City University
London

Conceptual Modeling and Systems Theory with an application using Real Options Analysis

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THESIS SUBMITTED FOR THE
AWARD OF THE DEGREE OF DOCTOR
OF PHILOSOPHY
IN

SYSTEMS & MODELING

CENTRE FOR SYSTEMS RESEARCH
DEPARTMENT OF ELECTRICAL, ELECTRONIC &
INFORMATION ENGINEERING
CITY UNIVERSITY
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April 2007

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Overview of the Energy problem and Conceptual Modeling

In the previous chapters, the development of the fundamentals of conceptual modeling along with concepts of what is a model and a system where introduced. In this section a specific problem is considered in order to demonstrate the development of a conceptual model and the use of decision making on it. The conceptualisation of that specific problem will be discussed and the focus will be put on what kind of decisions need to be taken and how a decision making mechanism can help to show a way forward.

Energy is one of today's top choices in everyone's agenda as a problem looking for solution. Energy is fundamental to almost everything we do and is expected to be available whenever it is wanted, to be affordable, safe and environmentally sustainable. Although everything in nowadays society rely on power to produce work, many take for granted that this power will be an ongoing driving force that meets no end. The truth is that this driving force, that is energy, will soon be reaching its nadir, and humankind must come up with some creative, if not breakthrough ideas, of sustaining the energy levels needed for continuing life on earth.

Furthermore this chapter will deal with the development of the conceptual model of the energy problem in the UK. In the early chapters we have considered the pre modeling stages and conceptualization of specific problems. The first aim of this chapter is to use a step by step approach to demonstrate the identification of the problem area, from which the system will emerge. The system will be defined; objects, relations and environment. The goals and objectives of the modelling process will be laid out clearly. These goals and objectives of this modelling exercise will provide a hint to choose a decision making mechanism, later needed in the modelling process. The identification of the methodology to be used, in this case Real Options Analysis (ROA), came as a result of the research done for the problem area, the system requirements and the modelling objectives. We required a time limit of options to incorporate new/existing energy sources for the UK Energy mix. The methodology is used due to the nature of the problem as well as the current trends of the market that needs tools/solutions easily understood and easily amendable according to the demands.

8.1 Overview of the Energy in the 20th century, today and in the 21st century

After many centuries in which energy consumption changed little, in the 20th century the amount used suddenly rose by 5.5 times. Most of this rise happened in the second half of this century. In part this was driven by the increase in the world population, but this multiplied only some threefold during the century. This means that per capita energy consumption almost doubled, driven by technological and economic development. The energy revolution was, of course, part of the industrial revolution. It facilitated and fuelled the technologies that emerged, while at the same time *the spread of technology drove demand for energy* [Mur].

As economic development moved the emphasis first from agriculture to manufacturing and then to services and information industries, the dominant energy use also shifted. In the predominantly agricultural economy the dominant use was residential. As manufacturing developed, it itself became the dominant use. With the so-called post-industrial, service sector dominated economy, transport and, interestingly once again, residential uses are becoming dominant. Not surprisingly these shifts have brought in their train dramatic *changes in the sources of energy used.* The agricultural age was dominated by what we call traditional fuels, especially firewood. With the rise of manufacturing, solid and then liquid fuels became more important. In the post-industrial era, non-solid, *grid-based energies (electricity and gas) are becoming more dominant.*

The World Energy Council has invested a great deal of time in thinking about energy in the twenty first century. The *three fundamental determinants of energy demand are population, economic development and technological progress*, though the relationship between them is complex. The WEC/IIASA report used the World Bank's population projections, which see the global population reaching around 10 billion by 2050 and then stabilising around 12 billion at the end of the century. Other projections differ somewhat, but the present demographic momentum means that significant differences only appear after 2050. [Mur]

8.2 Challenges for the future of Energy

Many technology developments introduce new sources of energy due to the demand. Quite often though they enable people to be more efficient in using energy, either creating more useable energy from a given quantity of energy raw material, or introducing equipment which achieves the same end use task with less energy.

Very broadly, energy demand will be driven up by *rising population* and *development aspirations* and will be tempered by *energy efficiency* and *conservation*. However, economic growth typically drives energy growth up more quickly than improved energy intensity moderates it (at the national level, *energy intensity* is the ratio of total domestic primary energy consumption or final energy consumption to gross domestic product or physical output). Overall, lower energy intensity is strongly correlated with high per capita incomes in absolute terms.

Further to the challenge to meet the increases in energy use, more challenges present themselves:

- The first of these is the need to deal with *environmental pollution.* Energy related pollution takes various forms. Traditional fuels used in the confined spaces of the homes of the poor result in high levels of harmful indoor pollution. Rapidly increasing use of coal and oil in sub-standard equipment in the most populous areas of developing countries leads to high levels of local air pollution. Both of these causes result in developing country populations suffering 20 times the atmospheric pollution that developed country populations do.
- The burning of fossil fuels for transport and electricity generation is an important source (about 6 GtC) of *man-made greenhouse gas emissions.* While there is no final consensus that global warming will result from increased concentrations of greenhouse gases, pressures to reduce the carbon emissions from energy production and use are growing. The UNFCCC (United Nations Framework Convention on Climate Change) and its Kyoto Protocol demonstrate that it is possible to reach global agreement on action, but far more needs to be done. The Protocol contains legally binding emissions targets for Annex I Parties, requiring them to reduce their collective emissions of six key greenhouse gases 5 by at least 5.2% up to the period 2008-2012 (the "commitment period"), with the emissions being calculated as an average over the 5-year period.
- *Sustainability* refers to doing something with the long term in mind, the ability to provide for the needs of the world's current population without damaging the ability of future generations to provide for themselves. When a process is sustainable, it can be carried out over and over without negative environmental effects or impossibly high costs to anyone involved [Sust]. Until the last ten or twenty years sustainable energy was thought of simply in terms of availability relative to the rate of use. Today, in the context of the ethical framework of sustainable development, other aspects are equally important. These include *environmental effects* and *the*

question of wastes, even if they have no environmental effect. *Safety and security* is also an issue, as well as the broad and indefinite aspect of *maximising the options available to future generations* [UIC1].

- The total resource base of oil and gas is the entire volume formed and trapped within the Earth before any production. The largest portion of this total resource base is nonrecoverable by current or foreseeable technology. Most of the nonrecoverable volume occurs at very low concentrations throughout the earth's crust and cannot be extracted short of mining the rock or the application of some other approach that would consume more energy than it produced. An additional portion of the total resource base cannot be recovered because currently available production techniques cannot extract all of the in–place oil and gas even when present in commercially viable concentrations. The inability to recover all of the in-place oil and gas from a producible deposit occurs because of unfavorable economics, intractable physical forces, or a combination of both [EIA1].

Thus the increased energy supply in the twenty-first century *must be cleaner and emit less carbon*. At same time, liberalisation of the more sophisticated energy markets is placing increased power in the hands of customers. Customers want *cleaner, more flexible and more convenient energy*. They also want it to be low cost, be it through cheaper energy or through more efficient conversion and use, so that they get the energy service they want with less energy. Competitive conditions mean suppliers must respond to these customer preferences.

What do all these varying pressures do to the structure of energy supply in the twenty-first century? Due to the long life times of energy infrastructure, relatively little can change for a decade or so. Thereafter a continuation of two trends already evident is foreseen [Mur]:

- The shift from solid fuels (coal and biomass) to liquids (oil products, methanol/ethanol), and
- The shift from liquids to grid based supply (gas, district heat, electricity and hydrogen).

Within these broad trends, the fortunes of the individual energy sources can vary considerably:

- The market share of oil peaked in the seventies, but its future use may increase if technology to exploit unconventional resources and to moderate the environmental impact of its end uses is aggressively pursued, or may decrease if it fails to adapt and conventional deposits are depleted.
- Gas is seen as the key transitional fuel from traditional fossil fuels to a lower carbon future.
- The market share of coal peaked at the beginning of the twentieth century, but its use will increase in absolute terms, although increasingly converted to electric, gaseous or liquid form.
- The capacity to expand the market share of hydroelectricity is limited, but full development of mini-hydro could see it maintain market share.
- Biomass is seen as expanding significantly in all scenarios up to limits that may be set by competition for fertile land with food production. Some biomass will still be in the form of traditional woodfuel, but hopefully produced in more sustainable regimes.
- There are many other potentially significant renewables, but they will be growing off a very low base and significant technical and economic breakthroughs are needed in many cases.

8.2.1 Nuclear Power today - A small review

The obvious constraint on expansion of nuclear power in the past two decades has been public opposition. Sociologists have spent much time analysing the roots of opposition to nuclear power in the context of fundamental changes that have been taking place in society, including changing perceptions of science, risk, scale and authority. The point of immediate practical relevance is that, in anything but an extreme totalitarian state, it is simply not practicable to supply such a key product as electricity through a technology that is not accepted by most of the population. The public must be broadly satisfied that nuclear plants are needed and that they are adequately safe.

Cost has an important bearing on the need for nuclear power. It is popularly supposed that nuclear power plants have proved expensive. The reality is very variable, some have, some have not. Nuclear electricity is towards the high capital cost, low operating cost end of the spectrum. Fossil fuel fired plants, in particular gas, are towards the opposite side of this spectrum, where capital costs are low and operating cost, notably fuel, are, relatively speaking, high. Herein lay one of the miscalculations of the seventies and early eighties, however. Fossil fuel prices did not rise as expected and nuclear operators did not quickly appreciate how much lower the competitive bar had got. Moreover, some had saddled themselves with excessive capital costs from extended construction periods in a high interest rate era. With the passage of time, however, capital costs are depreciated. More importantly, there has been a concentrated effort by industry to improve performance and cost competitiveness [Mur].

The good cost performance of nuclear plants is despite the fact that they must cover the costs of managing their wastes in a way that no fossil plant has to. Being competitive is not sufficient, however. Nuclear plants must be safe. That does not mean that there must never be an operating error or mishap. That is not realistic. But it does mean that design and operation must combine to achieve the critical requirement - if it happens, it must not matter and, if it matters, it must not happen. Nuclear energy will always be a demanding technology in terms of the high quality standards needed [Mur].

(IMPORTANT NOTE: Appendix 6 contains further reading, statistics and figures for a more spherical point of view, regarding *energy demand and production, the constraints of the current energy sources, the Kyoto Protocol and Sustainable energy***)**

8.3 The step-by-step approach to modeling

In a previous chapter on model definition and the process of modelling, certain key questions emerged, such as:

- What are the incentives to model?
- How do you actually begin to model?

- What are the first things you have to consider in the process?
- How detailed or how simplified does the model have to be in order to satisfy specifications and what are those specifications?
- How does the purpose of modelling affect the modelling process?
- How does ones personal skills affect the modelling process?

It will be demonstrated how these questions naturally emerge in the context of the specific case study which leads to the specification of the system and the need to create a model using the prescriptive steps earlier defined.

8.4 Problem Definition-First step to Conceptualisation

The overview regarding the energy demand and use shows the necessity of immediate plans to conform to the new era that requires:

- Stability of energy production
- Economically viable energy sources
- Energy sources that emit less carbon and are environmentally friendlier.

To come to the specific problem, electricity consumption is growing faster than other energy sectors in industrialized economies. Compared to primary fuels such as coal and oil, electricity is clean and safe. No waste is produced at the user's end. All pollution is caused by the producer, not the end-user. Unlike most other fuels which require storage and processing, electricity is immediately available and easily controllable at point of use. Precisely for these attractive characteristics, electricity has become the essential driver of the economy. Electricity supply is expected to be reliable, that is, available when needed, and affordable.

The electricity supply industry (ESI) is one of the most capital intensive of all industries, with huge investments in power stations that are expected to pay off over several decades. Long construction lead times and operating lives imply the need for capacity planning to determine the types, sizes, and timing of new plants to be built as older plants are retired. These decisions are made in the face of great uncertainty, and the often irreversible commitments are translated into future costs. In the presence of rapidly changing technology, economics, and shifting social attitudes, new commitments may quickly become obsolete and inadequate. New responsibilities and priorities in the UK and elsewhere have redefined what constitutes capacity planning, from once an engineering-dominated operational task to the domain of strategic decision making where responsiveness and other measures against complex and uncertain environments are paramount.

So far we have identified the problem area, that being the energy, and more specifically the electricity production in the UK. The more possible sources of electricity generation are given in the following figure:

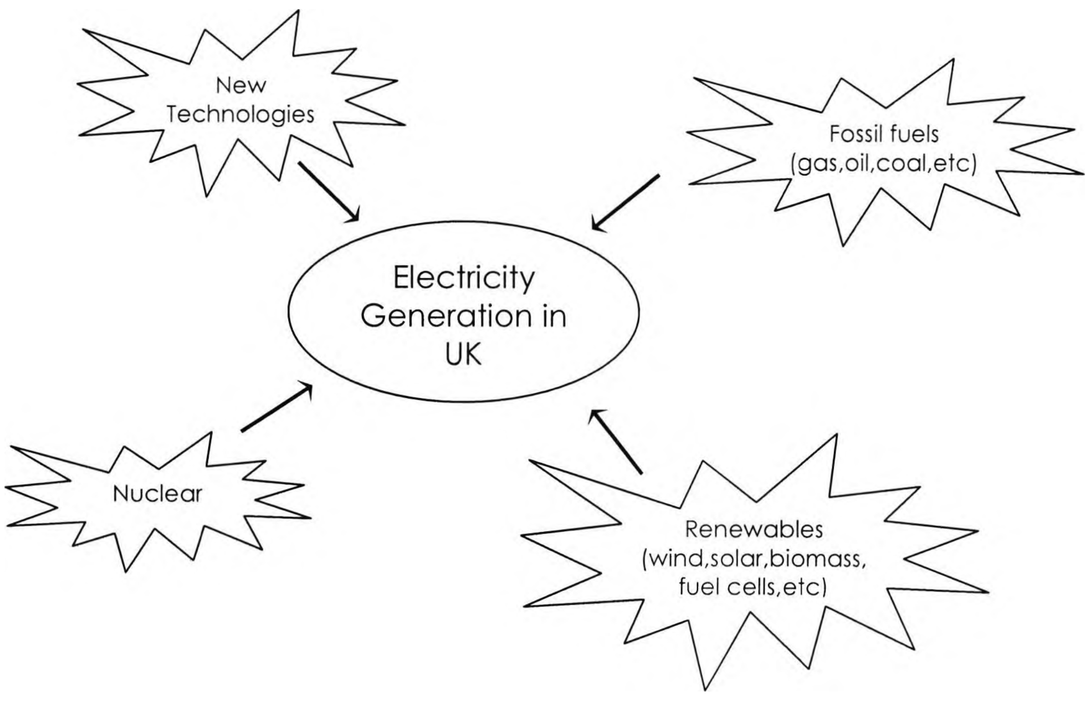

Figure 8.1: Possible sources for electricity generation.

The electricity production fuel mix in the UK has changed considerably in the last 15 years, with progressive replacement of coal-fired plants by gas-fired ones and to a lesser extent by switching from oil to gas. In 1990, nearly 80% of generation came from coal-fired generators. The UK currently enjoys healthy fuel mix diversity, but the attractiveness of combined cycle gas turbines (CCGT) for new investments combined with declining gas production of the UK raises concerns about increasing fuel import dependency [JESS].

Environmental legislation in the form of emission limits and fuel taxes favours cleaner and more efficient plants. Confronted with increasingly stringent emission controls, generating companies in the UK are considering the early closure of less economic and "dirty" coal and oil fired stations, life extension of existing nuclear power stations, and investment in cleaner plant. Concern for the environment and competition in the new electricity market have led to the phenomenon known as the "dash for gas." No longer restricted from use in electricity generation, natural gas is now a much sought after fuel. The availability of gas from the North Sea and the technology of combined cycle gas turbines (CCGT) answer the call to lower emissions with its negligible sulphur and reduced carbon dioxide emissions. Its high thermal efficiency, typically around 50%, gives greater electricity output and thus value for money. Shorter construction times make CCGT an attractive and viable choice of new plant as well as a means for independent power producers to enter this competitive market. [Ku]

The UK now enjoys a healthy diversity in generation of electricity with coal, gas, nuclear and renewables, all playing significant roles as shown in the Figure 8.2 [JESS]. Most of the new power plants built in the UK during the 1990s were Combined Cycle Gas Turbines (CCGT) and this trend is expected to continue in the next decade as CCGT are forecast to remain the cheapest technology. The Joint Energy Security of Supply (JESS) forecasts show gas-fired generation to be producing by 2010, 46 TWh more than it was produced in 2000, rising to an additional 137 TWh in 2020.

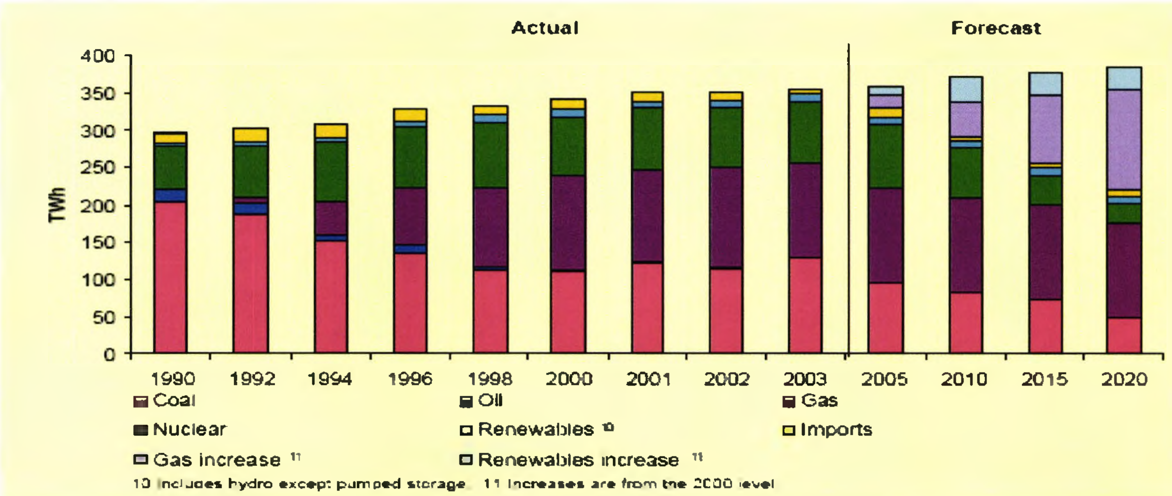

Figure 8.2: Fuel mix evolution forecasts [JESS]

As a consequence of the growing reliance on gas imports, the UK supply security will be increasingly dependent on gas exporting countries. This is due to the conjunction of two main factors:

- The increasing share of gas in electricity generation in the late 1990s
- The decrease of UK gas production.

