology industrial indicators (ASTII) to support monitoring and benchmarking the state of the innovation system.

6.4 Indicators used for the following reasons

Indicators are important to show the image and the state of the country among others and here are some good reasons and explanations what indicators can do.

6.4.1 Monitoring present and past

Government and civil society need indicators to understand the state of the system, to support the development of evidence-based policy, and the public policy debate which is important for policy research institutes, universities and industry. Here are some examples:

The ratio between gross domestic expenditure on R&D and the gross domestic product of a country, the number of university graduates in science and engineering, the value of imports of capital equipment.

Indicators in general describe the present state of the system, or as close as indicators can come to doing that, and permit the comparison with the past. The principal requirement for an indicator used for monitoring is that it has to be comparable over time.

6.4.2 Benchmarking present and future

The same indicators used for monitoring can be used for benchmarking. The difference is that they are compared with target values of the indicators for some other system, or for some future time.

The indicators support debate on how to move from the present state of the indicator to the desired target. The debate may point to the need for additional indicators that illuminate the paths to be followed.

An example is the Lagos target of a ratio of R&D spending to GDP (gross domestic product) of 1 % for African countries by 2008.

It becomes immediately evident that indicators of number of people engaged in research at the present time are needed, to suggest how many will be required if the target is to be achieved. Sometimes the target may not be achieved, but functioning of the system may have been improved. This is an important issue of any benchmarking exercise.

6.4.3 Foresight present and future

Foresight is a process focused on a technology or a set of practices. It involves participants expert in the subject who meet to discern, based on their expert knowledge, the future trajectories of the subject and the interventions which might improve its development.

One example is the future of 'voice over internet protocol' (VOIP) as it could provide inexpensive telecommunications worldwide.

The relevant indicator would be the penetration of the use of the internet by business and by the individuals.

These are core indicators in the World Summit of the Information Society (WSIS, 2005).

6.4.4 Evaluation present and past

Evaluation tends to be project based and answers questions about whether the objects were achieved or are being achieved, and if so, whether this is being done in the most efficient and effective manner. These indicators might be compared against national or regional indicators to situate the project within an existing community of practice.

6.5 Important indicators to S&T

1- Gross Domestic Product (GDP) per capita,

It is obtained by dividing annual or period GDP at current market prices by population, a variation of the indicator could be the growth of real GDP per capita.

2- Net Investment share in gross domestic product, This indicator measures the net share of investment in relation to total production. It is obtained by dividing gross production capita formation by GDP, both at purchasers' prices.

3- Share of Manufacturing Value-added in Gross Domestic Product (MVA).

This indicator measures the contribution of manufacturing sector in total production. It is obtained by dividing the value added in manufacturing by the total gross value-added to GDP at basic producers prices.

4- Foreign Direct Investment (FDI)

It is defined as the value of net flows of foreign direct investment.

5- Share of Manufactured Goods in total Merchandise Exports

This indicator is defined as the percentage share of manufactured goods in total merchandise exports.

6- Technical Cooperation Grants

The indicator represents technology transferred through-non commercial sources.

7- Share of Consumption of Renewable Energy Resources,

This indicator measures the proportion of energy mix between renewable and non-renewable energy.

8- Proven Fossil Fuel Energy Resources

The purpose of the indicator is to measure availability of fossil fuel energy resources.

9- Lifetime of Proven Energy Resources

It is known as the production life index, the ratio of the energy reserves remaining at the end of any year to production of energy in that year.

10- Intensity of Material Use,

The intensity of material use provides a good indication of long-terms trends in changing consumption patterns of the key non-fuel, non-renewable natural materials.

11- Scientific and Educational Institutions,

Organisations teach science and engineering knowledge.

12- R&D Institutions,

Organisations conduct the R&D activities in different sectors.

13- Scientific and Networking Organisations

The purpose is to link individual scientist to others and to their socio-economic environment.

14- Human Development Index (HDI)

This indicator aggregates three measures that are; life expectancy, education, and GDP together.

15- Literacy Rate (%), the ability to read and write.

16- Population Size, the human inhabitants of a given country.

17- Technical Enrolment Index

The number of student enrolled in the science, maths and engineering in the universities and educational institutes.

18- Number of Researches, represents the number of researchers working in engineering, science and industrial sectors.

19- The Quality of Higher Education

This indicator can show the country's higher educational system and the amount of research production and publications related to technical promotion and industrial innovation.

20- Number of Scientific Publications

As an output indicator for S&T to show the performance of the output indicator and measured by the number of publications in the science and technology field (country self publications, joinet publications and publications with cooperation with foreign institutes).

6.6 Composition of Indexes

There are some composite indexes measuring technological capabilities and these are as follows:

A- The World Economic Forum Technology Index (WEF)

B- United Nations Development Program (UNDP), Technology Achievement Index (TAI).

C- Archibugi and Coco (ArCo).

D- United Nations Industrial Development Organisation (UNIDO) and Industrial Development Scoreboard.

E- The Science and Technology Capacity Index (RAND).

6.6.1 The WEF technology index

Includes three main categories of technology:

a- Innovation capacity (measured by a combination of: patents granted at USPTO, tertiary enrolment ratio, and survey data);

b- ICT diffusion (measured by Internet, telephone, PCs, and survey data); and

c- Technology transfer (measured by non-primary exports and survey data).

6.6.2 The UNDP technology achievement index

There are four dimensions of technology achievement considered, each of which is base on two indicators;

a- Creation of technology (based on patents registration at their national offices).

b- Diffusion of newest technologies (based on Internet hosts, medium-and high technology exports).

c- Diffusion of oldest technologies (based on telephone mainlines and electricity consumption).

d- Human skills (based on years of schooling and tertiary science education).

6.6.3 The technological capabilities index (ArCo)

This index takes three dimensions of technology into account:

a- Innovative capacity (based on patents registered at US patent office and scientific publications);

b- Technology infrastructure (including old and new ones based on internet, telephone mainlines and mobile, and electricity consumption);

c- Human capital (based on scientific tertiary enrolment, years of schooling and literacy rate).

Another indicator or component may be added namely;

d- Important technology (based on the possibility of a country to access technology developed elsewhere). This index considers three other indicators namely:

1- Inward foreign direct investment (FDI);

2- Technology licensing payment and import of capital goods.

6.6.4 The industrial development scoreboard (UNIDO)

This index considers four categories:

a- Technological effort (based on patents at the US patent office and enterprise financed R&D);

b- Competitive industrial performance (based on manufactured value added (MVA)), medium and high-technology share in MVA, manufactured exports, and medium and high-technology share in exports);

c- Technology imports (based on FDI, foreign royalties payment, and capital goods); and

d- Skills and infrastructures (based on tertiary technical enrolment and telephone mainlines).

6.6.5 Science and technology capacity index (STCI)

Three categories are used in this indicator:

a- Enabling factors (based on GDP and tertiary science enrolment);

b- Resources (based on R&D expenditure, number of institutions and the number of scientists and engineers).

c- Enabling knowledge (base on patents, S&T publications and co-authored scientific and technical papers).

6.7 Selection of important indicators

These indicators are the most recognised as important indicators for a country. These also represent the economic situation, foreign investment, R&D state, human development index, diffusion of ICT and some other important indicators.

Table 6.1, presents the important indicators recognised by some international organisation such as United Nations Industrial Development Organisation, United Nations Development Programs, World Bank, International Monetary Fund, World Economic Forum Technology Index and United Nations University. Also, these indicators are recommended by some publications.

Table 6.1 The most important indicators recognised by international organisations

Current list of indicators											
	Used by International Organisations						**Literature (publications)**				
	UNIDO	UNDP	WB	IMF	WEF		Lall., 2003	DA,AC.,2004	Unu.2006	Samia&Nour,2005	
GDP	X	X						X		X	
Investment share in GDP	X										
Manufacturing value added (MVA) in GDP	X						X				
Forign direct investment FDI	X		X	X			X				
Share of manufacturing in total exports	X						X				
R&D Institutes, & Universities	X	X						X	X	X	
Scintific Network organisations	X	X			X						
HDI	X	X						X	X	X	
Literacy rate (%)		X						X			
Tertiary technical enrolment ratio	X	X			X					X	
Quality of High education	X									X	
Number of scientifc publications	X						X	X		X	
R&D expenditure							X	X	X		
Scientists & engineers in R&D	X	X						X		X	
H. &mediume technology exports (%) manuf. exports	X	X			X		X			X	
Diffusion of ICT	X		X				X	X		X	

Table 6.2 The international technology leaders and indicators values

Technology leaders											
				Technology creation		Diff. recent innovation		Diff. old innovation		Human skill	
	GDP,us$bill	TAI	HDI.2004	patent/mill	recipents of roy.us$/1000	intent host/1000	H.M tech.exprt%	telephone main/1000	electricity Kwh/cap	mean yrs.school	tertiart science enrol%
Finland	209.45	0.7	0.947	187	125.6	200.2	50.7	1203	14129	10	27.4
USA	13201.82	0.7	0.948	289	130	179.1	66.2	993	11832	12	13.9
Swedon	384.93	0.7	0.951	271	156.6	125.8	59.7	1247	13955	11.4	15.3
Japan	4340.13	0.7	0.949	994	64.6	49	80.8	1007	7322	9.5	10
Korea, rep.	888.02	0.7	0.912	779	9.8	4.8	66.7	938	4497	10.8	23.3
Netherland	657.59	0.6	0.947	189	151.2	136	50.9	1042	5908	9.4	9.5
UK	2345.02	0.6	0.94	82	134	57.4	61.9	1037	5327	9.4	14.9
Canada	1251.46	0.6	0.95	31	38.6	108	48.7	881	15071	11.6	14.2
Australia	768.18	0.6	0.957	75	18.6	125.9	16.2	862	8717	10.9	25.3
Singapor	132.16	0.6	0.916	8	25.5	72.3	74.9	901	6771	7.1	24.2