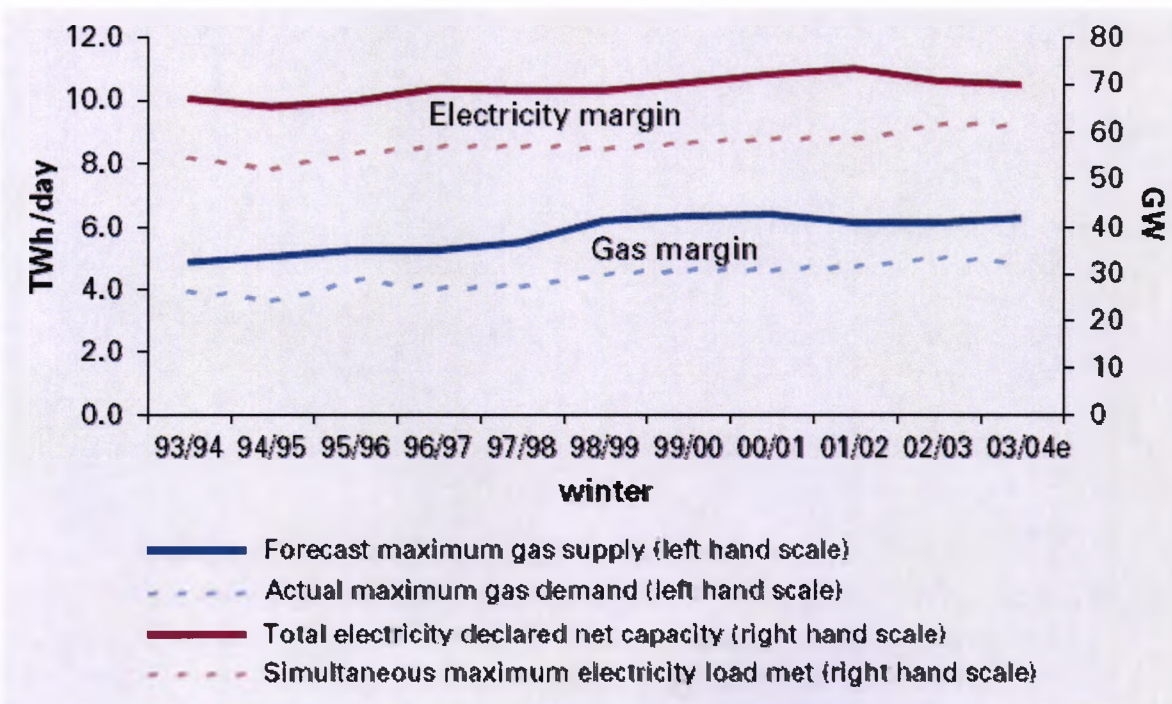

Figure 8.3: Gas and electricity capacity margins – maximum supply and maximum demand 1993/4 to 2003/4 [DTI-SEPN]

This understanding of the importance of gas in the UK electricity market, makes it a significant factor in this research. At the moment the reader understands that gas is the main leading influence to the electricity prices and that those two are interdependent. The figure below gives more evidence to the argument that electricity generation increasingly depends on gas as its source of prime energy.

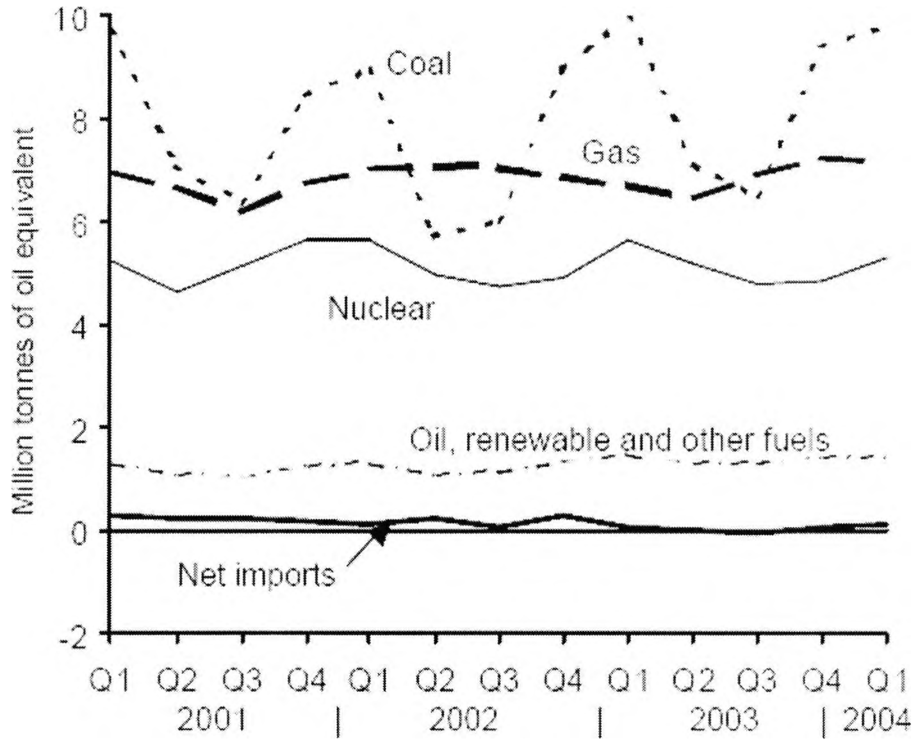

Figure 8.4: Fuel used for electricity generation. [E.T.DTI]

The Problem specification

From what we have seen so far (for further reading, figures and statistics refer to Appendix 6), the *main source of electricity production is gas*. With this source becoming slowly extinct and therefore more expensive, new sources need to be identified and their spectrum of their ability needs to conform to the new era needs. Having identified possible scenarios of energy sources, the process continues with trying to find the one that is best suited to the UK energy market according to the constraints and the specifications of that market:

- *Kyoto protocol.*

- *Resources coming to deadlock.*
- *Sustainability.*
- *Economic factors, efficiency, etc.* (refer to Appendix 6 and previous section)

It is obvious that there are several serious milestones in the pursuit of that goal. What is also obvious is the fact that although the pressure of time to complete the goals remains, the important decisions to be made of how to move forward are yet to be addressed. The immediate action that is needed does not exist. At the moment the world is entering a phase of transition that was not fully prepared for and thus is losing valuable time. This delay on taking decisions can only have negative results since it eliminates several options.

There is an urgency to successfully:

- promote new technologies (either to "clean" the residues of the existing energy sources, or to discover a completely new energy source)
- "push" renewables to their limits
- befriend with the idea of introducing a leading role to the nuclear power
- conservation of energy.

The incentive to begin a modelling process in this situation is the transition period, mentioned in the previous section, and the delay due to that transition that will cost to the UK, in particular, loss of money and sustainability. The immediate reaction to that lingering is to try to make the most of it by introducing *options*. New ideas and plans need to be acknowledged immediately and without any further stalling, need to become targets in time and space. Their feasibility needs to be addressed and demonstrated. Techniques need to be found to ensure that the solution to the problem of energy in the UK and around the world exists. And it is only a matter of time, coordination and synchronization from the government, to ensure that when the option of a cheaper, cleaner, more efficient source of energy is introduced, "to grab" it.

Natural gas at this point can be thought as the most competitive source of electricity production. This realization is the trigger to look at natural gas as one of the *variables* in this problem. At this point the possible options for electricity generation will be weighed and a process of decision making will begin. The proposed solution is to identify a competent successor of natural gas, and then find the right place in time to switch from one source to the other, for generation of electricity.

The next variable-the successor- must be one that can, at the moment, be as competitive as natural gas, in matters of:

- price (of the end product, that is electricity)
- feasibility as a resource (that is, needs to be an already known resource that is not reaching its peak)
- feasibility as a project (plant construction, distribution , etc.)

Obviously the *constraints* put on this new variable, are minimal since the modeling process is still in the very early stages, and the problem is still formulated in a more formal language. These constraints will be enriched as well as populated with other ones as the formulation continues and the unraveling of every aspect of the problem begins. At the moment though, we are concerned with the identification of the main constraints that formulate the *specifications* of the problem.

Available Options

So far the discussion is driven by assumptions and general descriptions of how the new competitive source of electricity would be. Now it is time to look through the several *options* and choose the most suitable according to the *specifications* that were previously embedded on that source. As previously discussed we consider the following *options*:

- promote new technologies (either to "clean" the residues of the existing energy sources, or to discover a completely new energy source)
- "push" renewables to their limits
- befriend with the idea of introducing a leading role to the nuclear power
- conservation of energy.

At this point a short description of the options available now, will be made, along with the thoughts of how feasible these options are. It must be noted here that the options that will be discussed in this thesis are options that are generally accepted, as possibilities. Their description will pinpoint the advantages of using options but concentrate on the feasibility of those options at this point in time, as that will be one of the deciding forces at this early stage in the conceptualisation process. It will draw the path and the step by step approach that was taken during the research to find the appropriate alternative energy source.

8.4.1 New Technologies

Technological innovation and development is the most appealing way to reconcile expanded energy services with protection of the environment, as it holds the promise of moderating the difficult choices to be made. With respect to supply, technological advance is vital to securing and maintaining discovery and production capacities, as well as reducing the environmental impact of present systems. In particular, given our expected future dependence on fossil fuels, a priority is systems for their cleaner use.

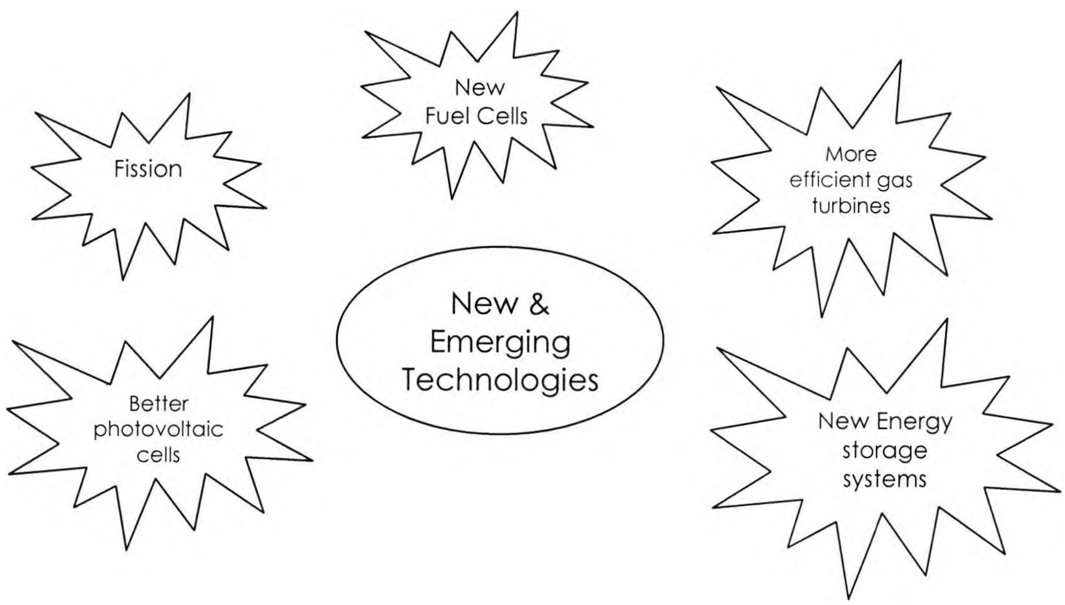

Figure 8.5: New and emerging technologies.

This decade will see a number of new and emerging technologies become commercial. These will include Integrated Gasification Combined Cycle (IGCC), new generations of fuel cells, more efficient gas turbines, new electric energy storage systems (liquid batteries, better solar collectors), better and cheaper photovoltaic cells, improved nuclear systems and. Electric energy storage technologies will have improved greatly, but large scale thermal energy storage will remain an elusive goal.

It is urgent for energy research and development to be strongly and consistently supported by both governments and industry. Governments and industry need to renew and expand their partnerships. The British government believes that decisions regarding energy R&D are largely the concern of the energy industries. In fact, over the past decade, government energy R&D investments have fallen by more than 90% in real terms, as a result of a deliberate strategy on the part of the government to reduce its interventions in the marketplace and its overall budget outlays [Run]. In the government's view, the introduction of competition and free-market incentives in these industries would help to improve efficiency, provide better quality of service to consumers, and reduce associated operating costs [Run]. Figure 8.6 shows the British government's recent investments in energy R&D. The decline in energy R&D support between 1996 and 1998 is consistent with the broader trend of the past decade, during which the U.K. public energy R&D expenditures have fallen by more than 90%.

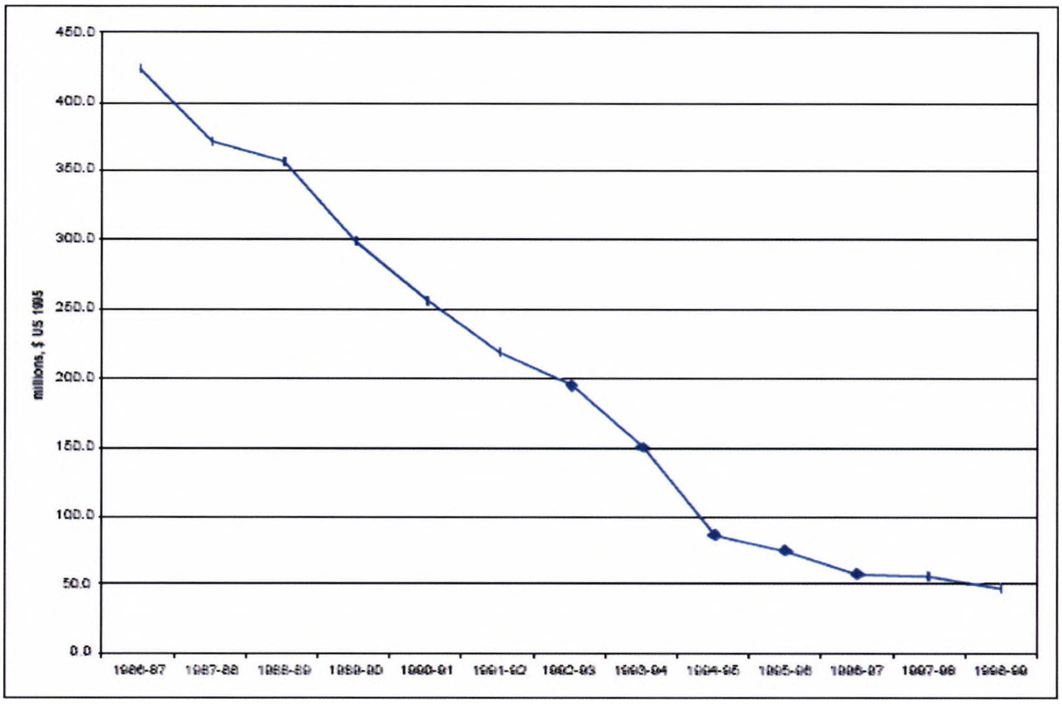

Figure 8.6: Total Government R&D Energy expenditures 1986-1998. [Run]

Government funding for energy R&D now focuses to some extent on efforts to finalize development of technologies that are thought to have commercial promise, but that are not yet ready for introduction to the market.

Independently of whether R&D development in the energy sector is funded by the government (as far as we are concerned, this type of expenditure should not only be funded by governments only, but by industry as well), the fact is that most of the new technologies are not yet ready to be used and thus are not, at the moment, of any research value. Since there is no statistical data, information about pricing and generally we have not seen it in practice yet, only assumptions can be made and thus generalize the problem so much that it is impossible to compare it with a project that has proven feasible, such natural gas, oil, coal, as an energy source. Furthermore these new technologies will not have a major impact on power generation during this decade since no-one wishes to prematurely write off a nation's modern coal fired power stations costing perhaps $2 billion each [WEC3].

8.4.2 Renewables

The government aims to increase renewables's share to 10% by 2010. The government gives priority to support for renewables R&D projects in technology areas that are likely to have the greatest impact, in the short term, in both domestic and export technology markets [Run]. Currently, technologies considered closest to being competitive in the UK or abroad, in the government's estimation, include waste-to energy and biomass electricity generation, landfill gas, onshore wind, and passive solar technologies. Additional technologies that are being considered both for their export potential and for their potential contributions to the UK's 2010 target of 10% renewables include fuel cells, photovoltaics, offshore wind, and energy crops. Research supported by this program aims to make cost-reducing improvements that will enable the commercial deployment of renewable energy systems on a significant scale [Run].

If the fundamental opportunity of renewables is their abundance and relatively widespread occurrence, the fundamental problem, especially for electricity supply, is their variable and diffuse nature (the exception is geothermal, which is not widely accessible). This means either that there must be reliable duplicate sources of electricity, or some means of electricity storage on a large scale. For several decades there has been intensive research for the development of electric energy storage technologies and several technologies are now emerging that have a promising perspective. Among those are the so-called redox flow systems. With this technology it is possible to separate the power and energy capacity of the battery and the cells have the potential of a very long life. However, it is not yet known whether such technology can be competitive in the energy market.

For a stand-alone system the energy storage problem remains paramount. If linking to a grid, the question of duplicate sources arises. For large-scale and especially base-load electricity generation there is little scope for harnessing the sun. Sun, wind, tides and waves cannot be controlled to provide directly either continuous base-load power or peak-load power when it is needed. In practical terms they are therefore limited to some 10-20% of the capacity of an electricity grid, and cannot directly be applied as economic substitutes for coal or nuclear power, however important they may become in particular areas with favorable conditions. Nevertheless, such technologies will to some extent contribute to the world's energy future, even if they are unsuitable for carrying the main burden of supply [UIC2].

If there were some way that large amounts of electricity from intermittent producers such as solar and wind could be stored efficiently, the contribution of these technologies to supplying base-load energy demand would be much greater. Already in some places pumped storage is used to even out the daily generating load by pumping water to a high storage dam during off-peak hours and weekends, using the excess base-load capacity from coal or nuclear sources. During peak hours this water can be used for hydro-electric generation. Relatively few places have scope for pumped storage dams close to where the power is needed, and overall efficiency is low. Means of storing large amounts of electricity as such in giant batteries or by other means have not yet been commercialised [UIC2].

Independently of the fact that in the future a solution might be found for the storage of electricity, as well as, the non-existence of continuous base load power produced by renewables, the share of renewables, towards the total electricity produced by fuel type, will remain significantly low. Renewables although inadequate to produce a considerable share of electricity, still remain an important, undivided part of fuel type. For the purposes of this report, though, it is unrealistic to compare a fuel type so weak in production of power, with a fuel such as natural gas. The comparison itself -not even competition- is overwhelmed by the figures (for example, see Figure 8.2).

8.4.3 Conservation of energy

Although introducing a more conservative approach to energy, and thus electricity consumption, is not given as an option to replace any energy source per se, it is an option to sustain the levels of fuel types available to produce electricity, keep the prices of the resources at competitive and yet logical levels and reduce the emissions of greenhouse gases, among them carbon dioxide (CO_2). Conservative energy consumption could provide a helping percentage towards the energy problem in the world. At this point a short description will be made of the end-use effects in the environment, along with recommendations of end-use technologies that could make a change.

All energy resources are of little use or value without being subjected to some kind of conversion process. Just having a lump of coal, uranium or oil shale is of no benefit to anyone. Conversion may be simple, (burning gas to provide heat) or complex (refining crude oil to a host of petroleum products or generation of electricity from coal etc.).

Consequently, a most important issue for sustainability, particularly from a greenhouse mitigation perspective, is the development and use of the most efficient and cost effective technologies for energy conversion. The introduction of these technologies (which are at various stages of imagination, research, development and commercialisation now), together with a much greater emphasis on energy conservation, demand side management, including a wide range of new and improved end-use technologies, will broadly define the world's path to energy sustainability.

Energy consumption can be seen as a twofold process, one is the industrial-transportation consumption and the other is the residential-commercial. Just under one-third of UK energy consumption takes place at home. It increased by 20 per cent between 1990 and 2004, driven by changes in the way we live. First, there has been an increase in the number of households, as more people live in households with fewer people. Secondly, we keep our homes warmer in winter than we used to. Average temperatures inside domestic dwellings are estimated to have increased from 16 degrees in 1990 to 19 degrees in 2002, helped by the increased prevalence of central heating. Thirdly, household incomes have risen steadily and this has resulted in the purchase of more and bigger appliances in homes [DTI].

Choices that we make about where we live and work, how we keep ourselves warm, where we holiday and how we choose to interact with technology impact on the quantity of energy we use and thus the amount of carbon emissions for which we are responsible. It shows that key decisions that we each make can determine our rates of energy consumption for many years to come. The energy consumption in our homes and moving around, mainly in cars, accounts for half of total UK final energy consumption.

The figure below shows the change in energy consumption from 1990 to 2004. It is obvious how important it is to try to control the energy consumption in the domestic sector since it happens to be the one with the highest change.

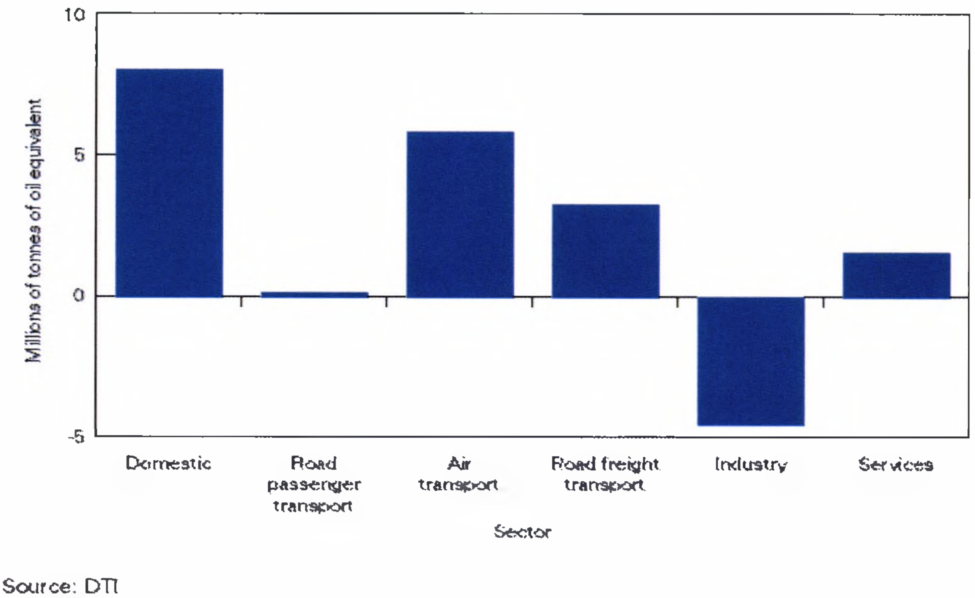

Figure 8.7: Change in Energy Consumption from 1990 to 2004

The increase in energy consumption from these factors has been offset significantly by increases in thermal insulation of the housing stock and improvement in the efficiency of some appliances. By the end of 2002, only one in ten of all homes in Great Britain had no insulation. Also, in the five years to 2004, around one million homes had their wall cavities filled with insulating material, in almost all cases at low cost through schemes promoted by suppliers in connection with the Energy Efficiency Commitment (EEC) and its predecessor.

EEC is the Government's principal policy mechanism for improving the energy efficiency of existing homes. Under EEC, suppliers are required to achieve targets for energy savings through the promotion of a range of approved measures including cavity wall insulation, other insulation measures, high efficiency boilers and low energy light bulbs. Other government measures improving energy efficiency in this sector include the introduction of tighter building regulations – for both new dwellings and improvements – in 2005 [DTI]. Energy end-use is everywhere, crossing all sectors of the economy. In the USA a wide range of new and improved energy end use technologies have been documented and are at various stages of R&D and demonstration and commercialisation. These cover buildings, transport, and various energy-intensive sectors like iron and steel, oil refining, petrochemicals, pulp and paper, and cement. Some are briefly described below [EIA2]:

- *Equipment and Appliances.*Replacements of equipment and appliances with more energy-efficient units to reduce greenhouse gas emissions are frequently reported energy end-use projects.
- *Lighting and Lighting Control.* Lighting and lighting control projects, such as installing compact fluorescent bulbs and occupancy sensor lighting controls, have consistently been popular projects in the Voluntary Reporting Program
- *Heating, Ventilation, and Air Conditioning (HVAC).*HVAC projects involve the reduced use or upgrade of HVAC systems in homes, businesses, offices, or industrial plants.
- *Building Shell.* Building shell projects improve the energy efficiency of buildings through upgrades to ceilings, walls, floors, windows, or doors (e.g., insulation, air sealing, or efficient materials). The additional design costs of a high-performance building, are based on the recognition that constructing a highly energy-efficient building takes more up-front design time and cost.

- *Load Controls*. Load controls are energy management techniques for minimizing—either overall or at specific times of the day—the load demands on electric power providers. Power companies themselves can use load management options and, through DSM programs, encourage their customers to apply load controls. Independently, power consumers can employ load controls to reduce their energy consumption, shift their demand to non-peak hours, reduce their consumption during peak hours, and reduce energy costs.
- *Motor and Motor Drive*. High or ultra-high-efficiency motors and variable-speed or variable-frequency motor drives are more energy efficient than regular motors and motor drives. In addition, controls can be used to reduce electricity consumption by adjusting motor speeds or turning off motors when appropriate.

New technology innovation and more rapid deployment of improved technologies are required to widen commercial availability of modern energy services, to accelerate efficiency improvements, and to tackle a range of environmental issues from the local to the global. But, at the same time, there is a perception that the commitment to technology research and development by governments and private companies is weakening. In the UK, government expenditure on energy conservation RD&D (Research, Development and Deployment) has dwindled away to almost nothing since 1993 [Run], [WEC2].

As an idea a more conservative approach to energy consumption, along with R&D expenditure in technologies that help control consumption, is very appealing. Again though funding support from the government is essential and urgent. This approach does not necessarily guarantee outstanding results but can be used as a supporting act towards tackling the problem of efficient energy use. It does not come as a surprise to see that governmental and non bodies in reports about the energy future in the UK strongly suggest to reduce consumption of fossil fuels through improving energy conservation and efficiency (such as reports from DTI, Royal Engineering Academy, etc.).

History suggests that we are more capable of reacting to and dealing with short term uncertainties than long-term ones [Senge]. Indeed, gradual changes over a long period of time seem to have less impact than sudden changes and as disappointing as it may be, while we may be aware of the hazards if energy resources reach their nadir, as long as we have electricity we are not too concerned.

8.4.4 Befriend with the idea of introducing a leading role to the Nuclear power

Current economic theory is based on growth and, ultimately, unlimited resources or substitutes for these resources. Traditional market economics *assumes* -"assumes", being the operative word-that if there is a shortage of something, the price increases until demand is dampened. However the increased price triggers more investment, which increases supply and thus prices fall. Things are thus kept in balance - so, in summary it has the view that:

economic 'stability' = economic growth = more energy each year.

This view though, contradicts what it has already discussed about sustainability and conservative way of living, regarding energy consumption. And furthermore it assumes that you can produce more by investing more. But it is a view that tends to be a rule in today's society. This rule doesn't apply to limited natural resources as no amount of investment will deliver something that isn't there. Substitutes are also made. In terms of energy we have moved from wood, to coal and to oil and gas. Each step has forwarded industrialisation as it employs a more concentrated and flexible energy source. After oil and gas, and following the above rule, many believe that there isn't an obvious step, no clear alternative, unless one considers nuclear power [Tooke]

Nuclear power is a seriously thorny subject. Detractors say the EROEI (Energy Return On Energy Invested- *How much energy do you put into a system and how much do you get out?*) is low and the environmental impact unacceptable. Supporters claim the cost and practicality has improved and that nuclear is the only real option. It has to be said that it is the only technology available today that could both produce the amount of energy required by current society – and avoid global warming [Tooke].

The global slowdown of interest in new nuclear plants may be over; vital signs within the electrical industry point to a rekindling of utility interest in nuclear power. The reasons are significant, and include the following [Paul]:

- Nuclear economics of advanced passive plants are now competitive with the lowest cost energy sources, such as natural gas and combined cycle.
- Step improvements in nuclear plant safety are also providing significantly reduced economic risks associated with nuclear plant ownership and operation.
- Environmental benefits derived from nuclear power's elimination of greenhouse gas emissions are yielding high levels of public acceptance.

With regard to nuclear power, the WEC (World Energy Council) adopted the following conclusion at its 17^{th} WEC Congress in Houston in September 1998:

"Nuclear power should play a major role in contributing to electricity provision and in strategies to combat global warming, where feasible. The nuclear industry will have to take the necessary steps to bring down costs and to satisfy public concerns about safety. Governments must take a more active role in assuring prudent regulatory oversight to ensure that nuclear waste is managed properly and the potential dangers of nuclear proliferation are addressed effectively everywhere." [WEC1]

Public debate about the virtues and threats of nuclear energy is about options for producing electricity. None of the options is without some risk or side effects. In the figure below, the side effects, in terms of greenhouse gas emissions, of every fuel type that produces electricity are portrayed.

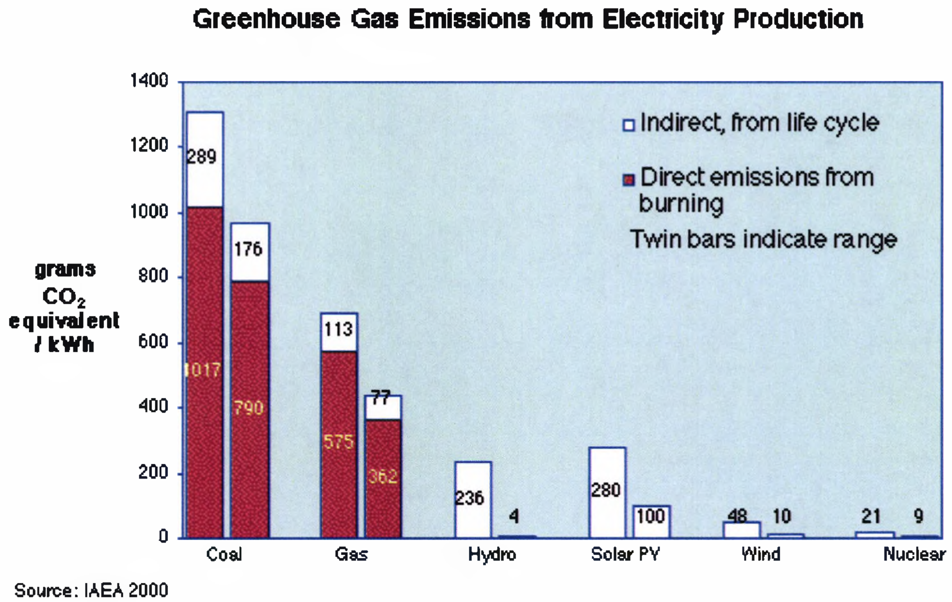

Figure 8.8: Greenhouse Gas Emissions from electricity production [Hor]

The obvious fact that nuclear power doesn't produce carbon dioxide is increasingly relevant to its role in the world's energy mix. In fact of course there is likely to be some carbon dioxide produced at various stages in the front end and the back end of the nuclear fuel cycle, the amount depending on what assumptions you make about the energy intensiveness of enrichment and the efficiency and source of that energy input. The amount is trivial. [Hor]

The present role of nuclear energy in reducing the global climate change threat can be assessed by estimating the amount of carbon dioxide emissions avoided owing to nuclear electricity generation. If all nuclear power plants in operation today would be replaced by gas-fired power plants, 300 million tonnes of carbon would be added to annual emissions, thereby increasing by 5% global energy-related carbon emissions. Were nuclear energy to be substituted by the mix of fossil fuels used today for electricity generation, the increase in annual carbon emissions would be around 8% [NEA].

"We have highlighted the possibility that at least one Member State, namely the UK, will fail to meet its indicative targets by 2010. We have examined the other sources of energy

that could be used to replace fossil fuels with minimal or no emissions of greenhouse gases. We recommend that large hydroelectric installations should have equal status with other renewables under the terms of the Directive. We also suggest that policies regarding energy from waste and the nuclear power industry be reviewed so that they can play a full and continued role in reducing emissions of GHGs."[RAE1]

Royal Academy of Engineering

(The role of the Renewables Directive in meeting Kyoto targets, October 2000)

There are, broadly, three types of safety issue associated with nuclear power [RAE2]:

- the risk of a catastrophic accident releasing uncontrolled amounts of radioactive material into the environment,
- any risks associated with radioactive leakage in daily operation, eg from plants or from stored waste,
- and the possibility of proliferation.

It is not difficult to show that counting all risks from uranium mining to (surface) storage of spent fuel, the number of casualties per kWh has so far been much less than for electricity generated with fossil fuel [RAE2]. Whilst reassuring, that observation does not in itself dispose of the problem. In a situation where an extremely unlikely event would have extremely undesirable consequences, statistics provide only limited comfort. However, within the limits of human endeavour, it is believed that the regulatory and inspection regime in the UK, which addresses both the construction of nuclear power stations and their daily operation, is highly rigorous and well adapted to the needs of a democratic society [RAE2].

The nuclear power industry has been developing and improving reactor technology for almost five decades and is now starting to launch the next generation of advanced reactors. They either require no active controls or operational intervention to avoid accidents in the event of major malfunction, or at least allow a lot of time for intervention.

Nuclear waste is frequently trotted out as the major disadvantage of nuclear energy. While the nuclear fuel cycle does generate various wastes, all of the hazardous ones are contained and managed, rather than being discharged to the environment. The main focus of attention is high-level waste containing the fission products and transuranic elements generated in the reactor core. The cost of waste disposal is generally paid for by a levy on the electricity as it is produced, and is thus funded in advance by consumers [Hor]. The Government has set up the Nuclear Decommissioning Authority to establish a strategy for the safe, secure, cost effective and environmentally responsible de-commissioning and clean up of public sector nuclear sites [DTI].

The international safeguards that prevent unauthorized diversion of fissionable materials, in the major nuclear energy countries during the last few decades, have been rigorous and effective [RAE2]. There are no concerns, on grounds of danger of proliferation, with the maintenance or moderate expansion of nuclear power in OECD countries. If however one were to look to nuclear power as a major part of the answer to the growing energy problem, the increased danger of proliferation is a factor that would have to be examined with the greatest care [RAE2].

8.4.5 Working Assumptions

Society must accept responsibility for balancing the constraints it places on the electricity suppliers against the demands it makes for their product. In that sense, getting energy policy right is everyone's responsibility.

This thesis makes the following assumption; that the main share of the future energy shortage can be covered by nuclear power, suggesting a time frame in which the succession from gas to nuclear can be made. The progression of that thinking and the conceptualisation of the problem will be showed in the following sections. This decision is solely dependent on the evidence and data that was studied throughout the reserach, from various sources, governmental and non bodies, pro-nuclear reports and sites as well as "green". Comparisons according to the constraints set for this variable:

- price (of the end product, that is electricity)
- feasibility as a resource (that is, needs to be an already known resource, that is not reaching its peak)
- feasibility as a project (plant construction, distribution, dissemination etc.)

were made, and although not going into too much detailed analysis (eg, pricing) at this stage, it was clear that the most appealing succesor to natural gas is nuclear power.

8.5 How do you actually begin to model?-The process of Conceptualisation

Identifying the main variables, constraints and specifications gives a general structure to the problem and an idea of how to move forward. This stage is crucial since it will be the cornerstone of the whole modeling process. The modeler needs to familiarize himself with the variables and how their selection is probable to affect the modeling process. Trying to identify probable future problems occurring from the present selection of the variables is a delicate process and it is tightly correlated with the modeler's previous knowledge and experience, as well as the depth of the research he or she has done for the relevant problem.

So far the way of thinking was a step by step approach that entailed the identification of the problem area, the definition of the problem, the familiarisation with the problem as well as a continuous questioning of the way forward. The path for the formulation of the conceptual model can be seen through a series of questions that were imposed from the ongoing modelling process:

- Is there a problem with the UK energy? Why?
- Are there any imposed constraints that make the problem worse?
- Which aspect of the energy consumption is the most appropriate to look into?
- What is the fuel type that should be grabbing this research's attention? Why?
- Are there any constraints imposed with the use of that fuel type?

- Should we be looking into other options for production of energy in the future?
- What options are available?
- How do we decide which one is the most competitive? Are there any constraints?
- Which one is the most competitive?
- Using what as a benchmark do we compare the two energy sources?
- How do we judge the suitability?

This mode of continuous questioning for the way forward is one of the most important aspects of modelling and is closely related with data, data acquisition and data management. Some of the questions will become a point to which the modelling process will return to answer and provide stepping stones for a detailed description of the problem.

The problem so far can be visualized by the following diagram:

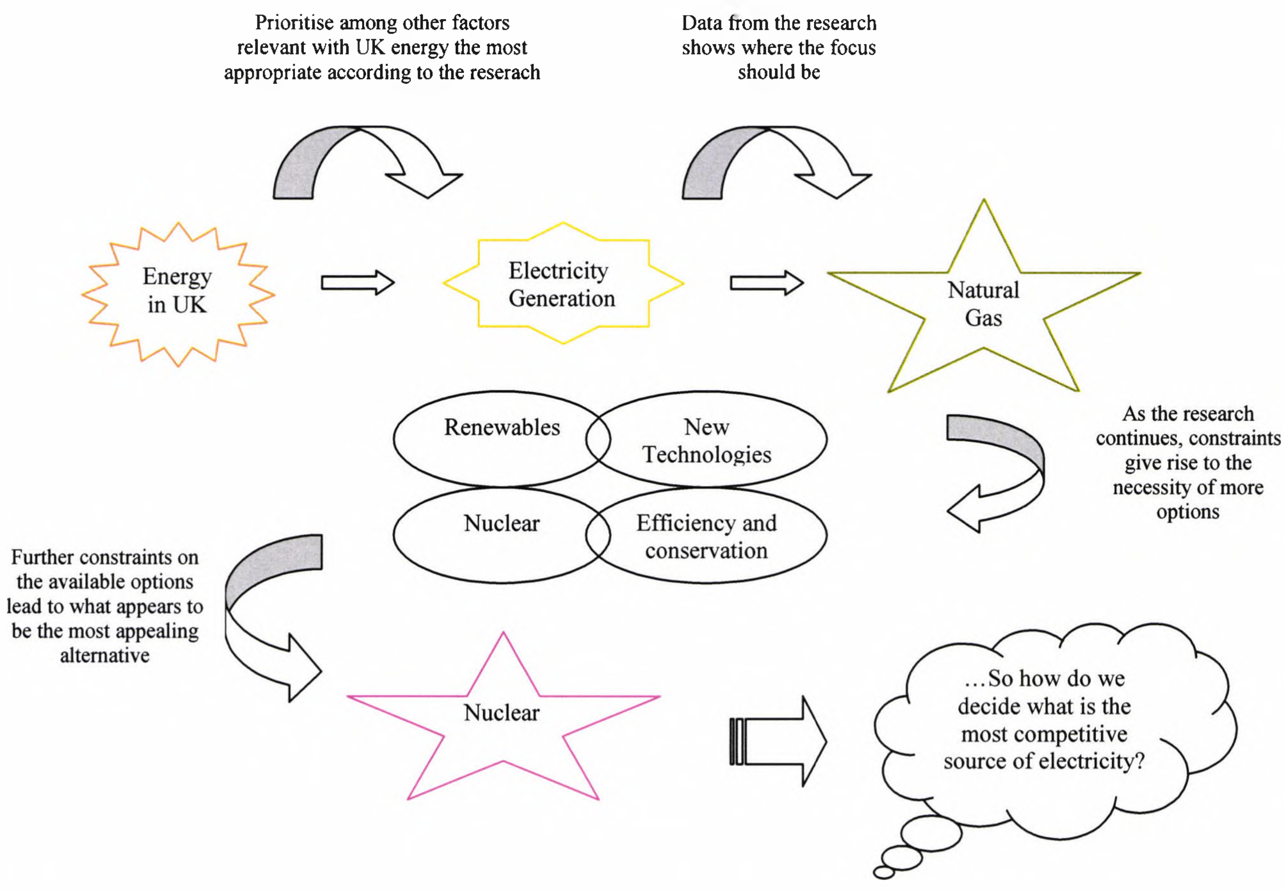

Figure 8.9: The evolution of the modeling process

Problem definition

Therefore, to summarise the conceptualisation of the problem this thesis will look into; the main problem is the generation of electricity. So far the main percentage of electricity generation was contributed by natural gas. New specifications though (pollution, sustainability, cost, resources, etc), are urging the substitution of that percentage. This thesis will look into the scenario where another energy source takes over from natural gas. These available options were: *New technologies, Renewables, Conservation of energy, Nuclear energy.*

It has to be noted at this stage of the thesis that the available options (new technologies, renewables, conservation of energy and nuclear energy) can all be combined to provide a stable percentage that would be equivalent with that given by natural gas in the generation of electricity.

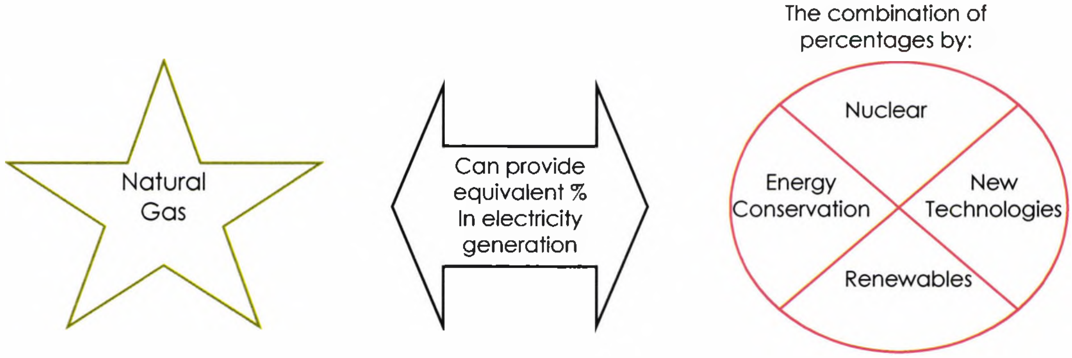

Figure 8.10: A combination of all options to provide equivalent percentage of electricity production as that of natural gas.