Table 6.3 The potential leaders and indicators values

Technology potential leaders											
				Technology creation		Diff. recent innovation		Diff. old innovation		Human skill	
	GDP,us$bill	TAI	HDI.2004	patent/mill	recipent of roy.us$/1000	intent host/1000	H.M tech.exprt %	telephone main/1000	electricity Kwh/cap	mean yrs.school	tertiart science enrol %
Spain	1224	0.5	0.938	42	8.6	21	53.4	730	4195	7.3	15.6
Italy	1844.7	0.5	0.94	13	9.8	30.4	51	991	4431	7.2	13
Cech.rep	141.8	0.5	0.885	28	4.2	25.4	51.7	560	4748	9.5	8.2
Hungary	114.3	0.5		26	6.2	21.6	63.5	533	2888	9.1	7.7
Slovenia	37.3	0.5	0.91	105	4	20.3	49.5	687	5096	7.1	10.6
Hong Kong	189.8	0.5	0.927	6	"	33.6	33.6	1212	5244	9.4	9.8
Slovakia	54.97	0.4		24	2.7	10.2	48.7	478	3899	9.3	9.5
Greece	244.92	0.4	0.921	(..)	0.01	16.4	17.9	839	3739	8.7	17.2
Malaysia	150.9	0.4	0.805	"	0	2.4	67.4	340	2554	6.8	3.3
Mexico	839.2	0.4	0.821	1	0.4	9.2	66.3	192	1513	7.2	5

Table 6.4 The technology dynamic adopters countries and their indicators values

Technology dynamic adopters											
				Technology creation		Diff. recent innovation		Diff. old innovation		Human skill	
Country	GDP,us$bill	TAI	HDI.2004	patent/mill	recipents of roy.us$/1000	internet host/1000	H.M tech.exprt %	telephone main/1000	electricity Kwh/cap	mean yrs.schol	tertiary science enrol%
South Africa	255.2	0.34	0.653	"	1.7	8.4	30.2	270	3832	6.1	3.4
Thailand	206.2	0.337	0.784	1	0.3	1.6	48.9	124	1345	6.5	4.6
Thrindad & Tob	19.3	0.328	0.809	"	0	7.7	14.2	246	3478	7.8	3.3
Panama	17.1	0.321	0.809	"	0	1.9	5.1	251	1211	8.6	8.5
Brazil	1067.7	0.311	0.792	2	0.8	7.2	32.9	238	1793	4.9	3.4
Philippines	116.3	0.3	0.763	(..)	0.1	0.4	32.8	77	451	8.2	5.2
China	2630	0.299	0.768	1	0.1	0.1	39	120	746	6.4	3.2
Colombia	135.8	0.274	0.79	1	0.2	1.9	13.7	236	866	5.3	5.2
Egypt	107.5	0.236	0.702	(..)	0.7	0.1	8.8	77	861	5.5	2.9
Indonesia	364.5	0.211	0.711	0.211	"	0.2	17.9	40	320	5	3.1

Table 6.5 The international technology marginalised countries and indicators values

Technology marginalised											
				Technology creation		Diff. recent innovation		Diff. old innovation		Human skill	
Country	GDP,us$bill	TAI	HDI.2004	patent/mill	recipents of roy.us$/1000	internet host/1000	H.M tech. exprt %	telephone main/1000	electricity Kwh/cap	mean yrs.schol	tertiary science enrol%
Nicaragua	5.4	0.2	0.693	"	"	0.4	3.6	39	281	4.6	3.8
Pakistan	128.99	0.2	0.539	"	(..)	0.1	7.9	24	337	3.9	1.4
Senegal	8.94	0.2	0.46	"	0.01	0.2	28.5	27	111	2.6	0.5
Ghana	12.2	0.1	0.532	(..)	"	(..)	4.1	12	289	3.9	0.4
Kenya	21.2	0.1	0.491	(..)	(..)	0.2	7.2	11	129	4.2	0.3
Nepal	8.1	0.1	0.526	"	0	0.1	1.9	12	47	2.4	0.7

Table 6.6 The poor technology countries (others) and indicators values

Technology (Others)											
				Technology creation		Diff. recent innovation		Diff. old innovation		Human skill	
Country	GDP,us$bill	TAI	HDI.2004	patent/mill	recipents of roy.us$/1000	interrnet host/1000	H.M tech.exprt %	telephone main/1000	electricity Kwh/cap	mean yrs.schol	tertiary science enrol %
Bangladesh	61.96	"	0.53	(.)	(.)	0	2.9	5	81	2.6	"
Botswana	10.3	"	0.57	1	"	2.7	0	150	"	6.3	1.6
Denmark	275.2	"	0.943	52	"	114.3	41	1179	6033	9.7	10.1
Jordan	14.2	"	0.76	"	"	0.2	"	105	1205	6.9	"
Libya	50.3	"	0.789	"	"	(.)	1.8	"	3677	"	"
Saudi Arabia	309.8	"	0.777	"	(.)	0.3	5.2	170	4692	"	2.8

6.8 Comments on technology indicators

The first table 6.1 shows the most important accepted indicators recognised by some international organisations.

These International organisations are UNIDO, UNDP, WB, IMF and WEF. The organisation recognise some important indicators such as GDP, investment share in GDP, manufacturing value added (MVA) in GDP, foreign direct investment (FDI), share of manufacturing in total exports, R&D institutes and universities, scientific network organisations, human development index (HDI), literacy rate (%), quality of high education, tertiary technical enrolment ratio, number of scientific publications, R&D expenditure, scientists and engineers in R&D, high and medium technology exports (%) and diffusion of ICT.. These indicators are agreed by some others including publishers (Lall, 2003), (DA, AC, 2004) and (United Nations University, 2006).

Tables 6.2, 6.3, 6.4, 6.5 and 6.6 represent the indicators of different countries and their classifications that is leaders, potential leaders, dynamic adopters, marginalised of technology and others countries respectively.

6.9 Introduction to soft technology

As traditionally understood, 'technology' describes an operable knowledge system that is mainly derived from the knowledge of natural science. Here, this is referred to as 'hard technology', namely, the skills, tools and rules that are employed by humans to alter, accommodate (human can only accommodate nature, not control it) and manage nature for human survival and development.

Operable knowledge system derived from social sciences, non-natural sciences and non-scientific (traditional) knowledge aimed at solving various practical problems also belong to the category of 'technology'. This class of technology is referred to here as 'soft technology'. Soft technology comes about through the conscious use of common laws or experiences in economics, social and humanistic activities; soft technology then shapes the rules, mechanisms, means, institutions, methods and procedures that contribute to the improvement, adaptation or control of the subjective and objective world (Zhouying, 2001).

Therefore, in general, technology is composed of hard and soft technology. As economies develop and as technology changes, the boundary between hard and soft technology blurs. However, in general, we can say that hard technology is manifested mainly through material forms, while soft technology is manifested mainly through human psychology and behaviour. Here, 'hard' refers to the physical entities through which operations are conducted. 'Soft' refers to entities without physical form. In other words, 'hard' refers to tangible phenomena, while 'soft' refers to intangible phenomena (Zhouying, 2004).

Soft technology must, by definition, exhibit two general sets of characteristics: it must be technological and it must be soft.

From the vantage of its technological characteristics, the following can be said about soft technology:

a- It should be an operable knowledge system of tools, procedures and rules for the solution of problems.

b- It should be directed towards practices for providing 'services' for social change and economic development.

From the vantage point of its softness characteristics, the following can be said about soft technology:

1- Its operating fields include the process of human psychology and human social activity systems. The latter comprises those human behaviours controlled by and embodying human psychological activities related to perceptions, emotions and values. The various psychological, social and cultural factors are therefore the distinguishing parameters of soft technology.

2- The way in which soft technology provides service, besides tangible products, is mostly through intangible modes such as services, procedures, rules and institutions.

3- The meaning, functions and characteristics of soft technologies can be presented, formed, modified and expressed in ways that accommodate distinctive features of psychological activities and social environments in which they operate.

4- Soft technology can also affect our level of understanding the subjective and objective world around us.

In short, soft technology is the intellectual technology of creation and innovation centred in human thought, ideology, emotion, values, world views, individual and organizational behaviours, as well as in human society.