This combination of percentages would be an ideal solution to the problem of substituting natural gas at some point in time. This proposal though is one that needs significant research, given the fact that for some of the options, there is no available data and only assumptions can be made about the percentages they can contribute (e.g, what is the percentage that energy conservation can contribute and by which means). For that reason, in this thesis we will look into the problem of substituting natural gas with nuclear energy, which at the moment can be a stand alone natural gas substitute. To summarise, in the research that followed we made the following *assumptions*:

- The available options, were:
  - New technologies
  - Renewables
  - Conservation of energy
  - Nuclear energy.
- For the purposes of this thesis we will take the option of nuclear energy to have a leading role for the production of electricity.

What will follow will be an effort to compare the two sources (natural gas and nuclear) from a purely economic point of view.

8.5.1 Structuring the information: Selection of "components" and ordering

At this point enough information is gathered to try to put a structure in the problem and the way of tackling it. Previously in this chapter the terms *variables, specifications, parameters* and *constraints* were used in the context of describing the issue of energy in UK. In fact through the research done so far:

- natural gas has been identified as a variable,
- control of greenhouse gases emissions has been identified as a constraint
- natural resources coming to a deadlock has been identified as a constraint
- the options that are available for consideration, as well as the optimum of those options, have been identified as the possible variables for the continuation of the process
- the price of the new fuel type, that is the new variable, has been identified as a parameter of the new variable
- the feasibility of the new variable as a resource is another parameter (is the proposed energy source one that can be readily found?)

- ✧ the feasibility of the new variable as a project is another parameter (are there bottlenecks with, for example, the construction of the plant?)

During the whole process of identification of variables and constraints it must be noted that data collection not only never stopped, but was necessary for the formulation of a concrete picture of the problem. Through data collection, the allocation of importance among the various aspects of the process is realized (e.g. Why should natural gas be considered as the most competitive electricity "generator" nowadays?). Furthermore by formulating a clearer picture makes it easier to define the specifications of the problem, introduce the constraints, name the variables and parameters, and leaves less experimentation with their selection. It serves both as a reduction method which screens out unrealistic options, and helps to achieve completeness of problem specification. Data collection will continue till the more formal parts of the modeling process. Ordering the variables, constraints, specifications and parameters and integrating them into a concrete structure able to give a complete picture of the problem, is the first attempt to model the problem.

At this stage a representation of the logical thinking taking place in the model conceptualisation can be visualized as follows in the figure below. Each stage represents a small step of the research that took place showing how the constraints and specifications, imposed either by the problem itself or by external sources (i.e. the environment, world protocols etc,), produced the evolution of the problem and the final stage of introducing the competitive alternative to gas.

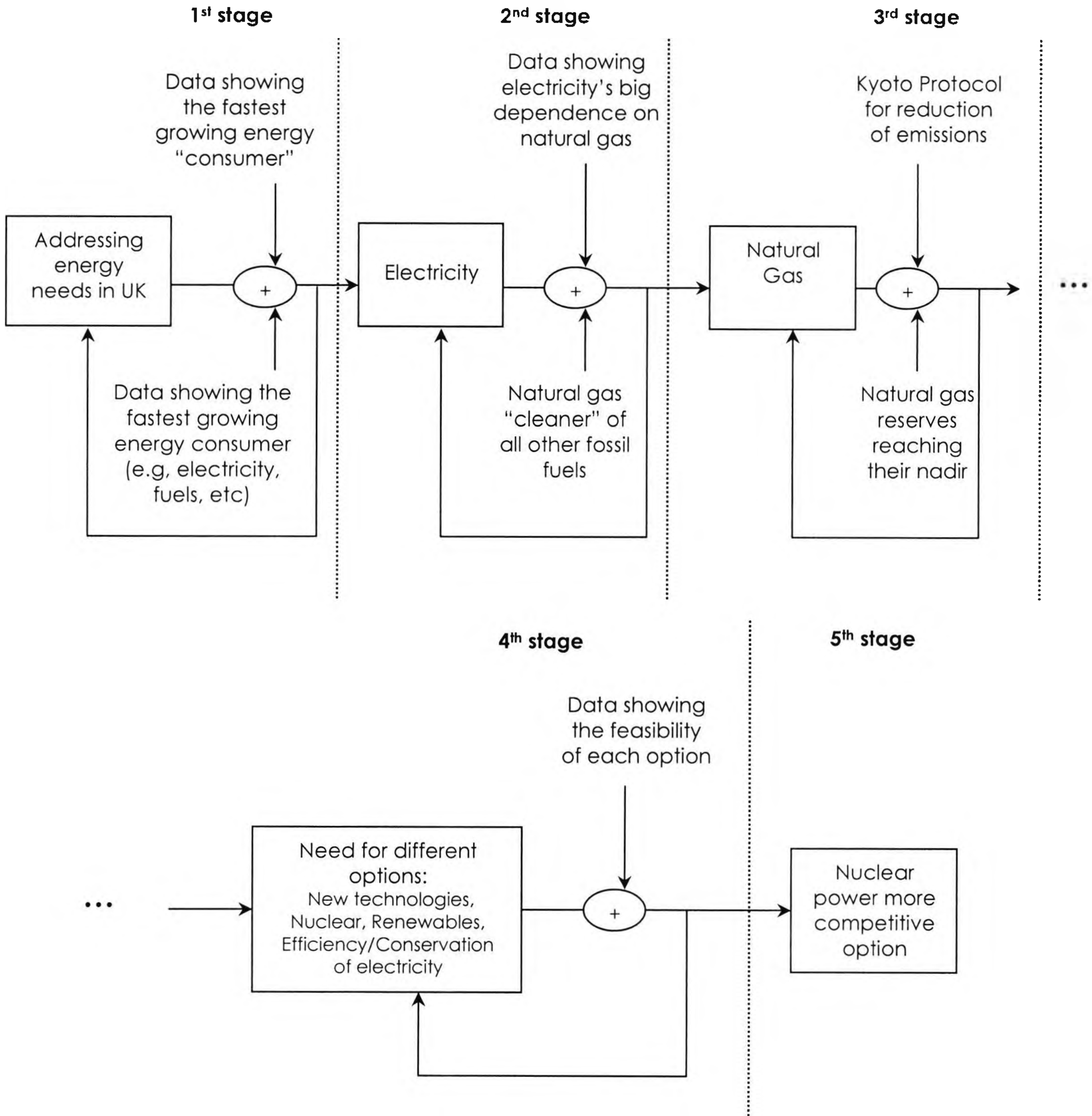

Figure 8.11: A representation of the path achieved through conceptualisation

8.5.2 Use of Conceptualisation in developing a decision making mechanism

At this stage we need to incorporate a decision making mechanism that will help in the pursuit of an answer concerning the future more competitive source of electricity.

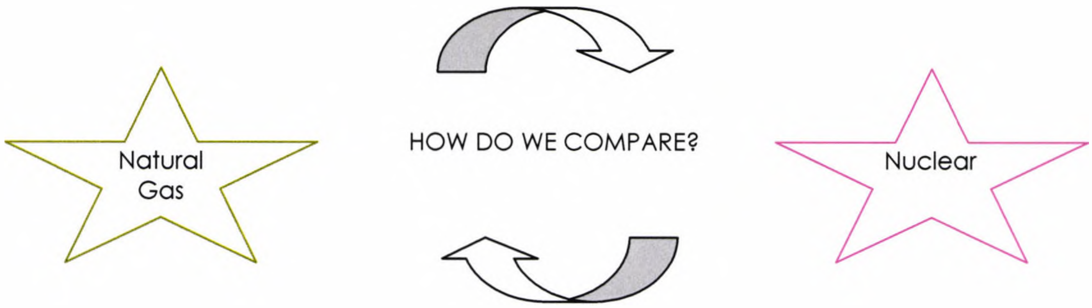

Figure 8.12: How do we decide which is the most competitive electricity generator?

Previously the set of constraints imposed to the nuclear option were:

- price (of the end product, that is electricity)
- feasibility as a resource (that is, needs to be an already known resource, that is not reaching its peak)
- feasibility as a project (plant construction, distribution, decommissioning etc.)

These constraints will also be the key points of comparison between natural gas and nuclear power.

▷ The feasibility of both natural gas and nuclear power to produce electricity is indisputable. Both resources are currently used to produce electricity, although different percentages, and thus the basic infrastructures to support electricity generation are already existent. The only argument here is that nuclear power is currently being phased out (the government has not yet taken action to postpone the phasing out-23 nuclear reactors throughout UK are still running with plans to shut down within the next 10 years). This means that if the option of nuclear is to be considered for a more leading role towards electricity generation plans to build new reactors as well as expand the life-span of the existing nuclear plants. Planning and building new nuclear plants takes something in the region of 5 to 7 years depending on the reactors used. This time needed to plan and build new plants will be taken into consideration when creating the model.

- ▷ The feasibility of natural gas as a resource as far as its reserves is something that many are disputing. Some say its reserves have already peaked in production, others insist that this peak will happen sometime in the next 50 years. The problem with natural gas in UK though is that most of it is imported. By 2020 most of the UK's supplies of gas will be imported from Europe and Countries of the Former Soviet Union [Gitt]. So independently of world reserves, the problem with the feasibility of natural gas as a resource is coming from the delicate geographical position of UK. The largest number of known reserves in the world is in countries with high political instability. Furthermore the pipes carrying the fuel pass from countries with high political instability. With the UK at the end of a long supply chain traversing areas of potential political instability, there will be serious risks to supply security and price stability.

  Fuel for nuclear power is abundant, and if well-proven, fast breeder technology is used, or thorium becomes a nuclear fuel, the supply is almost limitless [UIC1]. Where spent fuel is reprocessed, the recycled plutonium is used in mixed oxide fuel, which extends the uranium resource base [Hor].
- ▷ Costs have always been a very important factor in decision making, in particular for choices between alternative energy sources and electricity generation technologies. This case study, along with the model produced, will be driven by the financial aspect of this problem. Thus, the comparison of the two variables-natural gas and nuclear power-will be based on the cost of generating electricity each of them has. However, it must be noted that although the research will be driven by the price each resource produces electricity, the feasibility factors mentioned previously have been taken into consideration and will play significant roles in the model building.

8.6 Final thoughts

The need to bring together the available information so far is imperative. Synthesis is achieved through the availability of techniques or use of models. To demonstrate the competitiveness of the two energy resources, we need to show the difference of the costs while time progresses, as well as the right timing to introduce the new option. On a previous chapter the Real Options Analysis was analysed. This research will use the binomial model to show the evolution of the costs of generating electricity. The graphical representation that the binomial model uses will give the reader a concrete idea of the cost fluctuations of natural gas and nuclear power, in the time period set for this case study. The analysis as far as the computation of the costs and the realization of the binomial models for both nuclear power and natural gas, will take place in the next chapter.

Chapter 9

Problem Analysis

This chapter will give the step by step approach of the modelling process from the valuing of the parameters and constraints, to the formal model method selection, and finally the use of the formal method of analysis to evaluate the results.

9.1 Introduction

Previously the conceptualization of the UK energy problem was described, the variables of the problem were chosen and the constraints were identified. Furthermore in the previous section of the thesis a detailed description of Real Options Analysis took place, along with an investigation on the various option pricing models. In summary, the main outcome of the problem conceptualization was evident that natural gas was the most competitive source of electricity at the moment, having proved its reliability for many years. The problems begin with the realisation that:

- Natural gas is a finite source of energy

- The UK reserves of natural gas found in the North sea are finishing and UK has been a gas importer since 1997
- UK currently imports gas from Russia, with significant implications on the robustness of supplies.
- UK is at the end of a long supply chain traversing areas of potential political instability, and this introduces serious risks to supply security and price stability.In the long-term, the greatest risk is that of supply interruption in a major pipeline from outside the EU. This could result from political instability in the producer country or in a country that is transited by the pipeline.
- The Kyoto Protocol is putting pressure on the UK government to reduce emissions of greenhouse gases. For the UK government to reach its targets, it would have to seriously reduce the use of fossil fuels, natural gas included.

The issues described above are *limitations* put on the natural gas use, either by self inflicting factors (e.g., the resources running out), or external factors (the Kyoto protocol emission's reduction).

At some point in the future something needs to be done to balance out the percentage that gas will not be able to offer towards electricity production. There are several options:

- Renewables
- Energy efficiency and conservation
- New technologies
- Nuclear
- A combination of the above, as discussed in the previous chapter.

Several limitations apply to those options, such as:

- Renewables: Not able to provide a guaranteed sufficient percentage of electricity production.
- Energy efficiency and conservation: They should be part of the plan of energy sustainability in UK, but they cannot be considered a solution at the moment.

- New technologies: They are the future of energy production and energy efficiency, but most of them are still in an experimental phase.
- Nuclear: It has proven its reliability, the technology is there and there are no emissions (the limitations regarding nuclear will be discussed later on).

For the purposes of this thesis, the option of nuclear power taking a leading role in the electricity production of UK will be considered. The comparison of natural gas and nuclear will be based on the economic aspect of the two. The option value for a utility of investing in nuclear greatly depends on the correlation between electricity and gas prices and to a lesser extent carbon prices (carbon prices are not going to be considered here). There is an issue of comparison and taking the most appropriate, available option.

- Choice is the main feature of an option.
- In an open, competitive environment, energy is simply treated as another kind of commodity.

Combining the two statements and given the need of a forecasting model for this problem (since the problem will be cost driven, a forecast of the possible prices in the future in needed so as to chose the best option), the Real Options Analysis is selected as the means to move forward. Particularly, the method of using binomial lattices to price the options is the most appropriate technique. In this chapter the realization of the model will take place. Natural gas and nuclear will be looked at as two commodities, as two possible options with one being the most competitive. The two commodities will be judged by the cost they have to the end-user, which is the price of electricity produced by either of them that the consumer has to pay.

The diagram below is a rough representation of the conceptualisation that took place in the analysis. Since we identified the specific problem-that being the comparison of costs for generating electricity from natural gas and nuclear- we make it our aim to provide a method of comparison. The two sources can be treated as commodities thus we can begin the process of breaking down the costs of producing electricity from natural gas and nuclear and then using a forecasting model compare in time what is the best option, and at what instance it is more cost efficient to replace the existing percentage produced from natural gas with nuclear. The forecasting model that will be used is the binomial model (the specifics of this method were discussed in a previous chapter).

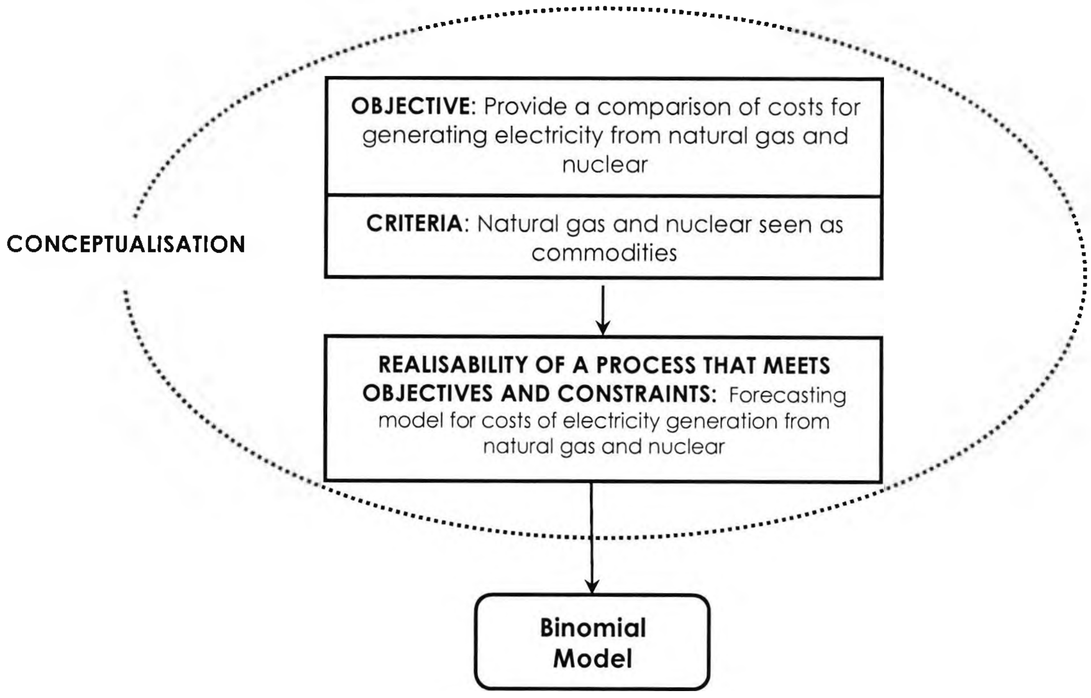

Figure 9.1: The conceptualization of the analysis.

Thus, the step by step plan to move forward is as follows:

- Calculate cost of producing electricity from natural gas and nuclear power
- Use the binomial model, with underlying asset being the cost of generating electricity from natural gas and nuclear. To "build" the binomial model the following steps need to be followed:
    - Calculate the volatility affecting the underlying assets (obviously the volatility is different for each resource).
    - Calculate the up and down step.
    - Specify the time period, steps, and risk-free interest rate. Run the binomial lattice for the valuation of underlying asset.

- Calculate the risk neutral probability. Run the binomial lattice for the option valuation.

9.2 The variables and the beginning of the analysis

In the analysis that took place in previous chapters, the two variables that were identified were natural gas and nuclear. The comparison though dictates that a more approachable way of dealing with the variables is used. A way that makes sense for the consumer of electricity, and that can be easily interpreted.

The comparison, as previously stated will be purely economic. Instead of using the price of natural gas and nuclear power, this thesis will look at the price of electricity produced by natural gas and nuclear power.

An extensive research took place the last year for the cost of production of electricity from natural gas and nuclear. It was impossible to find any information regarding costs of production of electricity. All data available publicly, was data regarding cost of natural gas and cost of U_3O_8 (what is internationally traded as the fuel of nuclear reactors-talks with BNFL have established that it is the same for UK reactors). Any reference to cost of production of electricity from these two resources was not available from any official (governmental or other) source. Many reports though, are written regarding this subject, both in America and in Europe, and specifically in UK as well, but the deviation of the costs from report to report is quite astonishing, reaching, for nuclear for example, 10£/MWh! It was unrealistic to use the mean of those costs from the reports that were published as it would become the subject of scrutiny of how the cost was calculated. The solution was to calculate the cost of producing electricity from both resources using available published data, and data available from official sources. It is important to draw a distinction between the cost of generating electricity and the price for which it is sold in the market. This study is solely concerned with generation costs and not with electricity prices. The question mark, though, of why all the secrecy regarding those costs of production remains and makes someone wonder what might be the profit of the providers of electricity.

9.2.1 Cost of electricity produced by natural gas

Since the cost of producing electricity will be calculated from the beginning, a breaking down of how to move forward will be made. For the calculations the use of two studies and information from the website of the DTI was used.

The two reports are:

- "The Costs of Generating Electricity", The Royal Academy of Engineering, 2004
- "Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs", U.S Department of Energy, prepared by Dominion Energy Inc., 2004

The cost of generating electricity here, is expressed in terms of a unit cost (pounds per MWh) delivered at the boundary of the power station site. The relevant costs of generating electricity can, for the purposes of this study, be divided into four main categories:

- **Capital costs**: the initial level of investment required to engineer, procure and construct the plant itself.
- **Costs of operation and maintenance**: These are in proportion to the actual quantum of electricity generated, insurance, rates and other costs, which remain constant irrespective of the actual quantum of electricity generated.
- **Overheads**: staff salaries and
- The **cost of fuel** consumed in generating electricity.

The assumptions made here, regarding the calculation of the cost of electricity are the following [Stup]:

- The power plant used to produce electricity is a Combined-Cycle Gas Turbine (CCGT)
- The station has 600MWe power generation
- The cost will be based on the assumption of base load production

- The efficiency of the plant will be 55%
- The cost of building the station was taken at the price of 300 million £
- The building time of the station is 2 years
- The capital repayment was taken over a period of 30 years at a discount rate of 8%

The following figures were identified for the various costs [Stup]:

- Capital cost: 3.3£/MWh
- Operation and Maintenance: 1.4 £/MWh
- Overheads: 0.8£/MWh
- Cost of fuel: 12.62£/MWh

Total cost of producing electricity from natural gas [Stup]: 18.12 £/MWh.

9.2.2 Cost of electricity produced by nuclear power

The main assumption of the cost break down applies in this case as well. That is, the overall cost is made up of the capital cost, the operational and maintenance cost, overheads and the fuel cost. For the calculations the following reports were used:

Sources for Cost Model:

- "The Costs of Generating Electricity", The Royal Academy of Engineering, 2004
- "Study of Construction Technologies and Schedules, O&M Staffing and Cost, and Decommissioning Costs and Funding Requirements for Advanced Reactor Designs", U.S Department of Energy, prepared by Dominion Energy Inc., 2004
- "Morgan Stanley's Equity research, Industry-Utilities, Industry Overview: Nuclear the core of the matter", Morgan Stanley, 2005.

The assumptions made in this report regarding the calculations of cost of producing electricity are the following [Stup]:

- The power plant is a new AP1000
- The plant has 1.1GWe power generation
- It has an 80% utilization factor, that is the availability of the stations
- The cost of building the power plant was taken at 1.7 billion £
- The operating lifetime of the plant is assumed to be 40 years

- Building time is assumed 5-7 years
- The capital repayment is taken over a period of 40 years with a discount rate of 8%

The following figures were identified for the various costs [Stup]:

- Capital cost: 21.8 £/MWh
- Operation and Maintenance: 4.6£/MWh
- Overheads: 0.8£/MWh
- Cost of fuel: 4£/MWh
- Decommissioning: 1 £/MWh

Total cost of producing electricity from nuclear power [Stup]: 32.2£/MWh

Note that in the costs of nuclear power there is an additional cost, that of decommissioning of the plant. It must also be noted that nuclear power, is the only resource that has allocated funds for decommissioning of the plants, and these funds are directly mirrored in the end price that the consumer has to pay for the electricity. With other resources that decommissioning fund is not part of what the consumer pays for his or hers electricity bill.

9.3 The Binomial model

This part will be divided in two smaller parts. One showing the calculations for the underlying asset valuation lattices and the other for the valuation of the option lattice. The first part will include the calculations of the volatility for both natural gas and nuclear, the specifications regarding the time period, and the risk-free rate and the valuation of the lattices. A small discussion and comparison of the results will be made, before the calculations for the second part begin, with the identification of the risk-neutral probability, and finally the calculation of the option lattice. The second part will conclude with discussion of the results and comparison with other published reports. The figure below summarises the modelling process so far and gives a preview of what the outcome of the modelling process will be.

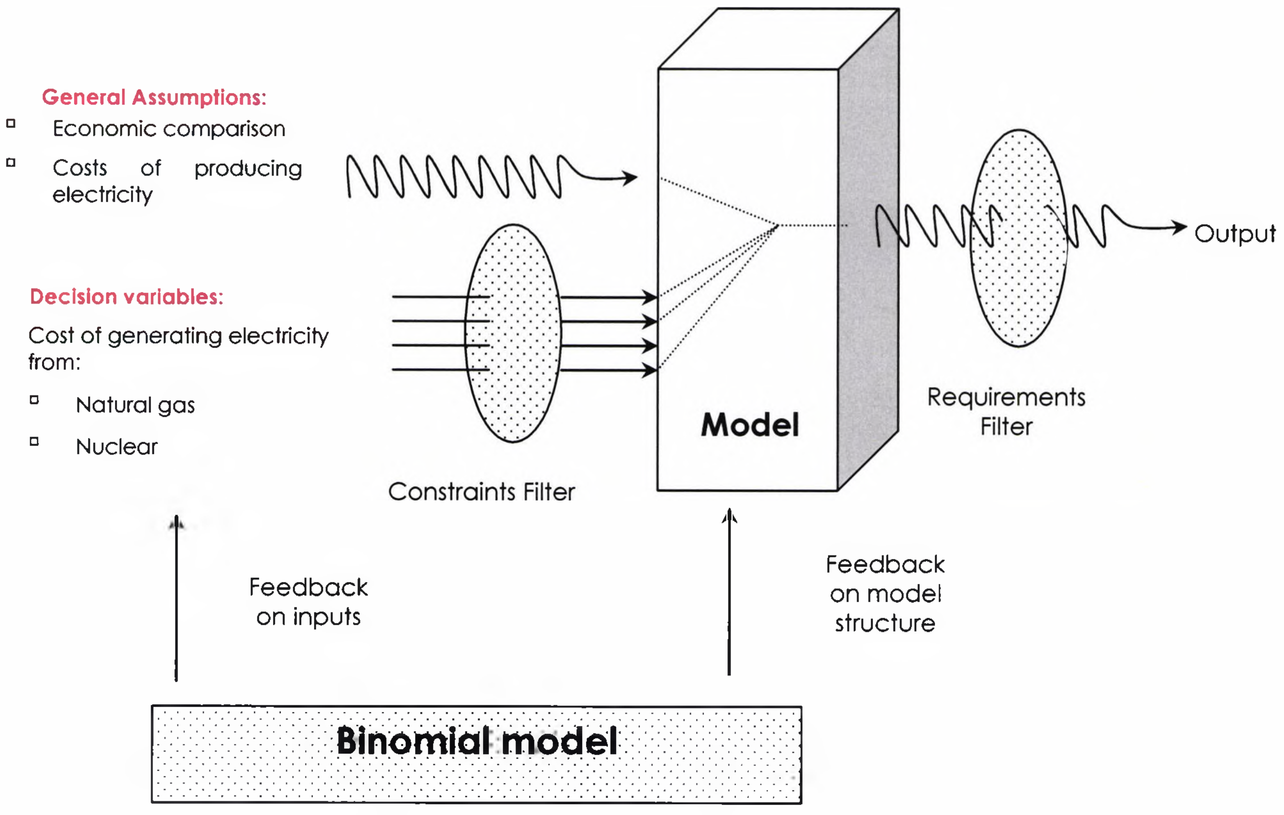

Figure 9.2: General view of the modelling process

The figure above can be broken down, into the two different processes that this thesis will look intno; the process of the evaluation of cost of production of electricity from:

(a) Natural gas

(b) Nuclear energy.

The following figures give a detailed view of the above processes along with comparison operator.

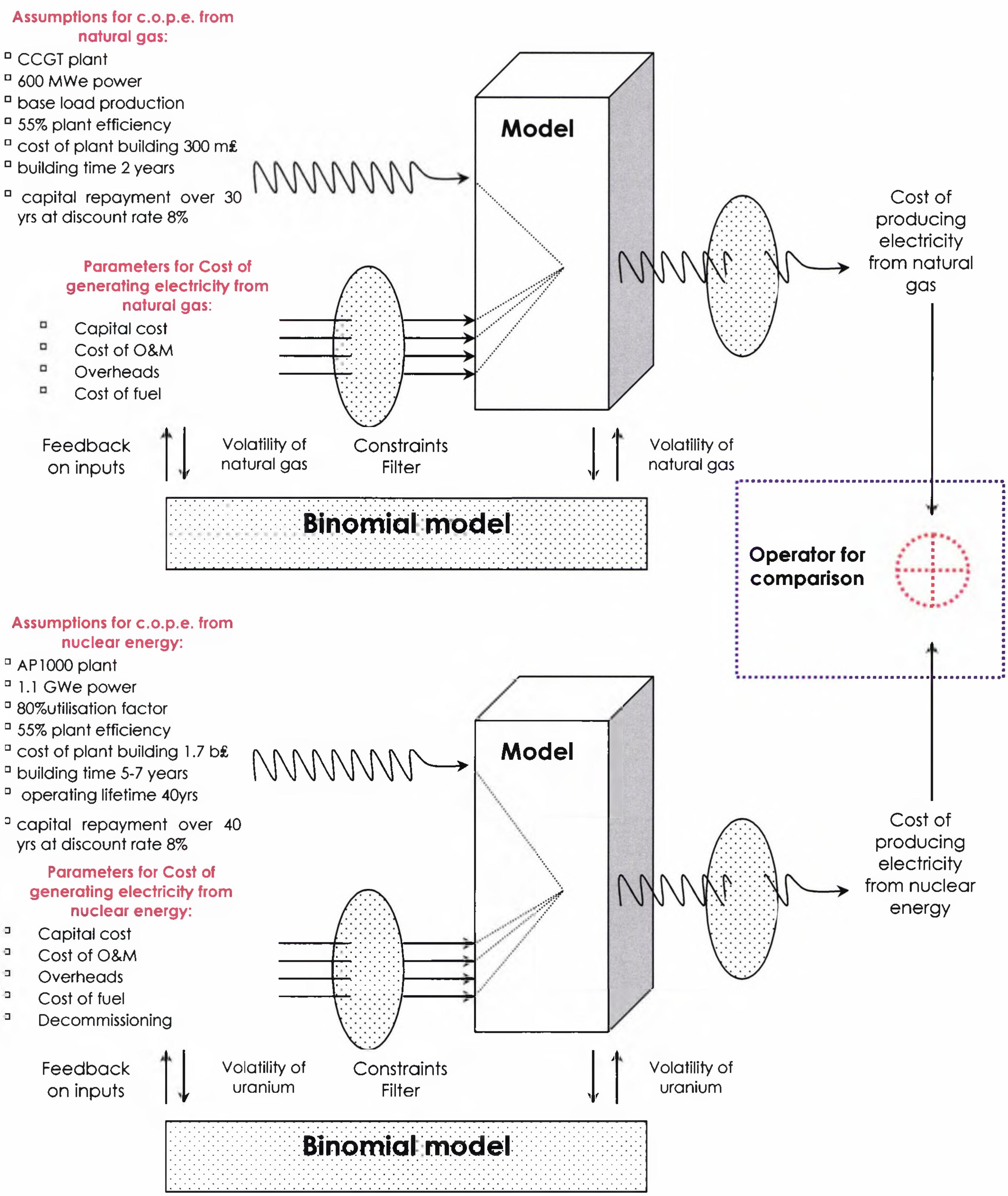

Figure 9.3: The process of cost evaluation of generating electricity and the cost comparison operator.

The comparison operator is more of a process that will happen by comparing the evolution of the evaluation lattices for the cost of generation of electricity from both natural gas and nuclear.

9.3.1 Calculation of the volatilities

Previously in Chapter 6 the description of the binomial model took place. On of the main features of Real option analysis, that happens to be one that the binomial model is based on as well, is the volatility. At this point the calculations of the volatilities for both natural gas and nuclear power will take place.

9.3.1.1 Calculation of the volatility of natural gas

Since the underlying asset was decided to be the cost of the electricity produced by natural gas and the nuclear power, the volatility will be affected by the prices of natural gas and U_3O_8.

To calculate the volatility of gas historic prices of natural gas were obtained through DTI, beginning from 1976 till 2003. The volatility estimate used in real options analysis has to be an annualized volatility [Mun]. The table below gives the information of the prices of natural gas in p/therm.

Year	Price of natural gas (p/therm)	Year	Price of natural gas (p/therm)	Year	Price of natural gas (p/therm)	Year	Price of natural gas (p/therm)
1976	1.8	**1983**	8.4	**1990**	14.3	**1997**	16.7
1977	2.1	**1984**	10	**1991**	16	**1998**	16.2
1978	3.1	**1985**	11.9	**1992**	15.8	**1999**	13.7
1979	3.8	**1986**	12.6	**1993**	14.9	**2000**	15.8
1980	4.9	**1987**	12.4	**1994**	16.3	**2001**	18.6
1981	6.5	**1988**	13.1	**1995**	16	**2002**	17.6
1982	7.4	**1989**	14.2	**1996**	16.6	**2003**	17.4

Table 9.1: Price of natural gas for years 1976-2003 (Source DTI)

The prices above were adjusted to 2003 prices. By taking the historic prices and "measuring them up" with 2003 prices, the inflation inflicted on those prices is lifted. The paper "Consumer price Inflation since 1750", available from the website of National Statistics, provides a method of converting these prices and thus lifting the inflation. By not taking into consideration the inflation in the prices, the "new" converted prices provide a clear idea of how the prices progress only because of demand. Below a table of the adjusted to 2003 and converted to £/MWh is illustrated.

Year	Price of natural gas (£/MWh)	Year	Price of natural gas (£/MWh)	Year	Price of natural gas (£/MWh)	Year	Price of natural gas (£/MWh)
1976	2.795	1983	6.109	1990	7.013	1997	6.552
1977	2.815	1984	6.928	1991	7.412	1998	6.143
1978	3.839	1985	7.781	1992	7.058	1999	5.119
1979	4.15	1986	7.969	1993	6.587	2000	5.733
1980	4.532	1987	7.508	1994	6.996	2001	6.638
1981	5.378	1988	7.576	1995	6.638	2002	6.177
1982	5.631	1989	7.624	1996	6.723	2003	5.938

Table 9.2: Price of natural gas for years 1976-2003, adjusted to 2003 prices.

Using an excel sheet the calculations of the future cash flow estimates and their corresponding logarithmic returns, the method previously discussed for calculating volatility. The volatility is therefore:

$$volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

Volatility of natural gas = 10.07% (Tables with the relevant calculations are provided in Appendix 1).

9.3.1.2 Calculation of the volatility of U_3O_8

The calculation of the volatility of U_3O_8, will follow a similar path to that of natural gas. The information of the historic prices was found in the U_x Consulting company website, and are given in the table below (note that the data was given in $/pound and was converted to £ with conversion factor 0.575):

Year	Price of U_3O_8 (£/pound)	Year	Price of U_3O_8 (£/pound)	Year	Price of U_3O_8 (£/pound)
1987	9.71	**1994**	5.4	**2001**	5.06
1988	8.4	**1995**	6.6	**2002**	5.68
1989	5.73	**1996**	9	**2003**	6.63
1990	5.6	**1997**	6.92		
1991	5.03	**1998**	5.92		
1992	4.9	**1999**	5.9		
1993	5.8	**2000**	4.7		

Table 9.3: Price of U_3O_8 for years 1987-2003 (Source U_x Consulting company).

The prices were adjusted to 2003 prices using the same method as before. The table below illustrates the results.

Year	Price of U_3O_8 (£/pound)	Year	Price of U_3O_8 (£/pound)	Year	Price of U_3O_8 (£/pound)
1987	17.27	**1994**	6.8	**2001**	5.3
1988	14.24	**1995**	8.02	**2002**	5.84
1989	8.45	**1996**	10.68	**2003**	6.63
1990	8.05	**1997**	7.96		
1991	6.83	**1998**	6.58		
1992	6.4	**1999**	6.46		
1993	7.47	**2000**	5		

Table 9.4: Price of U_3O_8 for years 1987-2003, adjusted to 2003 prices.

Using an excel sheet the calculations of the future cash flow estimates and their corresponding logarithmic returns, the method previously discussed for calculating volatility. The volatility is therefore:

$$volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}$$

Volatility of U_3O_8 = 21.8%

(Tables with the relevant calculations are provided in Appendix 2).

9.3.2 Regarding volatility

Energy prices transmit critical information about the balance between supply and demand, moving up and down in order to balance energy supplies with energy demand, both on a short-term, day-to-day basis, as well as over a longer, multi-year investment planning horizon. The volatility calculated in this research is the volatility put on the electricity production cost due to the fuel.

9.3.2.1 Regarding Natural gas volatility

Over the last five years, price volatility has become the most significant issue facing the natural gas industry and its customers. Natural gas, electricity and oil product markets have all exhibited extreme price volatility for some portion of the period. But the volatility of natural gas and electricity prices increased more dramatically than the rest. That is because, as previously discussed, the volatility of the world-market price for natural gas has a very large impact on the volatility of gas-generated electricity in the UK, because the cost of gas-generated electricity is dominated by the price of the fuel, gas. Specifically in many published reports, and figures from various sources show that a staggering 70% of the cost of generating electricity from gas (assuming CCGT plants), is the cost of the fuel, that is natural gas (while the rest 30% is operations and maintenance costs and capital-including overheads).

Energy markets such as natural gas, electricity, and heating oil are particularly susceptible to market and price volatility because fluctuations in weather can change the underlying demand for the commodities significantly, and the increase or decrease in demand affects all of these commodities in the same direction.

Sources say:

"We expect that gas price volatility will continue due to a supply/demand balance that remains tighter than the balance over the past decade. There will likely be periods (primarily when weather conditions differ significantly from normal conditions) during which gas prices will spike up well beyond the price of competing oil product prices. These periods will offer significant price arbitrage opportunities for traders and marketers. They will also make it more difficult for large industrial purchasers of gas to gauge the true value of the commodity... In a market where the gas-fired generation is needed, the electricity price will be high enough to justify almost anything for gas supply, ***provided the electricity price in the market is not capped.****"* -Natural Gas and Energy Price Volatility-American Gas Foundation, 2003.

In this research due to the big percentage of natural gas cost in the overall cost of production, the volatility will have significant role.

9.3.2.1 Regarding U_3O_8 volatility

By contrast, for nuclear-generated electricity, it is capital cost that dominates, followed by operating cost, with fuel cost (uranium) contributing only a very small fraction to the final cost. Specifically from various published reports, in US as well as Europe, 85% of the cost of generating electricity is due to the capital cost and the operations and maintenance (including overheads), while the rest 15% is due to fuel.

Thus the volatility previously calculated for the U_3O_8 applies only to the 15% of the overall cost, a miniscule percentage compared to the 70% that the volatility of natural gas has to apply to. Hence it is possible to regard the cost of nuclear-generated electricity as having approximately zero volatility, certainly only a very small volatility compared with gas-generated electricity. A similar conclusion has been reached by [Stanley]. The capital cost, as well as the operational and maintenance cost is more luckily to roll back during the next years since the technology of building and maintaining a nuclear station is past its years of being considered "exotic". Stations have evolved dramatically the last years (especially in countries such as US, Japan, Finland and France where the nuclear power is still a very much alive part of the electricity generation technology), putting the knowledge and the data collected forward for the rest of the world to seize.

Therefore one of the *main assumptions* made during this research, based on those figures and derived through logic thinking, is once the estimation of the total cost of producing electricity by nuclear is made, it can be regarded as *approximately constant* in real terms for the life of the station.

For that reason, the *strike price*, will be the *current cost of production of electricity form nuclear*, that is 32.2£/MWh. That will be the moment in time at which the nuclear option will be more affordable than the natural gas option. This point comes as a direct result of the main assumption made earlier; that the volatility of the nuclear electricity is zero and thus the current cost of production of nuclear electricity will remain *approximately constant* through the lifetime of the nuclear plant.

9.4 Evaluation of the cost of electricity binomial lattice

Making the previous assumptions means that the binomial lattice of the underlying asset will be calculated with asset being the cost of gas electricity, and the strike price of that asset will be the current price of the cost of nuclear electricity. Obviously the volatility applying to gas electricity will apply to this binomial lattice.

Realizing that the volatility of gas applies to 70% of the cost of gas electricity, will affect the way the binomial lattice will be built. The binomial model will be build using Excel. The formulas of the up and down steps

$$u = e^{\sigma\sqrt{t}}$$

$$d = e^{-\sigma\sqrt{t}} = \frac{1}{u}$$

will be fed into cells, along with the time period that the cost will be assessed, the volatility of the natural gas and the current price of the underlying asset. What will be different in the use of this specific binomial model is the way the volatility will apply to the asset. Since the volatility will apply to the fuel only, the binomial will be build as the summation of the *valuation lattice of the fuel* and *the capital, operational and maintenance costs*. The capital and operational and maintenance costs will be considered as a constant that is added to every cell throughout the process of the valuation. This way it will be ensured that the volatility of the fuel will only be affecting the percentage of the fuel and not the rest of the costs.