Table 6.7 The differences between hard and soft technologies (Zhouying, 2005)

	Standard	**Hard technology**	**Soft technology**
1	Sources	knowledge of natural science	knowledge of non-natural science and non traditional science
2	operational object	substance	human psychological action and social behaviour
3	operational field	physical world	spiritual world
4	operational goal	to change and control the nature and substance of material	to master, orchestrate and manage human ideology, emotion, thinking mode, values as well as the behaviour mode of individuals, groups and organizations
5	carrier	tangible substance	intangible human factors
6	technological parameter	physical factors	psychological, social and cultural factors
7	meaning of human factors	influence of extrinsic behaviour	1-influence of extrinsic behaviour-the performance of psychological action. 2-influence of extrinsic behaviour, viz., psychological action such as feeling, sensation, emotion, ideology, culture, value view, world view, tradition, individuality, etc.
8	position of human body	an organism; in the final analysis, a substance and cellular combination	a life that contains consciousness, sensation and spiritual dimensions
9	source of innovation	new inventions and discoveries	result of human's notions, life styles, values and points of view
10	characteristic of innovation	not necessary to destroy and can coexist with old system	need a creative new system to displace old broken system
11	process of innovation	materials-processing products; product design, manufacturing and marketing	dreams / originality _ forms systems / modes / methodology _exercise / regulations; design system and methodology _ run / implement _ cultivate the process from which the new institution grows _ displace the old system _ create and build new system
12	relationship with institutions	institutions are the environment of hard technology innovation and creation	institutions are the innovational environment of soft technology, on the contrary, soft-technology innovation is the content and basic of the new institutional innovation
13	whole and part	from part to whole	from whole to part
14	subjective purpose	independent of human will; no subjectivity	involves subjectivity; can be moulded, developed and affected by humans intellect, thinking modes and behaviours
15	mode of resolving problems	products and services	processes, rules, institutions, products and services
16	ontology	neutral	dualistic
17	standardization	tends towards standardization	involves strong individuality and is difficult to standardize
18	regional features	region-neutral	regionally specific

6.10 Characteristics of soft technology

Hard technologies and soft technologies, since they are both technologies, have many attributes in common. From the perspective of their intrinsic nature as technology, they both exhibit the following features:

1- They take the form of means, skills, tool, rules, mechanisms, methodologies or processes for the solution of problems.

2- They are intended to provide 'service' for social progress and economic development.

However, as it can be seen from the above table, when compared with hard technology, soft technology is completely new technological paradigm.

In general, soft technology contains the following characteristics when compared with hard technology:

1- Soft technology exhibits a closer relationship with humanity and culture. Soft technology takes the internal psychological activities and the external behaviours of human beings as its operational object and its content and levels are determined by its focus on the ways of thinking and action modes of human beings. Its application and popularization are directly related to local morality for particular times, cultural backgrounds, habits and knowledge levels, etc. Therefore, soft technology is a technology contains human thoughts, viewpoints and strong individuality and it controls the direction of hard technology application.

2- Soft technology embodies distinctive concepts of humanity and human factors. The concept of man is different in soft technology from hard technology where the object is 'outside the human body'. Although the human body is the operational object in western medical science and life science, it is treated as a 'physical' object or a complexity of cells and can be duplicated and cloned in the scientific sense; whereas in soft technology, the human body is regarded as an organic whole with consciousness, feelings, thoughts and values.

3- Soft technology is rooted in the spiritual world. The so-called spiritual world includes the abstract world (the object that is conceptualised through those actions processed in the immanent consciousness), the visual world (the reappearance of images of events through the memory and the mind's eye) and the presentational world (the reflection of sensory experience, emotion/mood and action, e.g., heartache, dread, enjoyment, etc.) Whereas abstract thinking operates concepts, visual thinking operated images and presentational thinking operates the consciousness itself.

4- Soft technology is not neutral. Soft technology is fundamentally dualistic. The dualism of soft technology stems from its dualistic functions, in that it simultaneously manifests both productive forces and the relations of production.

5- Soft technology is resistant to standardisation. The fact that soft technology embodies psychological, social and cultural factors creates sever obstacles to its standardisation. On the other hand, soft technology includes explicit and tactic technologies. The former can be presented by words, data, standardised procedures and general principles that are disseminated and shared by way of books, lectures and training; whereas the latter, which includes thinking technology and LPFE technology, cannot be properly presented in the form of written documents and formal languages.

6- Soft technology has imprecise boundaries. Since all soft technologies are closely related to human factors, the boundaries between science and technology, technology and associated knowledge and different types of soft technologies are very vague and each influences infiltrates the other.

7- Innovation in soft technology has distinctive causes. The reason for the obsolescence of hard technologies is usually the emergence of new - normally superior - inventions to replace the old technology.

Innovation in soft technology is differentiated by the fact that it is more strongly limited by relevant institutions, systems, laws, regulations and policies than is innovation in hard technology.

8- Soft technologies have to be combined or integrated in practice. The implementation and success of soft technology requires a comprehensive and holistic approach to its application. The primary criterion for judging the success of the commercialization and industrialisation of hard technologies is whether they integrate well with continuously advancing soft technologies. On the other hand, soft technology will only success if it is combined comprehensively with other relevant soft technologies, modified according to different conditions of local geographic and social-political circumstances and according to the demands that stem from ostensible design goals. Similarly, integration of with continuously advancing hard technologies is necessary for the promotion of soft-tech innovation and to ensure higher quality soft technology.

9- The relationship between soft technology and institutions is close. The dualism of soft technology means that it is, by nature, entwined and infused with institutions. In the case of hard technology, institutions are part of the environment and conditions for innovation. In the case of soft technology, however, institutions are not only part of the environment of technological innovation. Soft technology itself forms the foundation and content of innovation in relevant institutions, systems, law, regulations and policies.

10- Soft technology requires special talents. Hard technology requires specialists in particular technical fields but soft technology requires people with talents derived from interdisciplinary and cross-sector knowledge and experience.

6.11 Soft science in Japan

With continuous high speed development of its economy since World War II, Japan is now facing many of the social tensions and problems that are now common in western countries. Americans are using terms such as 'intelligence technology' and 'policy science' in their research; however Japan instead invented the concept of 'soft science' and has conducted centralised research on social problems within the framework of soft science.

The Soft Science Seminar set up by the Planning Bureau of the Science and Technology Agency (STA) in 1970 is the starting point for the development of soft science in Japan. The seminar's report points out that the 'research objective of soft science is not limited to natural phenomena and technology and it includes activities pertaining to the human race, social affairs and knowledge. After the 1971, Soft Science Seminar (STA) the Institute of Future Technology was entrusted to conduct specialised research (1971-3) on 'the science and technology policy and the research and development system of Japanese characteristics'.

Researchers travelled to United States from the Institute of Future Technology to investigate the research on social problems. As a result, the Institute published a series of research reports, entitled Basic Design of Japanese Type Science and Technology Development System, pointing out that soft science is the new trend in science and technology development. If soft science is not properly developed in the near future, the gap between Japan and the United States in soft science will result in major social problems. The Institute's reports also stressed the urgency of developing soft science in Japan. Firstly, it urged that Japan needed a different and more comprehensive scientific method if it wants to solve the complex social problems associated with the environment, energy, regions, cities and transportation; secondly, it showed that developed industrial countries had already conducted research, development and application in this field; and thirdly, it concluded that 60% of enterprises in Japan had already applied methods that could be considered soft science in these fields but that the gap between Japan and the advanced countries such as the United States was still large. After this report was carefully examined by some high-level experts from all fields, it was required to conduct centralised research on the concept of soft science, its necessity, its characteristics and the fields requiring research and basic knowledge from the vantage point of soft science.

The primary characteristics of soft science were considered to be that:

1- The research objectives are not the only natural phenomena (the traditional objective of science and technology) but also issues that contained human and social factors;

2- That understanding the above issues from a systematic viewpoint and putting the emphasis on research on soft intelligence technologies, could help solve real problems;

3- Soft science organically combines a wide range of fields of knowledge and systematically synthesizes theories and methods that can contribute to the solving of different problems; and

4- The basis and background of the discipline is information science, systems engineering, management science, behaviour science and social science.

The classification of soft science provided in the report Basic Design of Japanese Type Science and Technology Development System reflects the understanding of soft science that eventually dominated Japanese academic circles. The ten categories proposed in the report were: 'general' soft science, information soft science, energy soft science, material soft science, system soft science, environment soft science, behaviour soft science, policy soft science, life soft science and others. Here are some explanations of some soft sciences,

* Energy soft science conduct research on energy in four areas: energy of earth, biology, technology and society.

* System soft science includes the research, design and application of the systems.

* Environment soft science divides the environment into physical, technological, economic and social environments.

* Life soft science mainly addresses the problems biological science, ecological science, medicine and pharmacology, etc.

6.12 Soft technologies for power generation

By conducting the literature review, reading some case studies and consulting the experts in the UK and in Libya. Important soft technologies have been identified which enable the power generation hard technologies to work. The following are the soft technologies related to power generation sector:

1- Communication and Coordination

Industry requires appropriate communication and coordination strategy to ensure different units within a grid with collectively.

- Internal (at country level),
- External (regional and neighbouring countries).

2- Research and Development (R&D)

R & D activities will help to identify problems in power generation sector and develop solutions to enhance the power generation technologies. This type of R&D activities can include the private sector as well.

3- Health and Safety

This will maintain the power plants safer places and jobsite, and all workers should become familiar with safety manuals to perform work as safe as possible for human and equipments (safety regulation must be very tighten especially when dealing with nuclear power generation technology).

- It can include evacuation plans for employees and surrounding community in case of any emergency.

4- Information and Communication Technology (ICT)

Information should be flow freely, quickly, safely and privately inside power plants, national grids, ministry of energy and regulatory bodies.

5- Corporate with National and International Bodies

National institutions should be linked to international organisations such as UNIDO, UNDP and the International Energy Agency to the national and regional electricity power generation grids.

6- Employee Development Programs

Developing employee skills can be achieved by means of training related to type of technology. Universities can play a big role of conducting relative courses. Developing skills can be achieved in many ways such as:

- Intensive courses with the help of contractor in the field according to the hard technology selection.
- On-job training or learning by personal feeling (LPFE).

7- Financial Resources

For building any power generation plants, a financial support and investment is a crucial factor for developing country to guarantee the money before starting to build any power plants.

- International organisations such as World Bank (WB), International Monetary Funding (IMF), United Nations Industrial Development Organisation (UNIDO) and United Nations Developing Programs (UNDP).
- National funding systems (may be governmental or private).
- Foreign Direct Investment (FDI) or joint venture programs.

8- National and International Regulatory Framework

There is a great concern by power generation sector at national level to meet standards. This demands an extra attention to power generation units. Some examples can be given.

- National licence and approvals,
- Operation permissions and,
- Environmental permission (periodically re-issued).

9- Strategic and Operational Management

- Develop technical skills,
- Operation and maintenance,
- To maintain national fuel long-term reserve strategic plans.

10- Power Generation Watchdog

For all sectors in a country, it is needed to have an external body to watch your activity and provide an advice wherever it is needed.

- Industrial competitiveness,
- Transparency (it is required to avoiding any problems that can effect plants operation).

6.13 Integration of hard and soft technologies for power generation

Hard technology does not work alone and here comes the role of integration between hard and soft technology is recommended.

This part of work is a continuation of the research to achieve the goal of this study which is the selection of the electrical power generation technologies. In chapter five, the hard technology appropriates process was carried out using the AHP and these results were illustrated with the sensitivity analysis of this selection and decision. Secondly, in the first part of this chapter, the soft technologies are identified relating to the power generation sector. The technology management tools recommend the integration of hard and soft technologies and this process is carried out here. But there are some limitations which make the selection of the hard technology suitable for one developing country but unsuitable for another. These limitations must be taken into account when integrating these hard and soft technologies.

6.13.1 Hard technologies priorities

In chapter four, the hard technologies are identified and explained. Also, in chapter five, the appropriateness of each hard technology was carried out. The following are the hard technologies listed respectively;

1- Hydropower (Hp) generation technology has the highest value of 19%,

2- Wind power (Wp) generation technology has the second highest value of 17.7%,

3- Solar Photovoltaic (Spv) generation technology has the third highest value of 16.4%,

4- Geothermal (Gt) power generation technology has the fourth highest value of 10.4%,

5- Natural gas-fired (Ng) generation technology has the fifth highest value of 7.7%,

6- Nuclear (Np) power generation technology has the sixth highest value of 7.6%,

7- Oil-fired power (Op) generation technology has the seventh highest value of 7.5%,

8- Solar Thermal (St) power generation technology has the eighth highest value of 7.3% and finally,

9- Coal-fired (Cp) power generation technology has lowest value of 6.4%.

6.13.2 Soft technologies for power generation

Here are the most important soft technologies which may support the power generation hard technology selection;

1- Communication and Coordination technology,

2- Research and Development (R&D),

3- Health and Safety,

4- Information and Communication Technology (ICT),

5- Corporate with National and International bodies and organisation (UNIDO, UNDP),

6- Employee Development Programs,

7- Financial Resources,

8- National and International Regulatory Framework,

9- Strategic and Operational Management,

10- Power Generation Watchdog.

6.13.3 Hard technologies limitations

Each of the power generation hard technology has some limitations which makes it not possible to be applied for all environments. The following shows the limitations and barriers of each hard technology separately.

6.13.3.1 Hydropower limitations

- Amount of rainfall can not be guaranteed because it is a natural process outside the human control.
- Geological risk, any hydropower project construction will face some geological problem. To overcome the geological problem, its recommended to carry out feasibility study of the site. It is expensive but it is worth if the project to be successful.
- Head height is very important factor in determining small hydropower economics with higher head sites.
- Volume of water available.
- Availability of underground seismic activity (possibility of earthquake). Historical records are the solution but ten years are not enough, forty years barely sufficient.

6.13.3.2 Wind power limitations

- Require a large area of land,
- Noise will disturb the surrounding habitants,

- Wind turbines can cause electromagnetic interference. Can effect television reception or microwave signals transmission,

- Turbulence is less offshore, at sea due to its smooth service.

- Problem of variability (can not maintain constant airflow),

- Animal life (animals will leave and flea the region),

- Asthetics (people will be disturbed when seeing big wind turbines).

6.13.3.3 Solar photovoltaic limitations

- Winter supply is half of summer supply (variability),

- High cost (twenty times more than coal fired electricity),

- Intermittent thus storage problem occurs,

- Sun shines during the day only.

6.13.3.4 Geothermal power limitations

- Reservoirs contain a finite amount of water and energy,

- Wells can become depleted if over exploited (temperature and pressure decline),

- Difficult to gauge the size of reservoir,

- Temperature below 150°C will not be good and,

- Normally the brine is a corrosive liquid.

6.13.3.5 Natural gas-fired limitations

- High prices,

- Price fluctuations,

- Security of supply,

- Gas pipeline infrastructure and,

- Noise of turbines.

(Breeze, 2005)

6.13.3.6 Nuclear power limitations

- Technical experience experts,
- Safety regulations,
- Nuclear waste disposal,
- Public opinion and,
- Dependency in foreign countries.

6.13.3.7 Oil-fired technology limitations

- Highly influenced by politics (example, Arab embargo 1973-1974 and Iranian revolution 1979),
- Price fluctuation over time,
- High pollutant fuel.

6.13.3.8 Solar thermal technology limitations

- Confined to hot regions,
- Half the cost of PV without storage,
- Requires expensive storage system.

6.13.3.9 Coal fired technology limitations

- High pollution thus state environmental restrictions,
- Big area required for coal storage and,
- Cost of transportations of coal.

6.14 Integration of hard and soft technologies

The integration process is carried out in two steps.

6.14.1 Step one of Integration

In this step, we establish which hard technologies feasible, if so we decide to implement the soft technology according to the level of importance.