The volatility of the gas is:
Volatility of natural gas = 10.07%

The cost of producing electricity from gas and thus the underlying asset in this scenario is:
Total cost of producing electricity from natural gas: 18.12 £/MWh

But the volatility will be applied to the 70% of that cost, that is the fuel, previously evaluated at 12.62£/MWh. So the lattice that will describe the probabilities of the gas electricity cost will be made up from the lattice of evaluating the probable cost of natural gas plus an approximately constant cost of capital and operational and maintenance costs, that is 5.5£/MWh.

Following is a representation of the valuation lattice to show the evolution of the cost of natural gas in a period of 30 years from starting point the year 2004. Note that the time period of evaluation of the lattice has been agreed at 30 years from 2004.

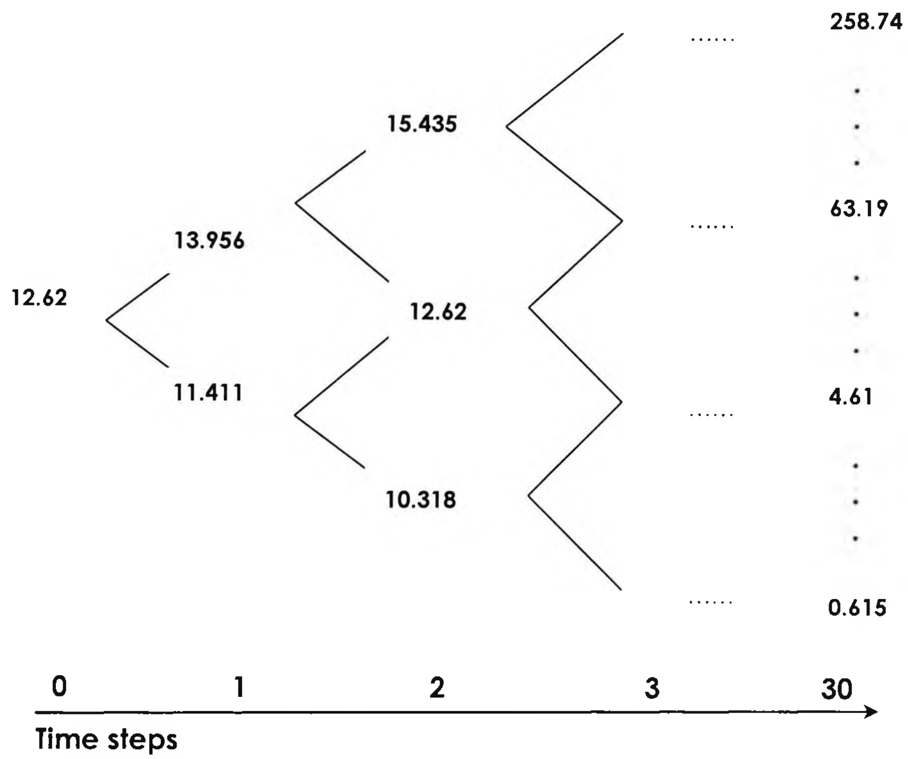

Figure 9.4: The valuation lattice of natural gas

The binomial lattice of valuation of the underlying asset can be found in its complete form in Appendix 3.

But as previously discussed the overall lattice will be comprised of the lattice of fuel plus a constant. The lattice was calculated using Excel and can be found in its entirety in Appendix 4.

Following is a representation of the lattice of valuation of the cost of gas electricity.

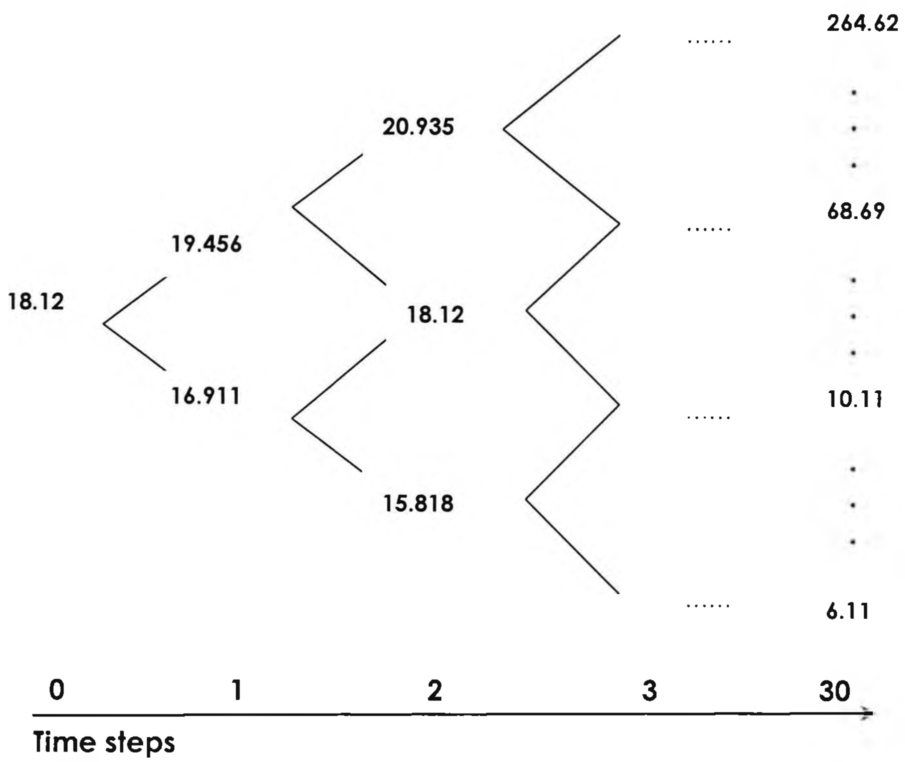

Figure 9.5: The valuation lattice of the cost of gas electricity

9.5 Evaluation of the option lattice

Creating the option valuation lattice proceeds in two steps using a process called "backward induction". The first step in evaluating the "backward" lattice is the calculation of option value at each final node. The formula used for this purpose was (S – Exercise price), where is the value of the underlying at the last node. The Exercise price for this project was 32.2£/MWh, the price of producing electricity from nuclear. The second step in this process is the progressive calculation of option value at each earlier node. For this stage the Binomial Value is found for each node, starting at the penultimate time step, and working back to the first node of the tree, the valuation date, where the calculated result is the value of the option. The Binomial Value is calculated as follows:

Binomial Value = [p × Option up + (1-p)× Option down] × exp (- r × t)

Where:

$$p = \frac{e^{rf*t} - d}{u - d}$$

where:

$$u = e^{\sigma\sqrt{t}}$$

$$d = e^{-\sigma\sqrt{t}} = \frac{1}{u}$$

Note that in this research no dividents were taken into consideration, due to the nature of the problem looked into. The risk free rate, *rf*, is a real discount rate appropriate for use over very long periods of time: 2.5% is used by BNFL in evaluating its long-term decommissioning liabilities; British Energy uses 3.0% for a similar purpose. Using a low discount rate is conservative, in that the option is given a lower value. In this project 2.5% was used as rf. The representation of the final lattice is shown below:

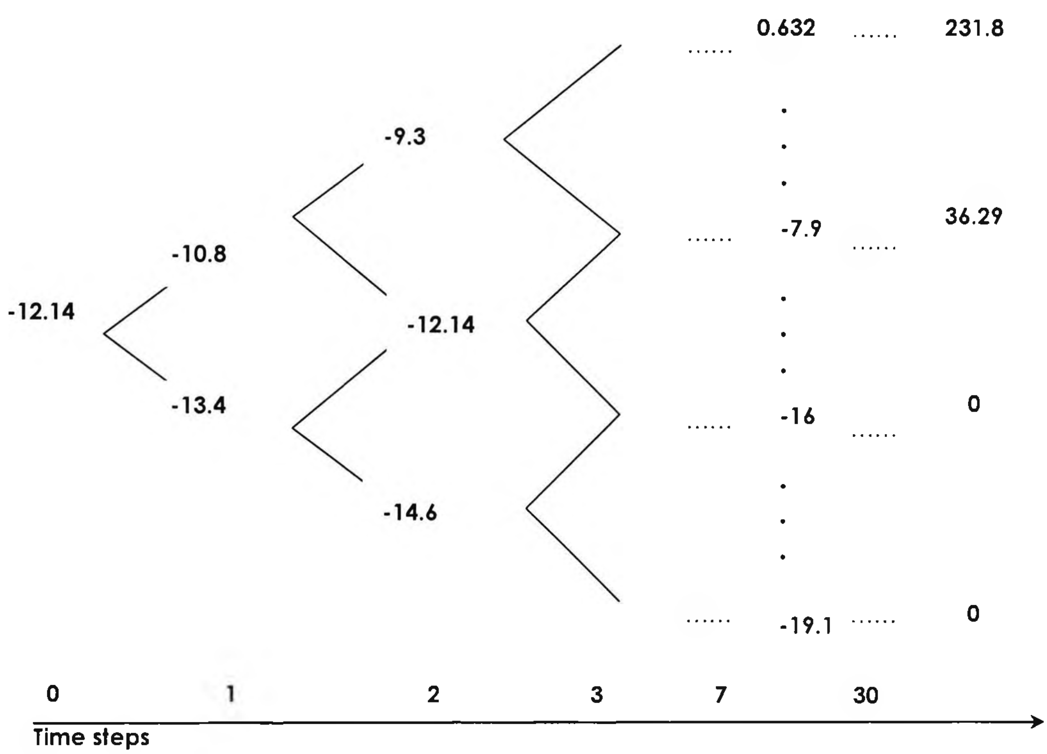

Figure 9.6: The binomial value lattice

Appendix 5 has the progressive calculation of the option valuaton lattice.

9.6 Discussion of the results

At the end of the 30 years, the period decided to look into closer regarding the cost of electricity, the decision makers have the option to continue with the gas electricity production and thus shoulder the increasing cost of production from gas, or decide to take on another fuel. The lattice of valuation of the option, is the means of showing to the decision makers when the other fuel begins to be more affordable than the one used already.

The valuation of the option lattice, is similar to comparing two lattices, the one being the evaluation of cost of gas electricity and the other the evaluation of the cost of nuclear electricity. The comparison of the two evaluation lattices is a more graphical way to see where one of the two options becomes more competitive than the other, while the option valuation lattice pinpoints the exact point in time.

This option can be considered as an option to abandon. What is meant by that is, at any time period within the next 30 years, the decision makers can review the progress of the cost of gas electricity an decide whether to "terminate" or continue exercising that option. Obviously the decision makers will chose the srategy that minimises the loss for the consumer. In this case we cannot talk about maximisation of profit since the underlying is a cost itself. is The overall termination of use of gas electricity is somewhat impossible to happen overnight, but what is meant in this report by termination is the gradual minimisation of use of natural gas as the primary fuel in electricity production, and the introduction of a more competitive source, that is nuclear.

The negative values in the valuation option lattice represent the "negative" profit, the loss, the decision makers would have if they were to undertake the option of nuclear at those specific times. It is evident that at time period 7, that is 2011, the option of undertaking nuclear as a fuel begins to have a value and thus becomes more competitive than gas. Usually in the binomial lattice all the negative values are substituted with zeros to emphasize that the option to abandon has no profit, in this case it has loss. The upper bound of time period 7 in that lattice, is the beginning of realisation that nuclear electricity becomes more competitive. As time passes, the option of nuclear electricity establishes itself and becomes even more affordable than gas electricity (this can be seen in appendix 5 Part II).

Furthermore, managers of technological systems do not require great accuracy because they typically only need to make choices, not precise judgments. In making a choice, one only needs to know the relative value of alternatives, not their precise value. To decide whether to do the R & D that will lead to a real option on the launch of a new product, for example, managers only need to know if the value of the option is greater than the cost to acquire it. If yes, then they should invest in the R & D. In this respect, the object of doing an options analysis is quite different for systems managers than for financial analysts who have to decide on a precise price to pay for options, as they trade them day after day. [Neuf]

In this research the approach of real options was used to evaluate the situation in this specific way. The approach is based on financial terms and arguments, but the decision of the taking on the more competitive option is not purely economic, and this makes the decision more flexible. The research is not basing on any account its arguments on the *value* of the option of taking nuclear electricity at time period 7. This research is basing its arguments on the fact that the option of nuclear electricity at time period 7 *has* a value! And from that time and on it would be wise to undertake any changes on the production of electricity. Note that the duration of building a new power plant is 5-7 years, so this needs to be taken into consideration. As time passes and the value of undertaking nuclear electricity increases, the argument becomes stronger from a financial point of view as well.

When the decision makers learn about the opportunities available in potential markets, they can design the facilities or equipment that can effectively use options. The decision makers can only appreciate this value, and thus be motivated to design and deliver the equipment, when they understand the nature of the price fluctuations in the markets for electric power. This is another instance in which the decision makers have to reframe their thinking when they use real options. In this case, they move shift from thinking about "capital efficiency" to "trading activity". [Neuf]

What is therefore understood from the analysis, is that the planning horizon, if the decision makers were to undertake nuclear electricity, is *here* and extending it will inflict further costs to the consumer.

It must be noted here that this planning horizon exists and is restrictive and limiting in its entirety independently of the fact that the solution to resource deficiency will be given by nuclear or not. Furthermore this horizon will be even tighter given the fact that nuclear was chosen as the best alternative to natural gas for the specifications and constraints imposed to the problem of electricity generation. The actual decision though is far more complicated than the economic side of the problem, and it will be affected by other factors other than the financial ones. These factors will be discussed in the next chapter.

Chapter 10

The factor "uncertainty" in Modeling

There are different notions of what uncertainty is and means. There is a distinction between uncertainties as viewed by *decision-makers*, uncertainties in the *real world* and *model* uncertainties. A general overview on the subject of uncertainty in modelling will take place. Our concentration will be focused on the outcome of the decision making, realized in the previous chapter; it will be discussed and measured against uncertainties and risks associated with the specific problem; first uncertainties regarding the identification of the problem, then uncertainties regarding the modeling process. Furthermore, uncertainty associated with the use of Real Options Analysis for the specific problem will be discussed. Finally, various issues regarding the outcome of the model, the timing of the proposed solution, reaction of the public, etc, will be analysed as well.

In the first step of identifying any possible risks and uncertainties, some questions need to be asked about the model:

- Is the model valid?

- Are the assumptions reasonable?
- Does the model make sense based on best scientific knowledge?
- Is the model credible enough?
- Do the model predictions match the observed data?
- How *uncertain* are the results?

10.1 Introduction to uncertainty

Mathematically, uncertainty is the difference between a measured, estimated or calculated value and the true value that is sought. Uncertainty includes errors in observation and in calculation and it can be the effect of *variability* or *lack of knowledge.*

Uncertainty due to lack of knowledge

By definition a model is an approximation of reality. Models reduce the complexities of the real world through simplification, reduction and generalisation. The goal of a modelling project may be to produce as close an approximation of reality as possible. In other instances a more abstract or less realistic representation of reality is a more useful goal as this removes confusing details to reveal the most fundamental factors, processes or trends. Whatever the goal there will be a lack of knowledge of:

- How well a model represents reality
- How good a representation of reality is required and therefore,
- How reliable the conclusions are which can be drawn from the model.

Other than these questions there will always be the issues of conflicting evidence, ignorance and lack of observations. This lack of knowledge can be expressed as uncertainty.

Uncertainty due to Variability

A model exists only to make the understanding of the real world more obvious and thus the intervention of the modeller towards this new understanding of the world can be effective.

Heraclitus had said "Πάντα ρεί" (panta rei), which means everything is changing. This variability that rules the world has as effect randomness. This natural randomness and behavioral variability, suggests that no matter what the cause of something, its nature is not only unknown but the consequences of its operation are also unknown [Wik]. This variability can be expressed as uncertainty.

10.2 Definitions of Uncertainty-Sources and Types

To clarify the meaning of "uncertainty" certain literature definitions and different views of uncertainty will be given. "Uncertainty" is a generic term used to describe something that is not known either because it occurs in the future or has an impact that is unknown. Uncertainty relates to the unknown at a given point in time. The term "uncertainty" has been used to mean an "unknown" that cannot be solved deterministically or an "unknown" that can only be resolved through time. Uncertainty arises because of incomplete information such as disagreement between information sources, linguistic imprecision, ambiguity, impreciseness, or simply missing information. Such incomplete information may also come from simplifications and approximations that are necessary to make models tractable. Uncertainty is not a newly introduced concept, in modelling. For the purpose of this thesis, uncertainty will be seen from a systemic point of view; that is it will be described for and related to the system and the system framework. The following diagram relates the causes of uncertainty to the system.

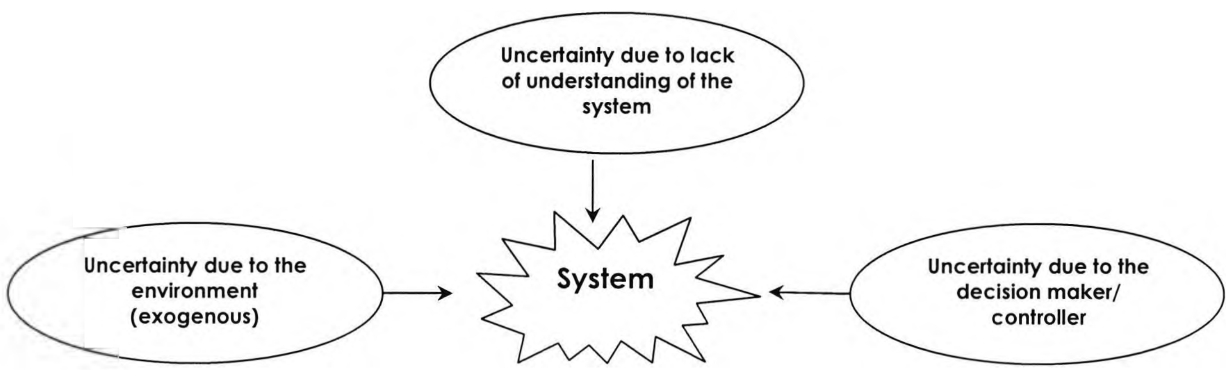

Figure 10.1: The sources of uncertainty in a systemic framework.

In this diagram we identify three sources of uncertainty:

- Uncertainty due to lack of understanding of the system, its parameters, its variables, its properties, etc, lack of observations that contributes to uncertainties in input data as well as the parameterization, uncertainty regarding validity of the assumptions.
- Uncertainty due to the decision maker/ controller. This type of uncertainty relates to the knowledge and judgment of the controller in various stages of the modelling process. The modeler plays a significant role in how he or she interprets the data available and how he or she chooses to acknowledge past knowledge and experiences to filter the existing data. The modeler's possible incapability to choose the correct parameters, variables, model structure or even create or enrich the list of specifications provides a very significant source of uncertainty. Even the external uncertainties that in a way are not completely under the control of the modeler, can be exaggerated or even diminished with appropriate handling. That is, an external uncertainty can only be accounted for if the modeller has done extensive research before attempting to model or if he or she has already have some previous experience in the same modeling framework. Due to the nature of the external uncertainties, that being outside of the model, it is easier to misinterpret or neglect information on the ground of being irrelevant. Obviously the same might happen with internal uncertainties but it would be more difficult to overlook them since they are part of the model itself, and their immediate effect is obvious.
- Uncertainty due to the environment. This exogenous type of uncertainty is what it is defined as disturbance in our systems framework; it is something not controllable or known from the original description of the system. This type may include unpredictable or volatile parameters or variables that need to be taken into consideration in the modeling process and whose values are beyond the control of the modeler. An example of an external uncertainty would be: consider the model of a power plant (the model is a simple one considering demand and supply of electricity), an external uncertainty would be environmental constraints that make the demand peak, thus introducing the possibility of availability problems in the power supply. The environmental constraints here, are an external uncertainty since it is not

something already accounted for in the model and comes from the environment of the model.