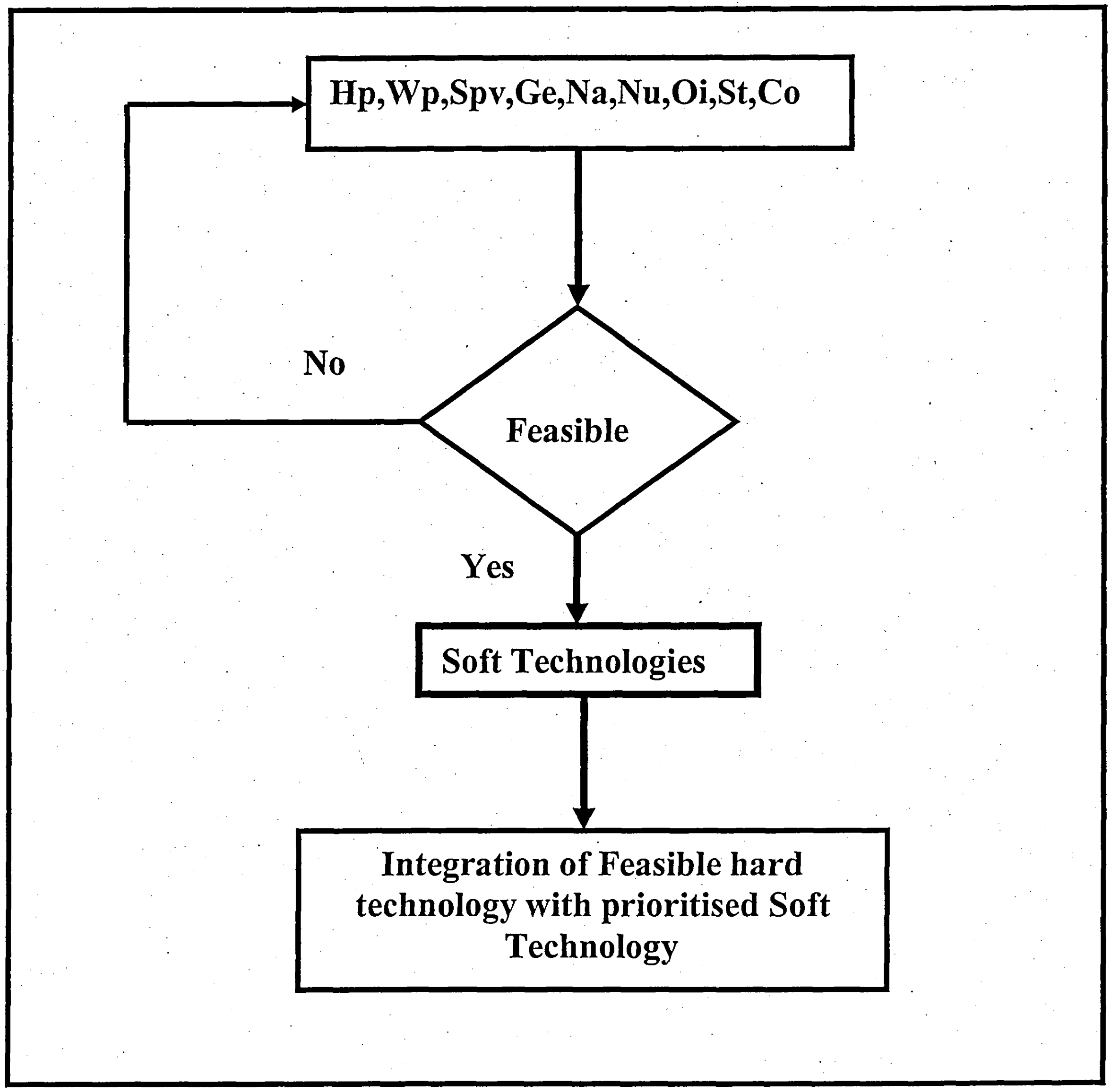


Fig. (6.1) The integration between hard and soft technologies

6.14.2 Step two of integration-Table 6.8 (soft technology matrix)

Hard technology	High priority soft technology	Medium priority soft technology	Low priority soft technology
Hydropower Technology	- Communication & coordination, - Meteorological information system, - Employee development programs, - Health & safety	-National and international regulatory framework - Strategic and operational management, - Power generation watchdog.	- Information and communication technology, - Linking national and international bodies, - Research and development (R&D).
Wind power Technology	- Communication & coordination, - Employee development programs, - Health & safety, - Financial resources.	- National and international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication technology, - Linking national and international bodies, - Research and development (R&D).
Solar photovoltaic Technology	- Communication & coordination, - Employee development programs, - Health & safety, - Financial resources.	- National & international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication, - Linking national and international bodies, - Research and development (R&D).
Geothermal Technology	- Communication & coordination, - Employee development programs, - Health & safety, - Financial resources.	- National & international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication, - Linking national and international bodies, - Research and development (R&D).
Natural gas Technology	- Communication & coordination, - Employee development programs, - Health & safety, - Financial resources.	- National & international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication, - Linking national and international bodies, - Research and development (R&D).
Nuclear power Technology	- Health & safety, - Employee development programs, - Communication & coordination, - Financial resources.	- National & international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication technology, - Linking national and international bodies, - Research and development (R&D).
Oil fired Technology.	- Employee development programs, - Communication & coordination , - Health & safety, - Financial resources.	- National & international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication, - Linking national and international bodies, - Research and development (R&D).
Solar thermal Technology	- Communication & coordination technology, - Employee development programs, - Health & safety, - Financial resources.	- National & international regulatory framework, - Strategic and operational management, - Power generation watchdog.	- Information and communication, - Linking national and international bodies, - Research and development (R&D).
Coal fired Technology.	- Employee development programs, - Communication & coordination, - Health & safety, - Financial resources.	- National & international regulatory framework, - Management teams, - Power generation watchdog.	- Information and communication, - Linking national and international bodies, - Research and development (R&D).

6.15 The proposed conceptual framework

Fig. (6.1), represents the main elements of the proposed conceptual framework of the technology management power generation in developing countries.

6.15.1 Implementation of framework

Chapter four identifies all of different power generation hard technologies and the environmental effect of each hard technology separately. The size of each hard technology around the world is presented in tables. The hard technology selection is presented. The filtration of these hard technologies is shown clearly with justifications. Some criteria and sub-criteria identification is given. In addition to this, real data collected from literature is listed in table 4.20. The model using the AHP is built and shown in figure 4.1. And finally the block diagram is draw as an output of the AHP model.

Chapter five discusses the implementation of the model built in chapter four using the AHP and using the real data collected. The results of the model are presented in section 5.3. In this chapter the hard technologies for power generation selection is worked out and shown by figure 5.1 Then the sensitivity analysis is carried out giving explanations for varying the criteria and sub-criteria and checking their impact on the final selection of the power generation technology. These sensitivity analysis results are presented in tables in chapter five and how the selection of the hard technologies is effected by varying the criteria.

Chapter six presents the implementation of the soft technologies selection and the integration of soft and hard technologies for the power generation for developing countries.

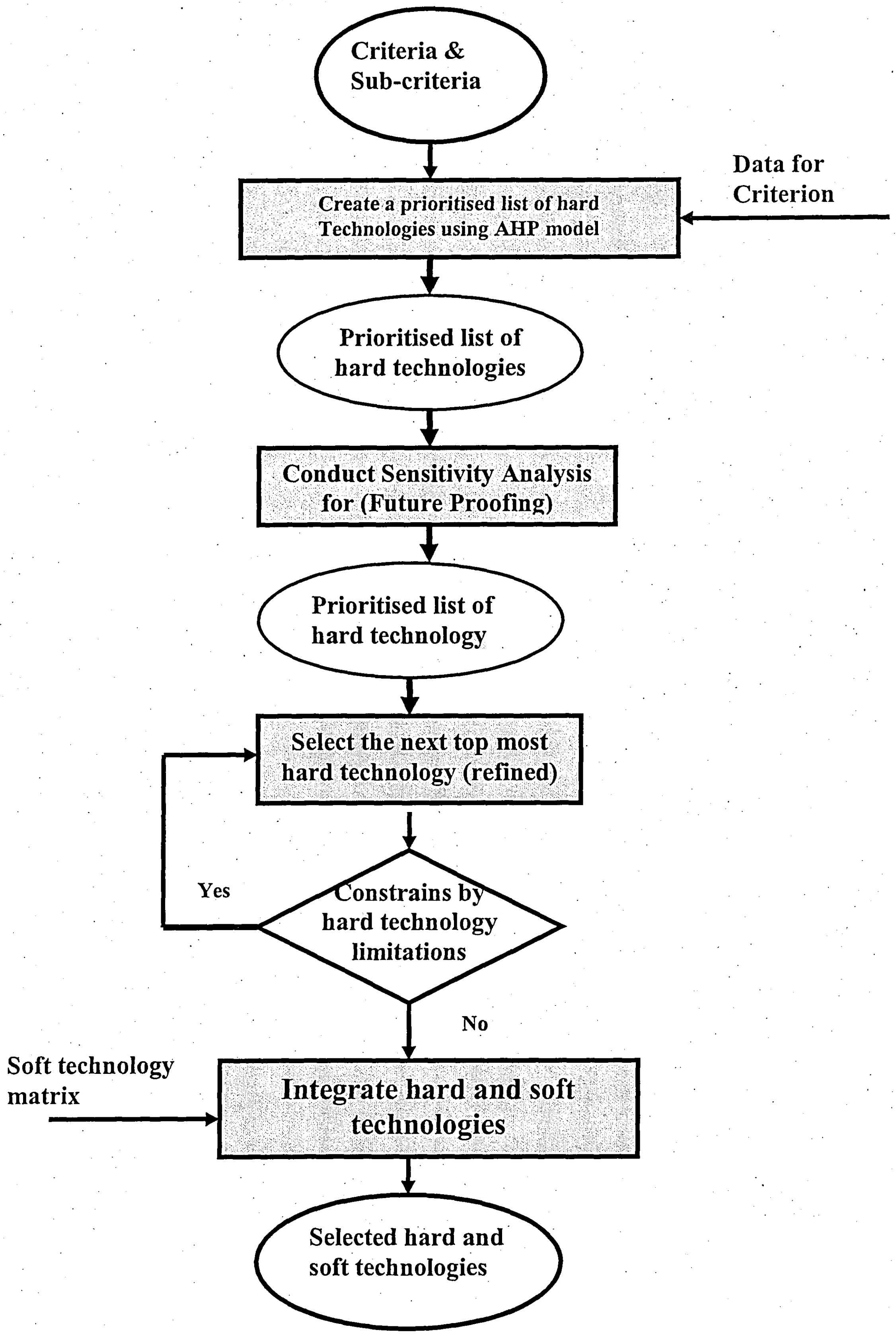


Fig. 6.2 The proposed framework of power generation technology selection

6.15.2 Justification of developed framework

The terms framework, taxonomy, conceptual model and typology are often used interchangeably. Taxonomies classify objects and typologies show how mutually exclusive types of things are related. Frameworks provide an organising approach and a conceptual model shows how ideas are related. The general desire is to create a set of labels that help people organise and categorise information (Power, 2001). Sprague and Watson (1996) argue typologies, frameworks or conceptual models are "often crucial to understanding of a new or complex subject." Decision support is not a new subject, but it is complex and evolving. A good framework shows the parts of the topic and how the parts are interrelated.

Liao (2003) indicated that knowledge management frameworks are used widely in different areas of research and practices as can be seen in table (6.9).

Table (6.9) Knowledge management framework and its applications (Liao, 2003)

Knowledge management framework applications	Authors
- Knowledge creation	Nonaka et al., (1996)
- Knowledge asset	Wilkins et al, (1997) and Wiig (1997).
- Methods and techniques	Wiig et al. (1997)
- KM development and history	Wiig. (1997)
- Organisational learning	Heijst et al (1997)
- Organisational innovation	Johannessen et al. (1999)
- Intellectual capital	Liebowitz and Wright (1999)
- Strategy management	Drew (1999), Hendriks and Vriens (1999)
- Organisational impact	Hendriks and Vriens (1999)
- Systems thinking	Rubenstein-Montano et al. (2001)
- Artificial intelligence / Expert systems	Liebowitz (2001)
- Knowledge inertia	Liao (200)

According to Holsapple and Joshi (1999), the lack of effective management of knowledge (KM) could be that most organisations are still struggling to comprehend the knowledge management concepts and shortage of development of related frameworks. The result of analysing knowledge management led to the conclusion that there was a need for developing a comprehensive and unified framework for describing the nature of knowledge management. Such descriptive framework could benefit both researches both researchers and practitioners by creating an organised foundation for future progress in understanding and conducting KM. These frameworks could be broadly classified into two categories: descriptive frameworks and prescriptive frameworks. The descriptive frameworks attempt to characterise the nature of KM phenomena. Descriptive can be further classified into broad and specific categories. A broad framework is one that attempts to describe the whole of KM phenomena. A specific framework focuses on a particular aspect of this phenomenon.

Jacobson and Johnson (1998) suggested that an analytical framework built around the concept of technological systems might be suitable. A technological system is a technological specific innovation system that is useful when the focus of the enquiry is to study the competition between various ways of supplying energy.

6.16 Comments on integration of hard and soft technologies

The second part of this chapter focuses on identification of soft technologies used in power generation sector and power plants. Limitations of different hard technologies are also discussed and explained. A table is developed to prioritise the soft technologies according to the limitation of hard technologies selection.

The third part of this chapter explains the integration process of hard and soft technologies in power generation sector according to hard technologies feasibility and after that integrating it with the soft technologies.