In the literature, "uncertainty" and "risk" are often used interchangeably. Knight [Knight] was the first to distinguish between measurable risk and unmeasurable uncertainty. Strangert [Stran] interprets Knight as follows: "uncertainty refers to an unstructured perception of uncertainty and risk to the situation in which alternative outcomes have been specified and probabilities been assigned to them." Building upon Knight's definitions, Barbier and Pearce [Barb] note that risk denotes broadly quantifiable probabilities while uncertainty refers to contexts in which probabilities are not known. Hertz and Thomas [Hertz] associate risk with the lack of predictability about the problem structure, outcomes, or consequences in decision or planning situation whereas uncertainty implies a lack of predictability. From an engineering perspective, Merrill and Wood [Mer] observe the causal relationship between uncertainty and risk: uncertainty refers to factors not under control and not known with certainty, whereas risk is a hazard because of uncertainty.

10.2.2 Uncertainty in the Energy and Power generation problem

Short-term uncertainties apply to factors which cause demand to be uncertain on a time scale that is substantially shorter than the time necessary to build even the shortest lead time power plant. Long term forecasts are more uncertain due to the additional consideration of factors and interactions. The latter type belongs to ***long-term uncertainties***.

The International Energy Agency [IEA2] classifies uncertainty into the quantifiable and the non-quantifiable. The ***normal*** and ***quantifiable uncertainties*** surround technological developments, facility lifetime and performance, retrofit or retirement of old plants, and the role of alternative energy. The ***non-quantifiable uncertainties*** have to do with environmental considerations, major accidents, political developments, and regulatory changes. The distinction between the two is sometimes attributed to the amount of foreknowledge and control [Mer]. Barbier and Pearce [Barb] discuss three types of uncertainties surrounding the Greenhouse Effect. The ***scientific uncertainties*** over precise atmospheric and geographical climatic responses are only resolved through advances in science. Nuclear decommissioning and other technological uncertainties fall into this category. ***Forecasting uncertainties*** are to do with predicting future changes and scale of their effects. ***Time-lag uncertainties*** are present in cause and effect cycles.

The International Energy Agency [IEA2] suggests two types of uncertainty that surround the value of a variable. Whether it is due to ***stochastic variability*** or ***lack of knowledge*** or both, the result is that we cannot be certain of its value. System imprecision due to unavailable information, imprecise data, or simply linguistic ambiguity gives rise to fuzziness. Choobineh and Behrens [Choo] argue that the principal sources of uncertainty are often non-random in nature and relate to fuzziness rather than to data frequency. Gerking [Gerk] distinguishes between sources of uncertainty and the changing impact of uncertainty over time. He lists four main sources of uncertainty:

- ***statistical uncertainty*** (associated with data collection and statistical regression),
- ***interpretational uncertainty*** (the ability of a model specification to accurately depict the essential causal relations of the socio-economic system to enable tracking the past and anticipating the future),
- ***decisional uncertainty*** (the potential for contemporary and future decisions to influence dependent variables), and
- ***external uncertainty-disturbances*** (events that are beyond the control of the system being modelled and the decision makers.) Classification according to the changing impact of uncertainty over time is important in the modelling process.

The figure below summarises the types of uncertainty we discussed in this section.

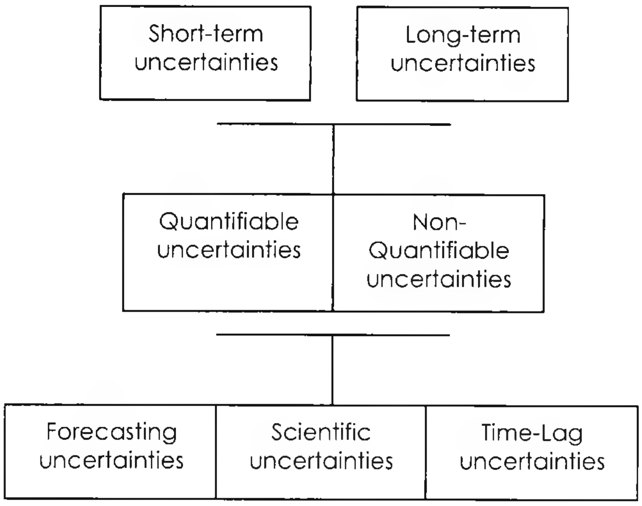

Figure 10.2: Types of uncertainty.

10.3 Techniques to deal with uncertainty

Amongst other techniques modelers use to deal with uncertainty, two techniques, *Sensitivity analysis* and *Uncertainty Analysis*, are very popular, because they can be used at every stage of the modelling process, from the very conceptual to the very formal.

Sensitivity Analysis

Sensitivity analysis works with determining the amount and kind of change produced in the model predictions by a change in a model parameter. Sensitivity analysis asks whether the conclusion changes in ways important to the purpose of the model, when the assumptions are varied over a range of uncertainty. Sensitivity can be numerical or behavioural [Ster]. Modellers conduct sensitivity analysis to determine [Scott]:

- If a model resembles the system or processes under study,
- The factors that mostly contribute to the output variability,
- The model parameters (or parts of the model itself) that are insignificant,

- If there is some region in the space of input factors for which the model variation is maximum,
- If and which (group of) factors interact with each other.

Below a diagram illustrates the conceptual methodology of sensitivity analysis.

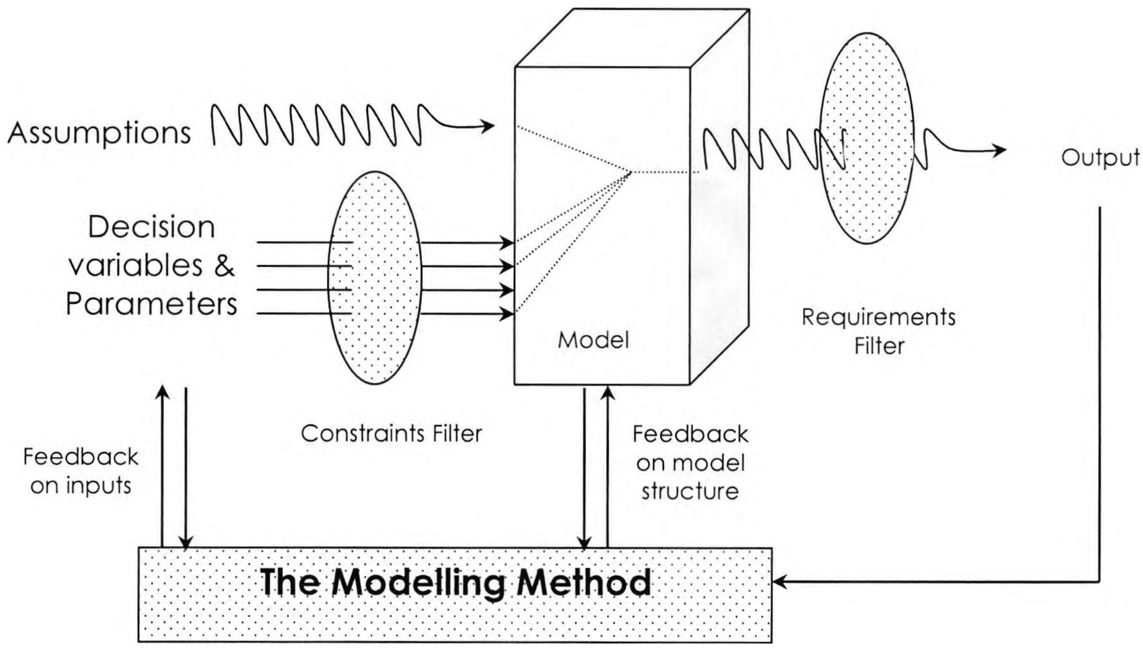

Figure 10.3: Sensitivity analysis flow chart.

The figure shows the interaction taking place between the input data and model with the modelling methodology. In a way the modelling methodology, in the sensitivity analysis will act as a tuner to the input data and the model structure. What that means is that by choosing a modelling methodology, the modeller is being helped into fitting the data of modelling into casts already provided by the modelling methodology. Particularly there exist different kinds of methods and techniques, such as screening methods, local and global sensitivity analysis using partial derivatives etc, to help identify the parameter subset that controls most of the output variability [Scott].

Uncertainty Analysis

Uncertainty analysis conducts assessment and quantification of the uncertainties associated with the parameters, the data and the model structure. Modellers conduct uncertainty analysis to determine [Scott]:

- Parameter uncertainty usually quantified in form of a distribution.
- Model structural uncertainty more than one model may be fit, expressed as a prior on model structure.
- Scenario uncertainty; uncertainty on future conditions.

The figure below gives a conceptual representation of the uncertainty analysis.

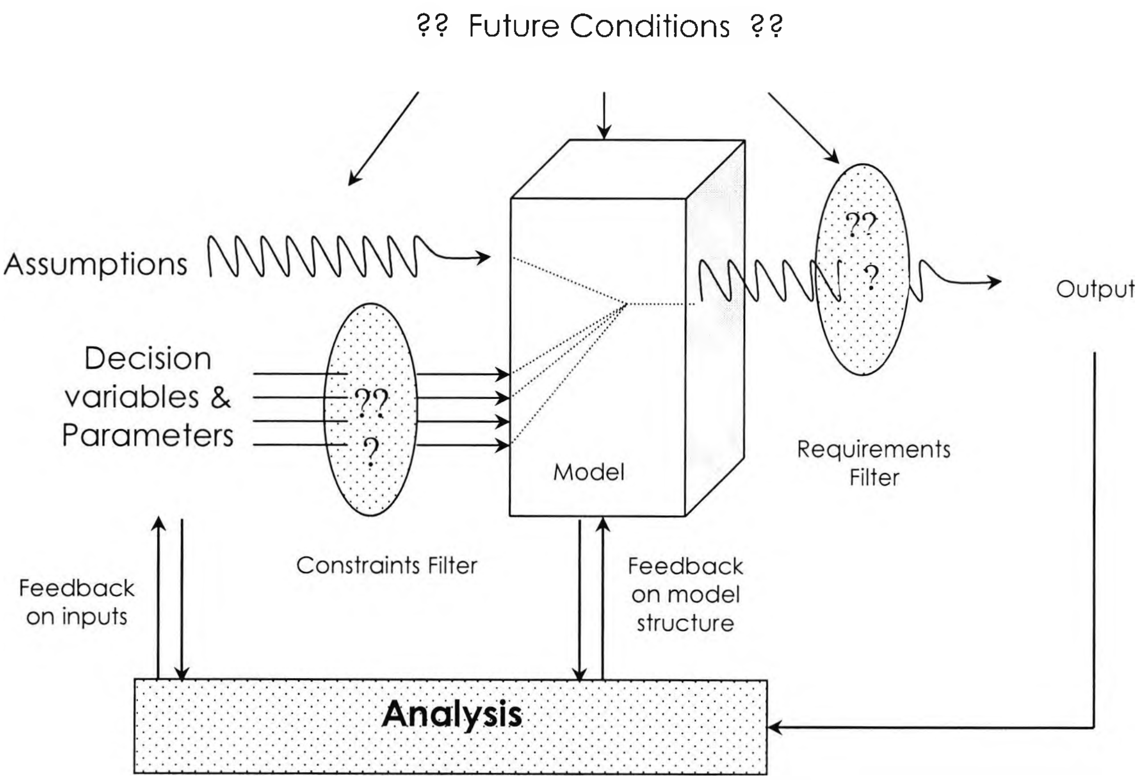

Figure 10.4: Uncertainty Analysis flow chart

The previous figure, although similar with the one representing sensitivity analysis, is fundamentally different. In this case there is no modelling methodology leading the way, but the problem itself is "choosing" what model structure is suitable for the specific case. That is, there is modelling methodology that the model is trying to fit into but the modelling methodology is adjusting to the needs of the problem. Uncertainty is diffused in various stages of the process, and furthermore there is an additional factor to take into consideration, probable unknown future conditions. Future conditions can be dealt with some kind of "levering"-readjustments in the structure of the model. By introducing levers it makes it easier to evaluate which condition has what effect on the model and the outcome of the model.

Dealing with uncertainty on the level of parameters and model structure

Structural uncertainty is a generic form of uncertainty. It deals with the basic stages of the modelling process and that is the choice of the suitable model, as well as the structure that this model should have for optimum results. One possibility of tackling the structural uncertainty is to define a discrete set of models that fit with the purpose of modelling. Some kind of questioning should then take place:

- Is the model structure consistent with relevant descriptive knowledge of the system?
- Is the level of aggregation appropriate?
- Does the model respond when subjected to extreme shocks-parameters?

When dealing with structural uncertainty the modeller should look out for inconsistencies and inappropriate assumptions about availability, flexibility of the model, identify externalities and side effects (*external uncertainties*) that should be captured endogenously [Ster].

10.4 Uncertainty and Risks in the process of modelling the specific problem

To understand how those qualities (*simplicity, realism, efficiency, usefulness, reliability, validity, etc.*) affect the way a model is judged, a step by step approach of the process of analysing the problem will be made from the realisation of the problem to the given solution. In each step several possible risks and uncertainties will be identified, giving rise to several problematic areas that need to be approached in a more careful manner for any solution to take effect. We will look into forms of uncertainty for the specific problem. The forms of uncertainty that we will look into are:

- Uncertainty in the identification of the problem
- Uncertainty in the process of modelling

10.4.1 Uncertainties in the identification of the problem

The percentage of natural gas in the production of electricity has been increasing over the last few decades, making it nowadays the leader in the production resources. The reserves of natural gas are limited and located in political unstable countries. UK is located at the end of a receiving pipe of natural gas, passing through most of Europe, including political unstable countries. The cost of electricity generated by gas is increasing with rapid movement. It is evident that some parts of the identification of the problem are strongly connected with the environment (gas reserves, emissions), and to be quantified some kind of statistical modelling needs to take place. This type of modelling is called environmental modelling and has a number of uncertainties associated with it.

Analysing the above arguments and the way the path of the problem solving is slowly opening one must stop and take a good look to the hidden discrepancies, usually overshadowed by the argument itself. Some of the arguments that will be described here have no immediate effect to the way the problem has been modelled. That is, in our original assumptions we did not take into consideration, for example, the environmental modelling and thus any uncertainty regarding emissions-if they are adequately monitored and accounted for, etc-have not been considered. The fact that this thesis does not take into consideration these parameters does not mean that they do not contribute to the overall problem of energy/electricity production. In fact they affect the overall modelling process of energy production.

Another option proves more feasible

This thesis progressed with a main assumption being that at the moment the main competitor for substituting natural gas for generation of electricity is nuclear energy. This assumption might be seriously ill selected, if a major breakthrough in alternative energy sources happens. This event would mean that the new option that has appeared in the spotlight, would bring a type of uncertainty related with the original selection of options, as well the selection of the implemented option, that is nuclear energy. This breakthrough would mean a rethinking, reorganisation process is eminent, to value the new option and place it against the same if not better odds with the nuclear option.

Gas Availability

The natural gas reserves are limited. In a previous chapter the truth lying behind this statement was discussed (for further reading refer to Appendix 6) and the conclusions were somewhat ill defined. However, we do not know exactly, or within limits of approximation, when this will happen. It is an *uncertain* event. Something though that is not uncertain are the rising gas prices. It might be assumed that this rapid rise of gas prices the last few years is due to the fact that the demand overleaps the supply, which comes down to the gas reserves-gas availability argument. But this may also mean that the gas provider has decided to increase the gas price creating a cloud of uncertainty regarding gas availability. Elongating that period of uncertainty as much as possible creates panic in the markets, profit for the producers and loss for the consumer who has to pay the ever increasing gas prices. This kind of uncertainty may suit the gas providers but is creating question marks for such research.

Political instability

It is forecast that there is one chance in 20, on current plans, that UK Generators will only provide about one third of their rated capacity in 2020. This shortfall, if it occurs, will largely be due to politically motivated interruptions in supplies of gas from Yamal in Russia through Belarus and Ukraine to the UK [Gittus]. With the UK at the end of a long supply chain traversing areas of potential political instability, there will be serious risks to supply security and price stability.

"In the long-term, the greatest risk is that of supply interruption in a major pipeline from outside the EU. This could result from political instability in the producer country or in a country that is transited by the pipeline".

(EU Commissioners' Statement)

Disruption of oil and coal supplies due to political activities has occurred twice per decade in the last 50 years. The following graph illustrates this. (Britain used more than a million barrels of oil equivalent per day throughout the period of this graph).

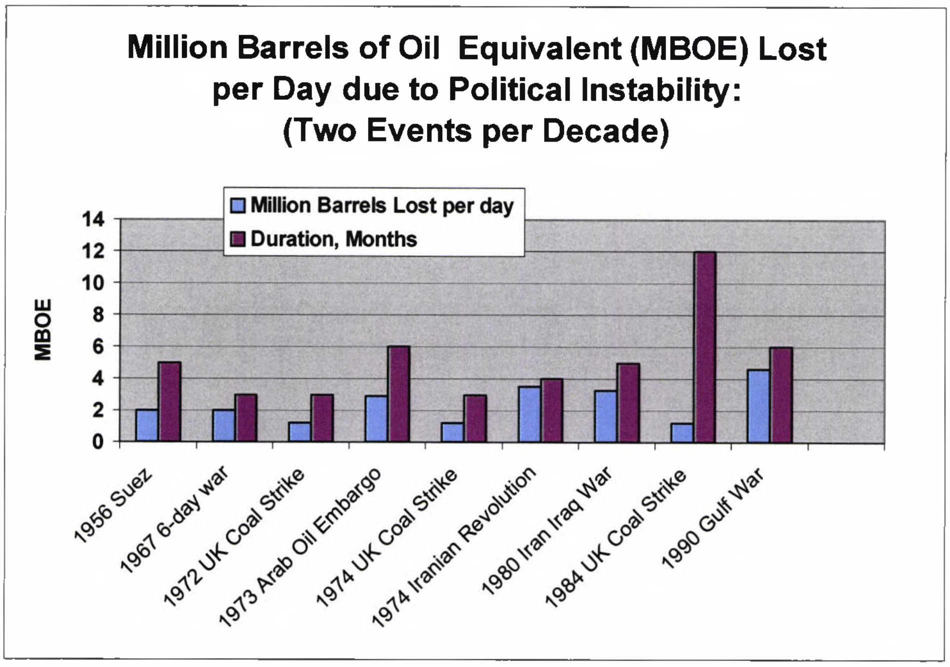

Figure 10.5: Disruption of oil and coal supplies due to political activities [Gittus]

The same disruptions can occur with the use of gas as a main resource as well. Several times in the first half of 2002, Russian companies cut off natural gas supplies to the Ukraine and Georgia to force payment of debts. Russian gas giant Gazprom is now suing Ukraine to pay for gas that Kiev has allegedly siphoned from the pipeline transiting its territory. Longer, less frequent stoppages may easily be envisaged [Gittus]. There is therefore proof of certain risks existing and unfortunately UK can only plan ahead with gas storage or even a change of resource.

Environmental Modelling-Emissions

Carbon dioxide (CO_2) is the most important greenhouse gas accounting for around 86 per cent of the UK's total emissions in 2003. In 2003, industry and the transport sector each accounted for just over 28 per cent of emissions and domestic users accounted for a further 27 per cent. Between 1970 and 2003, total carbon dioxide emissions fell by 19 per cent.

Much of this decline has come from a reduction in emissions attributable to industry which declined by almost half since 1970. Emissions caused by domestic users have declined by 24 per cent since 1970; those attributable to transport have increased by 89 per cent [DEFRA].

This type of statistical modelling used to calculate the various greenhouse emissions along with the effects they have in the atmosphere falls within the area of environmental modelling. Although nobody can argue about the existence of those emissions and the harmful effect they have on the atmosphere, they are prone to inaccurate measurements. The reason why this may happen is that environmental modelling may involve [Scott]:

- Understanding and handling variation
- Dealing with unusual observations
- Dealing with missing observations
- Evaluating uncertainties

Furthermore common features of environmental modelling and observations may include [Scott]:

- Knowledge of the processes creating the observational record may be incomplete
- The observational records may be incomplete (observed often irregularly in space and time)
- extreme events
- involve quantification of risk

As previously mentioned the uncertainties brought by inadequate, wrong or incomplete observations through environmental modelling, are not in the scope of this thesis but they contribute to the overall factor of uncertainty in the modelling process of the energy production. However how, for example, the emissions produced by domestic users may affect in the future the cost of production of electricity is not something we look into; but may as well, be a very important factor with future and not so distant measures for carbon emissions.