CHAPTER SEVEN

THE VALIDATION OF THE MODEL OF POWER GENERATION TECHNOLOGY

7. Validation of a systematic approach

After developing the model for power generation technology and indicating the most important criteria and sub-criteria, the derived model needs to be validated. This chapter deals with this problem.

7.1 Introduction

In this chapter, it is required to validate the systematic approach for power generation hard technology selection which is developed in this research work using the analytic hierarchy process (AHP) software and methodology.

There are many ways to validate proposed models to prove the validity of the proposed model. These methods of validation can be named as:

a)- Numerical methods or

b)- Statistical methods.

One of the well established statistical methods is the questionnaire technique and hence analysing the information collected from such questionnaire and survey.

7.2 Why questionnaires

According to Gillham (2007), questionnaires are an inexpensive way to gather data from a potentially large number of respondents. Although preparation may be costly and time consuming. The administration cost per person of a questionnaire can be as low as postage and a few photocopies. It is important to remember that a questionnaire should be viewed as a multi-stage process beginning with definition of the aspects to be examined and ending with interpretation of the results.

7.3 Designing questionnaires

The steps required to design and administrate a questionnaire include:

1- Defining the objectives of the survey,

3- Writing the questionnaire,

4- Administering the questionnaire,

5- Analysing and Interpretation of results.

7.3.1 Types of questionnaires

There are two types of questionnaires normally used, the first type includes,

1- Long ended questions,
2- Short ended questions,
3- Tick questions are normally the answers and are on the form of Yes or No or a scale type.

The second type, where you ask directly the experts on the field of survey but it is important to determine the number and the level of experts.

7.3.2 Instruction in questionnaires

1- Indicate that the work is undertaken as part of a university research work.

2- The issues of confidentiality and or anonymity should be addressed. Example: (all of the information you give us will be treated as completely confidential and it will not be possible for anyone to identify the information you pass to us when writing up my research report).

3- Indicate how the person was selected to receive the questionnaire.

4- Indicate how it is to be answered. For example, tick only one answer (box) and leave the rest blank.

5- Return questions (how).

6- Make sure a clear instruction on how to respond.

7- Indicate the form of the answer (numeric, tick-box, rank etc).

8- Where respondents answers to an earlier question affects subsequent sets of questions, ensure that the route which they should take is clearly specified. Example, "if yes, please go to question…."

9- Questionnaires must not begin with awkward or embarrassing questions.

7.3.3 The layout of questions

1- Print clearly (ask IT) for help if needed.

2- Allow adequate space between questions so that you can write down any comments made (do not leave too much).

3- Write the questionnaires themselves in a lower case. But instructions in upper case (capital letters)

7.4 Pilot your questionnaire

Before deliver any questionnaire, we should pilot it. There are number of reasons why it is important to pilot a questionnaire:

1- To test how long it takes to complete.

2- To check that the questions are not ambiguous.

3- Check instructions are clear.

4- To allow you to eliminate questions that does not yield usable date.

5- Try to pilot 5--10% of your final sample number.

6- Take account of comments made in the pilot study.

7.5 Criteria and sub criteria

The main criteria for this model are as follows:

1- Cost,
2- Plant life,
3- Requirements,
4- Dependency.
5- Safety,
6- Pollution,
7- Development.

These above main criteria are the determining factors of the goal and the selection of the power generation technology and all of them add to one (unity).

The main sub-criteria are as following:

For Cost: Capital cost, Fuel cost, Operation & Maintenance cost.

For Plant Life, there are no sub-criteria.

For Plant Requirements: Land used (hectare/GW), Water needed (m3/kW) and, Employment (person/GWh).

For Dependency: Foreign participation (%), Local participation (%).

For Safety: Noise level (dB), Physical discomfort (%), Psychological discomfort (%).

For Pollution: Global warming (gCO2/kWh), Air pollution (%), Thermal pollution (GJ/GWe),

For Development: Technology development (%), Industrial development (%).

7.6 Different hard technologies options

Referring to chapter four, the different hard technologies for electrical power generation are as following:

1- Coal fired power generation,
2- Oil fired power generation,
3- Gas fired power generation,
4- Hydropower generation,
5- Geothermal power generation,
6- Nuclear power generation,
7- Wind power generation,
8- Solar photovoltaic power generation and
9- Solar thermal power generation.

7.7 Questionnaire strategy

Here, the questionnaire strategy is decided to follow these guide lines:

- To consult and send off these questions to some leaders in the electrical power generation sector.

- Using postal and direct way to communicate with these managers in power stations.

- A number of 50 leaders or managers to be involved.

- The AHP software is chosen to be the analysing tool,

- A scale starting from 1 to 9 is to be used to indicate the answers by the respondents (the same scale in the AHP).

- A letter to be provided with the questionnaire to explain the objective of the research.

7.7.1 Sending out questionnaires

In this validation process, it is decided to send out about fifty questionnaires inside the UK in order to be able to validate the conceptual framework and suggested model for the power generation technologies selection. Also, an opportunity is taken by the author when visiting Libya (developing country) and handed out eighteen copies of the questionnaires to some power stations managers (different generation technologies). Because the author was unsure about the number and time of returning questionnaires in the UK, that is why some of these questionnaires were conducted in Libya as a developing country.

Thirty envelopes were sent to the managers of operation and maintenance in different power stations in the UK. In every envelop two copies of the questionnaires were included just in case the operation and maintenance departments were separated. On the other hand, the questionnaires in Libya were distributed by hand to ensure that managers of operation and maintenance answered them on time. It may be worth mentioning that the collection of the questionnaires from the respondents in Libya was very difficult indeed. Only fourteen respondents completed the questionnaires.

In the UK, nine respondents of questionnaires completed and sent back the questionnaires without any significant additional comment.

7.8 The Statistical analysis of the responses

Tables were drawn using the completed questionnaires and, rows and columns representing different criteria and sub-criteria against their frequencies. The second step is to think carefully how the answers can be averaged to represent the real reflection of the experts from different power stations.

We have one of the two ways to be used in this situation. The first is the arithmetic mean value and the second method is the geometric mean.

7.8.1 Averaging the respondents frequency

According to Gillham (2007), many people avoid and think this statistical analysis is not for them. Normally, the arithmetic mean is used in statistical and mathematical situations when directly dealt with numbers.

The geometric mean may be more appropriate than the arithmetic mean for describing percentage growth (Expert Choice, 2000). Here an example worth showing to illustrate the view: Imagine an apple produces 100 apples per year, 180, 210 and 300 the following years, so the growth is 80%, 16.7% and 42.9% for each of the years. Using the arithmetic mean, the average growth can be calculated as 46.5 (80% +16.7% + 42.9% divided by 3). However if we start with 100 apples and let it grow for three years with 46.5%, the result is 314 apples, not 300.

To overcome this problem, we can use the geometric mean. Growing with 80% corresponds to multiplying with 1.8, so we take the geometric mean of 1.8, 1.167 and 1.429, (1.8*1.167*1.429)^⅓, thus the average growth per year is 44.3%. If we start with 100 apples and let the number grows with 44.3% each year, the result is 300 apples which is the correct answer.

Probably the most common example of percentage growth is interest rates, e.g. a savings account where the bank pays a certain percentage growth per year.

7.8.2 Geometric mean of respondents

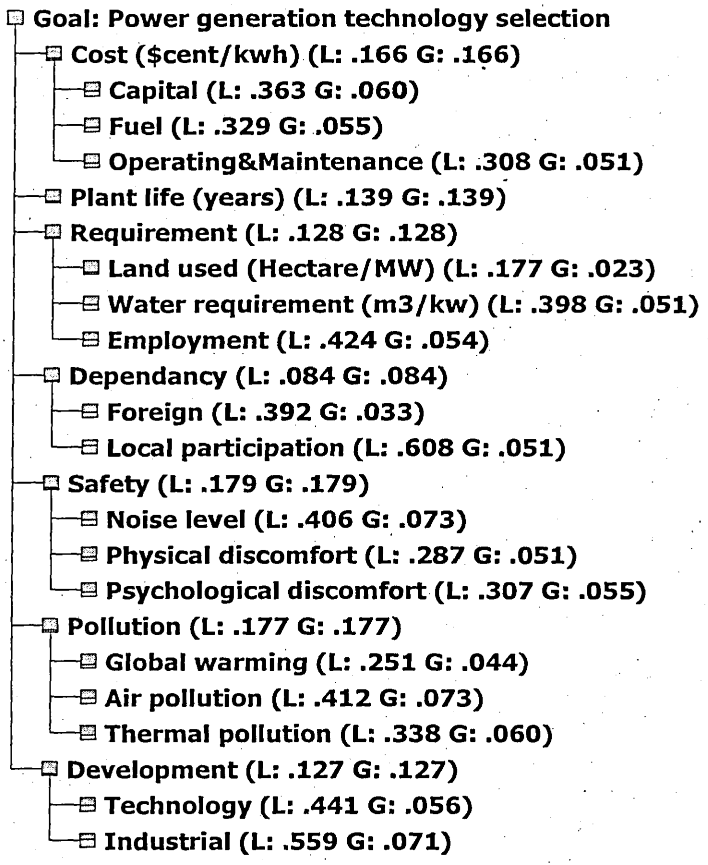
After the completed questionnaires were returned back, the author started to analyse the respondents responses. Before calculating the geometric mean a spread sheet is drawn and then the calculation started to take place.

The first column includes the multiplication of frequencies of the respondents of different criteria and sub criteria. The second column is to calculate the 23rd root of the product of the frequencies. The third column is to convert the calculated root and finally the forth column is to round it to three decimal places.

7.8.3 The AHP model

The AHP model is to show the different criteria and sub criteria arranged top down model under the objective of factors influencing hard technology comparison.

All the criteria and sub criteria are included in the model frame as can be seen in figure (7.1).



- Goal: Power generation technology selection
  - Cost ($cent/kwh) (L: .166 G: .166)
    - Capital (L: .363 G: .060)
    - Fuel (L: .329 G: .055)
    - Operating&Maintenance (L: .308 G: .051)
  - Plant life (years) (L: .139 G: .139)
  - Requirement (L: .128 G: .128)
    - Land used (Hectare/MW) (L: .177 G: .023)
    - Water requirement (m3/kw) (L: .398 G: .051)
    - Employment (L: .424 G: .054)
  - Dependancy (L: .084 G: .084)
    - Foreign (L: .392 G: .033)
    - Local participation (L: .608 G: .051)
  - Safety (L: .179 G: .179)
    - Noise level (L: .406 G: .073)
    - Physical discomfort (L: .287 G: .051)
    - Psychological discomfort (L: .307 G: .055)
  - Pollution (L: .177 G: .177)
    - Global warming (L: .251 G: .044)
    - Air pollution (L: .412 G: .073)
    - Thermal pollution (L: .338 G: .060)
  - Development (L: .127 G: .127)
    - Technology (L: .441 G: .056)
    - Industrial (L: .559 G: .071)

Fig. (7.1) The pair wise comparison between the main criteria and sub criteria (Respondents) with respect to the goal.

7.9 Results from the AHP

Taking the geometric mean values calculated and feeding it to the AHP software is a helpful way to validate the model.

All the criteria and sub criteria are compared against one another to see the outcome of the results and how much agree with the proposed earlier model.

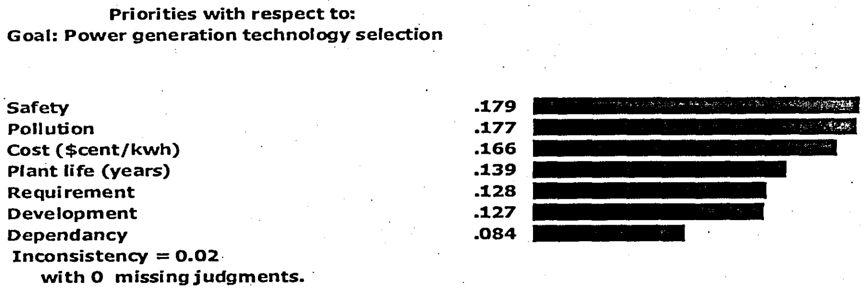
When looking to the output results from the AHP represented in graph (7.1), we can conclude the following:

Table (7.1) The values of the pair wise criteria from the AHP (Respondents)

Criteria	Priority (%)
Safety	17.9
Pollution	17.7
Cost	16.6
Plant Life	13.9
Plant Requirement	12.8
Development	12.7
Dependency	8.4
Inconsistency = 0.02	

From table (7.1) and graph (7.1), Safety is the most important criterion representing the highest value and this is logically speaking is right. Because the employees should not compromise with safety issues and work in a safe environment and protect the surrounding hardware as well. The second criterion is the pollution having a second highest value of the group and this is fine because polluting the environment can not be tolerated or forgiven. Mankind have to ensure the minimum of pollutants produced from any technology used to generate electricity even though the major pollution is caused by the industrial world. The third criterion is the cost, with third highest value participating in the importance and without doubt especially when talking business no company or organisation will give you free stuff.

The rest of criteria come with minor importance when compared with the most significant ones. The inconsistency of 0.02 is produced and confirmed by the AHP software and it's a small figure which is accepted.



Graph (7.1) The pair wise comparison between the main criteria (AHP)

7.9.1 Comparing the criteria using the AHP

After computing the relative importance of the criteria derived by the AHP program, some of these results are presented in the table (7.2) and compared with the proposed criteria to build the model presented in chapter five. It is worth here putting the results of respondents and the proposed in the same table to make it easy for the reader to see the comparison.

Table (7.2) The comparison between the proposed and observed criteria

Proposed criteria	**(%)**	**Respondents criteria**	**(%)**
Cost	33	Safety	17.9
Pollution	23	Pollution	17.7
Safety	20.6	Cost	16.6
Plant life	9.3	Plant life	13.9
Development	6.8	Plant requirement	12.8
Plant requirement	3.4	Development	12.7
Dependency	3.3	Dependency	8.4
Total	100%	Total	100%
Inconsistency	0.06	Inconsistency	0.02

From table (7.2), it can be seen that the proposed criteria has the cost as most significant criterion but the observed criteria has the safety as a first priority. Pollution is the second important criteria in the proposed and respondent criteria as can be seen from the above table. In the proposed criteria significance, safety is the third important criterion but cost in the respondents. Plant life is the fourth in both proposed and observed criteria. Development and plant requirement are a little different between the proposed and observed criteria and this difference is due to the difference between theoretical assumption and the practical. The last factor in the table is the dependency, and agrees in both proposed and observed criteria.

Now the author would like to examine how much is the deviation between proposed and observed criteria and their impact on prioritising and the selection of the hard technologies.

Table (7.3) The impact of different criteria on the power generation hard technology selection.

Hard technology priority based on proposed model (%)		**Hard technology priority based on observed respondents (%)**	
Hydropower	19	Hydropower	14.7
Wind power	17.7	Wind power	14.7
Solar photovoltaic	16.4	Solar photovoltaic	13.9
Geothermal	10.4	Natural gas	9.9
Natural gas	7.7	Geothermal	9.8
Nuclear	7.6	Oil fired	9.8
Oil fired	7.5	Solar thermal	9.5
Solar thermal	7.3	Nuclear	9.1
Coal fired	6.4	Coal fired	8.7
Total	100	Total	100

7.10 Comments on validation results

After analysing the questionnaires and using the geometric mean technique and the output values from the AHP software for multi-criteria decision making process. The checking of the validation of the proposed model took place. The sample size of the respondents was just over 50 but only 23 respondents answered the questionnaires. It is worth mentioning both respondents agreed in the majority of the questionnaires and this is because mangers from both sides are working in the same environment and same field.

The following results were obtained (proposed and observed):

Hydropower electrical generation technology is having the highest priority for both cases. Wind power hard technology is the second priority option in both cases. Photovoltaic power generation hard technology is the third priority option in both cases as well. Geothermal and natural gas hard technologies are vice versa in both cases but this represents a small share out of the total.

Nuclear, oil fired and solar thermal hard technologies are the sixth, seventh and eight priorities for both cases. The last priority is the coal fired hard technology and this is may be due the environmental effect of the oil fired hard technology as this technology produces large amount of pollutants.

The results of the questionnaire about the priorities of the criteria and sub criteria which may effect the selection of power generation hard technology option, there is a significant agreement between the proposed model criteria importance and the observed.

As mentioned above, there is a little of non-homogeneous between the respondents from the UK to the respondents came from Libya. The UK engineers for operation and maintenance working in different power stations are more careful about the general safety in power stations as some belonging to private sectors. Engineers in Libya gave a higher priority to the life of the power plants compared with cost and other criteria because the comments they get from their mangers in charge of power stations "how long can the power station equipment survive". This may satisfy mangers working for the electricity national grid company. Engineers in Libya have given less importance to cost, safety and pollution. These engineers are not alerted and aware of importance of safety and pollution because they only see the problem of pollution as a single issue for their country only.

From the discussion above, it can be concluded that the proposed model for power generation hard technologies selection and prioritising is successful and validated for the developing countries as it shows agreement between proposed with observed information in this validation analysis.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.1 Discussion of research

From the literature review about sustainable development in developing countries, the majority of sectors fall short of scientific policies. Power generation is an important field to focus on because it will help other sectors to develop and make some contribution to the national economy of developing countries. Technology management was the answer to link limited resources, science and knowledge, engineering, economic aspects, health, employments and information, and communication technologies. Man needs electricity because daily life of everybody demands machines, lighting, heating, transports, communication with some others needs. All equipments mentioned above require electrical energy to operate. By looking back to the research work done in this field of power generation sector, a little work was carried out regarding the optimisation and filtration of hard technologies in developing countries. The previous work focused on a single or comparing few technologies together of the same type. No doubt most of developing countries are short of resources (economic and financial). Due to the increase in population, more electrical energy is needed to satisfy this demand. Also some research is considering the hard technology only and not paying attention to soft technologies. The integration of hard and soft technologies is important and crucial in the field of power generation.

The problem in developing countries is the short fall of most governments in developing countries to develop a successful technology policy and conceptual frameworks for power generation sector. It is decided to focus on developing a conceptual framework and to draw guidelines to optimize and prioritise power generation and select hard technology options for developing countries.

The conceptual framework is developed and presented after integrating the main elements of the framework together.

Hard technologies for power generation are identified and explained including their effect on environment and cost is focused on as well. Important criteria and sub criteria having a significant effect on power generation are determined by looking to economic, social, technological, financial and environmental aspects. AHP model is built based on the identified criteria and sub criteria determining the goal.

Using data collected from the literature and the built AHP model after deciding the pair wise comparison between the criteria and sub criteria. The results were computed and presented as prioritised list of hydropower, wind power, solar photovoltaic, geothermal, natural gas, nuclear, oil fired, solar thermal and coal fired power generation technologies respectively. Sensitivity analysis is conducted to future proof and to determine the impact of parameter changing on the output final decision of power generation technology selection. Results are presented by graphs and tables, and discussed.

Some technology indicators are determined and listed in tables to enhance the identification of the soft technologies required for power generation. Soft technologies matrix is developed with the help of expert advice in Libya. The integration of hared technologies and soft technologies is conducted.

The validation of the AHP model is done using the questionnaire technique and the proposed model agreed with the respondent results outcome of questionnaire. Both of them are discussed and presented in a table.

8.2 Contribution to knowledge

The main contribution to the knowledge is the development of a comprehensive framework which includes a several stages such as:

1)- Identifying the main criteria and sub criteria of power generation technology management as no other study have identified them for power generation technology selection in developing countries.

2)- Building AHP model based on the criteria and sub criteria identified earlier to support and enhance achieving the goal of the research work.

3)- Identifying hard technologies used in power generation and filtering them using the AHP built model. Nine hard technologies were included and the prioritizing process outcome is as hydropower generation technology, wind power technology, solar photovoltaic technology, geothermal power technology, natural gas technology, nuclear power technology, oil fired technology, solar thermal technology and coal fired power generation technology respectively.

4)- Soft technologies used in power generation are identified with the help of technology indicators and a soft technologies matrix is developed to support and proprieties the selection of hard technologies.

5)- The integration of hard and soft technologies is executed and presented in this research to get the power generation hard technology working.

8.3 Recommendations for further research

For future research work, the author would like to recommend the following points to be included and focused on:

1)- As power generation technologies develop quickly, most of the criteria are identified to build the framework but in future other criteria may appear to be significant with the development with technology. Including new criteria and sub criteria for power generation can help to improve or develop the new framework.

2)- In this research a supply side of technology management power generation is dealt with and the demand side is also a big area to research and discover. A framework of demand side management could be developed and integrated with the supply side options.

3)- More hard technologies could be included in future research because they are not commercial yet and can not compete with existing ones to build a new framework. Examples of these hard technologies are hydrogen technology, tidal technology, sea wave technology and bio fuels power generation technologies.

4- For any feasible fossil fuel power generation technology, a CO2 capturing technology has got to be combined with the hard power generation technology to reduce the amount of harmful gases released to the environment but more research is needed in this area.

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APPENDIX

Questionnaire

As an integral part of an on-going research work, we are aiming to develop a framework which will enable developing countries to select suitable power generation technologies.

We have identified a range of factors that might influence the selection of suitable power generation technologies (please see page 2) and we are seeking your help to identify relative importance of these factors. We have listed pairs of factors in this questionnaire and it is much appreciated, if you could indicate the relative importance of factors by circling a number in the given scale.

In the example below, two factors "Cost" and "Plant Life" to be compared. The mid-point, 1, indicates that both factors are equally important. Three possible comparisons are shown below.

Example

Cost		**Plant Life**	
(Capital, fuel and operation & maintenance)		(Operation life of plant)	
9 8 7 6 5 4 3 2	[✓ 1]	2 3 4 5 6 7 8 9	**<< Cost & plant life are equally importa**
9 8 [✓ 7] 6 5 4 3 2	1	2 3 4 5 6 7 8 9	**<< Cost is more important than plant lii**
9 8 7 6 5 4 3 2	1	2 3 4 5 [✓ 6] 7 8 9	**<< Plant life is more important than cos**

Factors which may affect the selection of Power Generation Technologies

COST - the total cost of capital, fuel and operation & maintenance costs.

PLANT LIFE - the number of years a plant operates with minimum maintenance (years).

PLANT REQUIREMENT - land space needed for plant and fuel storage, water to run plant and total number of people to operate, and maintain the plant.

DEPENDENCY – the level of contribution that the developing country make in building and operating the plant.

SAFETY - Physical & psychological discomfort to surrounding caused by the plant.

POLLUTION - the global warming, air and thermal pollutions.

DEVELOPMENT - technology and industrial development added to a developing countries when utilising a certain generation technology.

CAPITAL COST - the construction cost divided by the net electricity generated in and its unit is in £/kWh.

FUEL COST is defined as the cost of fuel supplied to the plant to generate electricity in £/kWh.

OPERATION & MAINTENANCE COST - the actual cost to operate the plant and maintain it from any stoppage and it is measured in £/kWh

LAND USE - the area required for the plant and fuel storage in Hectare/GW.

EMPLOYMENT - the total number of persons to run the plant and measured in Person/GWh.

WATER REQUIREMENT - the amount of water required to run the plant and accessories measured in m3/Kw.

FOREIGN PARTICIPATION -the percentage shared by a foreign country to help a developing country to build and operate a power plant and expressed in percentage (%).

LOCAL PARTICIPATION - how much a developing country can participate to build and operate a power plant and expressed in percentage.

NOISE LEVEL - the amount of unwanted sound produced by the power plant when generating electricity in decibels (dB).

PHYSICAL DISCOMFORT - the disruption caused by a power plant to the surrounding people and expressed in (%).

PSYCHOLOGICAL DISCOMFORT - the mental pressure on people caused by the power plant operation and existence, and expressed in (%).

GLOBAL WARMING - the amount of carbon dioxide in grams released by the power plant to generate electricity and measured in (gCO2/KWh).

AIR POLLUTION - the amount of different particles released to the air from the power plant and it is expressed as percentage (%).

THERMAL POLLUTION - the amount of heat released by the plant and expressed in GJ/GWe.

TECHNOLOGY DEVELOPMENT - how much technological value can be added to the country when using a specific generation technology and normally expressed as percentage (%).

INDUSTRIAL DEVELOPMENT - how much a generation technology affects other industries and expressed as percentage (%).

Please circle an appropriate number in the scale to indicate the relative importance of two factors shown in each question.

Section A:

Q1

Cost		**Plant Life**
(Capital, fuel and operation & maintenance)		(Operation life of plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q2

Cost		**Plant Requirement**
(Capital, fuel and operation & maintenance)		(Land space, water and people)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q3

Cost		**Dependency**
(Capital, fuel and operation & maintenance)		(Local & foreign participation)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q4

Cost		**Safety**
(Capital, fuel and operation & maintenance)		(Noise, physical & psychological discomfort)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q5

Cost		**Pollution**
(Capital, fuel and operation & maintenance)		(Global warming, air & thermal)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q6

Cost		**Development**
(Capital, fuel and operation & maintenance)		(Technology & industrial)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q7

Plant Life		**Plant Requirement**
(Operation life of plant)		(Land space, water and people)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q8

Plant Life		**Dependency**
(Operation life of plant)		(Local & foreign participation)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q9

Plant Life		**Safety**
(Operation life of plant)		(Noise, physical & psychological discomfort)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q10

Plant Life		**Pollution**
(Operation life of plant)		(Global warming, air & thermal)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q11

Plant Life		**Development**
(Operation life of plant)		(Technology & industrial)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q12

Plant Requirement		**Dependency**
(Land space, water & employment)		(Local & foreign participation)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q13

Plant Requirement		**Safety**
(Land space, water & employment)		(Noise, physical & psychological discomfort)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q14

Plant Requirement		**Pollution**
(Land space, water & employment)		(Global warming, air and thermal)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q15

Plant Requirement		**Development**
(Land space, water & employment)		Technology & industrial)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q16

Dependency		**Safety**
(Local & foreign participation)		(Noise, physical & psychological discomfort)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q17

Dependency		**Pollution**
(Local & foreign participation)		(Global warming, air & thermal)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q18

Dependency		**Development**
(Local & foreign participation)		(Technology & industrial)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q19

Safety		**Pollution**
(Noise, physical & psychological discomfort)		(Global warming, air & thermal)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q20

Safety		**Development**
(Noise, physical & psychological discomfort)		(Technology & industrial)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q21

Pollution		**Development**
(Global warming, air & thermal)		(Technology & industrial)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

SECTION B:

Please use the same way as above to compare importance of the following sub-criteria.

Q22

Capital cost		**Fuel cost**
(Ratio between construction cost & elec. generated)		(Fuel supplied to generate electricity)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q23

Capital cost		**Operation & maintenance cost**
(Ratio between construction cost & elec. generated)		(Cost to operate and maintain plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q24

Fuel cost		**Operation & maintenance cost**
(Fuel supplied to generate electricity)		(Cost to operate and maintain plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q25

Land use		**Water requirement**
(Area to build plant & fuel storage)		Water to run plant & accessories)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q26

Land use		**Employment**
(Area to build plant & fuel storage)		(Number of people to run plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q27

Water requirement		**Employment**
(Water to run plant & accessories)		(Number of people to run plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q28

Foreign participation		**Local participation**
(Share of foreign country to build & run plant)		(Share of developing country run plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q29

Noise level		**Physical discomfort**
(Unwanted sound caused by operating plant)		(Actual disruption to surrounding people)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q30

Noise level		**Psychological discomfort**
(Unwanted sound caused by operating plant)		(Mental pressure to surrounding people)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q31

Global warming		**Air pollution**
(Carbon dioxide released to atmosphere by plant)		(Different particles released to atmosphere by plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q32

Global warming		**Thermal pollution**
(Carbon dioxide released to atmosphere by plant)		(Amount of heat released to atmosphere by plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q33

Air pollution		**Thermal pollution**
(Different particles released to atmosphere by plant)		(Amount of heat released to atmosphere by plant)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

Q34

Technology development		**Industrial development**
(Technology value added)		(Effect on other industries)
9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9

End of Questionnaires

SECTION C:

Question,

Do you have different views about the Criteria and Sub-criteria included in this questionnaire relating to the selection of power generation technology for developing countries? Please feel free to add any comments.

Answer,

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Thank you very much