10.4.2 Uncertainties in the sequence of actions in the process of modelling

Further to the uncertainties associated with the identification of the problem, which can be mainly influenced by uncertainties due to incomplete or lack of observations, the process of modelling can sometimes be filled with ambiguous areas. Trying to make decisions about the way to move forward when ambiguities are present may lead to errors in the decisions. The approach used in this thesis is illustrated in the following figure:

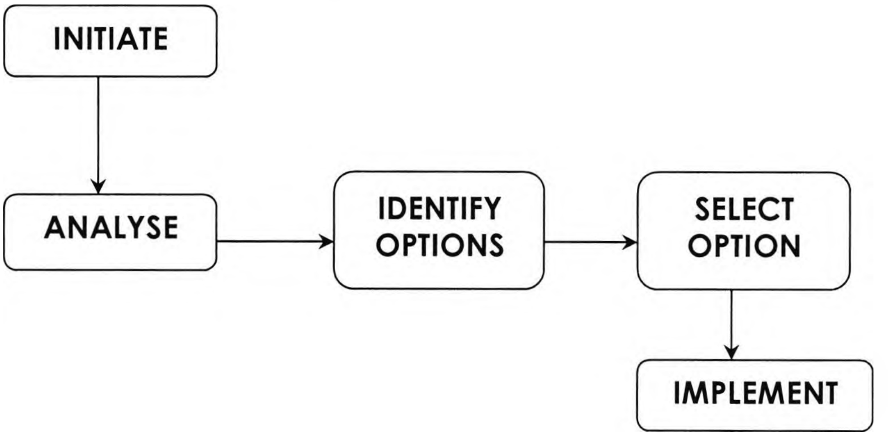

Figure 10.6: Linear Strategic Action Sequence [Fowler].

It is evident that there are no feedback loops associated with that approach. The identification of the problem was the initiation, followed by the analysis, the identification of the options, the selection of the option and the implementation. It is a straightforward approach but it is not realistic to be used as the first approach, especially since there are no feedback loops. Modelling is a feedback process and cannot be a linear sequence of steps. Processes go through continual questioning, testing and refinement. The initial purpose dictates the boundary and scope of the modeling effort, but what is learned from the process of modeling may feedback to alter the basic understanding of the problem and the purpose of the effort [Ster]. Results of any step can yield insights that lead to revisions in any earlier step.

The feedback loops would provide missing information, or pinpoint areas that were blurred, providing this way a compensation for uncertainties. Feeding that information back to the main process of strategic thinking, it would take them into consideration, thus not making any omissions. This approach should be the last step of a long and complete analysis, thus not risking to miss important data in the process (even then this step by step approach is prone to uncertainties). In its simplest form, the prescriptive model may be seen as a linear, sequential process as identified in Figure 10.6. However, most contemporary thinking would probably accept that a more representative view would be inherently more systemic with blurred cause and effect linkages and sequences of action that are iterative, dynamic, and nonlinear [Fowler].

Ways to "work" with related uncertainties

A more realistic approach should always include feedback loops that can make the process richer at every step. The process of modelling should be a platform of trials and errors. Planning the way forward from the beginning may be thought as something wise, but the problem is that aspects of the problem may be visible when the analysis is further ahead. By planning the solution from the beginning any aspect of flexibility of the analysis is lost along with insight to locate uncertainties in the analysis. Extension of this representation into a form of double loop of learning is also evident in Figure 10.7.

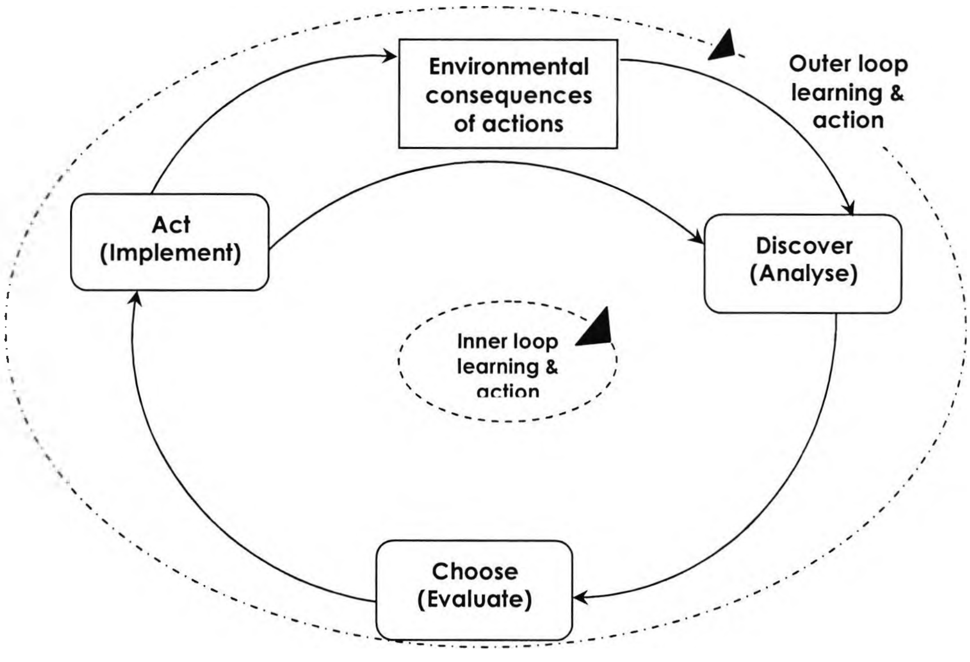

Figure 10.7: Looped Strategic action sequence [Fowler].

The external loop acknowledges the consequences of internal actions, with respect to their impact on the environment. Hence, choice of strategic options may now be further modified through changes in the target settings applied to the inner control loop. Figure 9.7 represents the realistic way of thinking when modelling.

The first steps of this research due to the nature of the problem and the choice of the modelling methodology used (Real Options Analysis), had to be somewhat predetermined, and so a big part of the uncertainty related to the sequence of the actions were eliminated. The identification of the problem and the decision to use Real Options Analysis encompasses some predefined steps:

- Introduction-definition of the "asset"
- Collection of data for that asset
- Calculations
- Solution

Overall the sequence of the steps is logical and complete. It is also realistic to base the analysis in such a framework at the early stages of modelling. However one must acknowledge that such a process should be enhanced at each step with a wide array of data, collected at each step and then transformed into knowledge and fed back at the process. This was the case in this project as well. In each step, several different kinds of uncertainties needed to be identified and tackled. Examples of such uncertainties could be found in the identification of the problem as discussed earlier, in the selection of the asset (that being gas electricity), the collection of the data for that asset and the calculations themselves. It was a trial and error approach especially in the fist steps of identification and selection of the asset, and the uncertainties associated with them were diminished as much as possible with the use of feedback loops in the processes of the collection of data and verification of it, as well as the calculations. It must be noted that the collection of data throughout the research and the verification of it, that is the most essential part of the research, was the one part that required the most effort and the one that needed the most analysis since it was considered the cornerstone of the whole research. Errors and uncertainties in the input data in such a sensitive methodology, would give uncertain results that would most likely be wrong. Due to the nature of the solution that can be proposed with real options analysis, that entails specific time periods to implement an option, any discrepancies regarding the input data would surface as a wrong time period. Simulation models are informed by our mental models and by information gleaned from the real world [Ster].

One of the factors affected directly by the input data is volatility. Volatility was calculated using historical values of gas, found in the DTI web site. These values were changed with approximations of them, due to a system loss that happened within the DTI website. The values used for this research are "old" pre-approximated values. As one can understand this "small" setback, that changed the input data, can affect the "sensitive" volatility that is one of the main levers for this research.

10.5 Uncertainty related to Real Options Analysis

The analysis of "real options" is a blend of technical and market considerations. This observation has important implications for the way options analysis, as presented in financial textbooks, which focuses on financial contracts, is translated into systems planning and design. Two implications flow from the fact that real options deal with physical projects:

- the data available for the analysis of "real options" is normally far less accurate than that used in the analysis of financial options, and
- managers make decisions about whether to acquire a real option, only a few times, perhaps only once.

Analysts of financial options can expect to use detailed as sophisticated descriptions of the risks associated with these options, and can thus aspire to great precision and accuracy. Analysts of "real options", however, may have little historical data to draw upon and may thus have to use speculative assumptions. In these circumstances, they know their estimates of value are approximate within bands described by sensitivity analyses, and recognize that analytic niceties that might lead to greater precision may be a waste of effort. In short, the analysis of "real options" leads to approximate rather than precise values.

But, managers of technological systems do not require great accuracy because they typically only need to make choices, not precise judgments. In making a choice, one only needs to know the relative value of alternatives, not their precise value. To decide whether to do the R & D that will lead to a real option on the launch of a new product, for example, managers only need to know if the value of the option is greater than the cost to acquire it. If yes, then they should invest in the R & D. In this respect, the object of doing an options analysis is quite different for systems managers than for financial analysts who have to decide on a precise price to pay for options, as they trade them day after day [Neuf]. The integration of "real options" analysis can radically change the design of public and private systems. It can change the processes of system design, the way planners deal with uncertainly and risk. It will also change the outcomes, the kinds of elements designers build into the system as they develop it. [Neuf]

To think in terms of options alters the way one deals with uncertainty. Conventionally, good design minimizes risk. It focuses on increasing reliability and making the best decisions in risky situations. In short, it is reactive to risk. The framework of options thinking, however, recognizes that uncertainty adds value to options. In this context, uncertainty is a driver of value and can be viewed as a positive element. Correspondingly, systems design from this perspective is proactive towards risk. It seeks out opportunities to add value and commits to ongoing processes of information gathering to ensure that options can be exploited at the correct time [Neuf]. Thinking in terms of real options leads designers to build much more flexibility into a system than is common in current practice. For example, they may build duplicate combustion facilities that allow a plant to burn both natural gas and oil, or deliberately develop products that they may never launch. These investments that may be unused are "options"; they give the system managers the capability to change the design or product mix, without requiring them to do so [Neuf].

Adoption of the “real options” approach to the evaluation of projects, and thus of the design of systems, brings with it additional advantages that may be most important in the long run. The integration of "real options" analysis is likely to change radically the design of public and private systems. It will change the processes of system design, the way planners deal with uncertainly and risk. It will also change the outcomes, the kinds of elements designers build into the system as they develop it [Neuf]. The more risk there is, the more valuable options become. In short, options are attractive because they offer the prospect of high gains with limited losses. They thus constitute very attractive additions to the design of a system.

Management flexibility is the ability to affect the uncertain future cash flows of a project in a way that enhances its expected returns or reduces its expected losses. Typical project flexibilities include the option to expand operations in response to positive market conditions or to abandon a project that is performing poorly. Management may also have the option to defer investment for a period of time, to suspend operations temporarily, to switch inputs or outputs, to reduce the project scale or to resume operations after a temporary shutdown. All of these opportunities represent options on real assets that allow management to enhance the value of the project. The value of these options cannot be determined by the traditional DCF method, but only through option pricing or decision analysis methods. Moreover, the presence of real options affects the risk characteristics of the project and consequently the choice of the appropriate risk adjusted discount rate, which further complicates the analysis. Option pricing methods were first developed to value financial options. However, the potential application to the valuation of options on real assets was quickly identified, and hundreds of scholarly papers have been written on this topic. [Brand]

The binomial lattice model can be used to accurately approximate solutions from the Black-Scholes-Merton continuous-time valuation model for financial options, with the added advantage of allowing a solution for the value of early-exercise American options, whereas the Black-Scholes-Merton model can only value European options. Unfortunately, the process of working through lattices can be large and non intuitive, especially for more complex applications to real assets, which can involve several simultaneous and compound options. [Brand]

The distinction between market risks and project specific risks is often a very natural one in oil and gas exploration projects, since oil and gas prices are market risks, while the project specific risks may be the probability of a dry hole, or the probability distribution regarding the volume of reserves. This approach has a natural appeal in problem contexts such as these.

To summarise the uncertainties related to the chosen modeling methodology that is real options analysis are the following:

- The date of occurrence of a key event is uncertain.
- The data available for the analysis of "real options" is normally far less accurate than that used in the analysis of financial options.
- Analysts of real options may have little historical data to draw upon and may thus have to use speculative assumptions thus making the analysis of real options to lead to approximate rather than precise values
- Some researchers believe that applications of real options valuation methods to practical problems can be limited by the mathematical complexity of the approach.
- (Specifically for the use of the binomial model) it can produce large amount of information and can be very complicated if used for several simultaneous options.

10.6 Uncertainties related to the proposed solution

The uncertainties related to the proposed solution will be broken down into categories:

- Uncertainties related to the investment side of the proposed solution
- Uncertainties related to the technical side of the proposed solution

10.6.1 Uncertainties related to the investment side of the proposed solution

In liberalised markets investments are profit motivated, with the choice of technology left to the market. The redistribution of risk among the different stakeholders is likely to make nuclear generation unattractive for an investor, even when its levelised costs are similar to the levelised costs of the dominant technology, for several reasons.

First, investors have a strong preference for a shorter payback period, which makes investments with short lead time more attractive [Roq]. Nuclear lead time (5 years in the most optimistic scenario) are, for engineering and licensing reasons, much longer than CCGT lead time (2 years).

Second, construction costs for nuclear plant are two to four times greater (£900 to £1,400 per kWe installed) than for a CCGT (£300 to £500 per kWe installed). Of the three major components of nuclear generation cost – capital, fuel, and operation and maintenance – the capital cost component makes up approximately 60% of the total, while it only represents about 20% of total costs for a CCGT . In addition, the size of a typical nuclear unit is much larger than the size of a typical gas turbine: recent nuclear technologies range from 1000MWe (AP1000 from BNFL) to 1600MWe (EPR from Framatome-Siemens), while CCGTs units are only of about 200 to 650 MWe (although it is common to build several on one site). This implies that the required minimum upfront capital investment for a nuclear plant can be ten to fifteen times greater than the smallest investment required for a CCGT [Roq].

Third, the lack of recent experience with new build in UK makes it difficult to get reliable cost estimates. The traditional optimism of nuclear vendors reinforces investors' distrust of vendors' assessments. The history of nuclear electricity includes a list of seriously delayed construction and cost overruns [Nutt]. Besides, investors must confront the regulatory and political challenges associated with obtaining a license to build and operate a plant on a specific site [Roq].

10.6.1.1 Ways to "work" with related uncertainties

There are potentially two attributes of nuclear power generation that could make it more appealing to investors. First, nuclear generation costs are insensitive to both gas and carbon price risk (as are most renewables). Therefore, rising gas prices and carbon trading or carbon taxes will make nuclear more competitive against CCGTs and coal-fired plants [Roq]. (Nuclear fuel price has relatively little effect on electricity generation costs: a doubling of the uranium oxide price would increase the fuel cost for a light water reactor by 30%, and the electricity cost by only about 7%, whereas doubling the gas price would add 70% to the price of electricity (Uranium Information Center, 2004)).

Second, investing in nuclear provides a hedge against the volatility and risk of gas and carbon prices (In the EU, CO_2 emissions are now priced by the emissions trading scheme). The uncertainty over the evolution of gas and carbon prices implies that there is an option value associated with being able to choose between nuclear power and other fossil fuel technologies in the future. Moreover, the hedging value of a nuclear power investment to a company is not restricted to the insensitivity of this plant to gas and carbon prices. For a company already operating some fossil fuel generation plants, investing in a nuclear plant reduces the company's overall exposure to fossil fuel and gas prices [Roq].

While most valuation studies of competitive generation technologies take account of different gas and carbon prices through sensitivity analysis, there is no published study valuing nuclear as a hedge against uncertain gas and carbon prices from a company perspective.

10.6.2 Uncertainties related to the technical side of the proposed solution

When a new product or a cost saving process is invented, policy makers have to decide whether to allow it or not. In taking this decision they try to evaluate expected costs and benefits. In this context imperfect scientific knowledge is an important source of uncertainty.

10.6.2.1 Restructuring of the Electric power industry

Restructuring in the electric power industry raises a fundamental question: how will the sweeping transformations caused by restructuring affect the reliability of the nation's electricity grid? In the past, utilities traditionally provided a complete, or bundled, set of power-related services and maintained reliability under an obligation to serve in exchange for market privileges such as a monopolistic franchise. In the future, many of these power-providing institutions will evolve into new business entities, fragment into independent organizations, or cease to exist as new participants enter the emerging, competitive environment. Reliable electric power, according to many analysts of the coming changes, will become a graded commodity for sale at variable levels of quality and cost [CERTS].

The task of keeping power flowing reliably across the network, will be complicated by new market forces, many new participants, and new rules regarding electric power generation, transmission, distribution, trading, and sales. Yet a fundamental change is underway in the electric power industry with respect to these processes, which now must successfully manage the higher levels of uncertainty accompanying restructuring. In addition, the information gathering and processing tools now widely used cannot be readily extended to deal with new requirements. For these reasons, a shift in the information and decision-making framework, or paradigm, of the electric power industry will be required in the future. At the heart of this shift are changes in how information is collected, the type of information needed, how it is used in decision processes, and the time spans between data collection, decision, and action. One of the driving motivations for this shift will be the reliability of electric power. [CERTS]

10.6.2.2 System reliability and social impact

Assessment of power system reliability is generally divided into two aspects [CERTS]:

- system adequacy and
- system security.

Assessment of system adequacy deals with steady-state operation and planning of the power system, i.e., it evaluates the ability of a power system to supply and deliver electric energy to satisfy customer demand. System security assessment evaluates the ability of a power system to respond to sudden changes and/or disturbances such as the loss of a generator or transmission line. There are two aspects to power system security. The first deals with the ability of the system to withstand internal failures and sudden natural disturbances, including network overload, voltage problems, and instability problems. The second aspect deals with the ability of the system to avoid external interference, attack, or coordinated physical assault on the system.

Traditionally system planners dealt only with the first aspect of security, i.e., problems arising from system operation, random failures of system equipment and natural disturbances. However, most of the attention nowadays has mitigated towards the external aspects of security that being external interference, e.g., due to an attack.

A quarter of a century ago Alvin Weinberg offered one of the most insightful and unsettling observations anyone has made about modern technology. Speaking of the decision to use nuclear power, the long time director of Oak Ridge National Laboratory warned that society had made a "Faustian Bargain". On one hand, he said the atom offers us a nearly limitless supply of energy which is cheaper than that from oil or coal and which is nearly non-polluting. But on the other hand, the risk from nuclear power plants and nuclear waste disposal sites demands "both vigilance and longevity of our social institutions that we are quite unaccustomed to". We cannot afford, he said, to treat nuclear power as casually as we do some of other technological servants-coal fired power plants, for instance-but must instead commit ourselves to maintaining a close and steady control over it. [Pool]

According to Steve Rayner and Robin Cantor, two analysts from Oak Ridge National Laboratory, the public at large places great significance on the social contexts in which decisions about risky technologies are made. In particular the researchers say that the public focuses on three factors in deciding whether a risk is acceptable [Pool]:

- Is the process by which decisions are made about technology acceptable to those who stand to be hurt by an accident?

- In case of an accident, does everyone agree ahead of time, who is responsible for what?
- Do people trust the institutions that manage and regulate the technology?

If the answer to all three questions is yes, Rayner and Cantor say, then the public will likely not worry about the sorts of low-probability, high-consequence accidents that have plagued nuclear power [Pool].

10.6.2.2.1 Ways to "work" with related uncertainties

Nuclear energy is a well-established component of electricity supply in many OECD (Organisation for Economic Cooperation and Development) countries and is attracting renewed interest from policy makers and the public in the light of its potential role in long-term strategies aiming at alleviating the risk of global climate change and more generally in sustainable development policies. However, the implementation of nuclear projects often raises social concerns about risks associated with possible releases of radioactivity in routine and accidental situations, radioactive waste disposal and nuclear weapons proliferation. *Understanding risk perception, communicating with civil society on the issues at stake and associating the public with decision making in an effective way are essential for the future of nuclear energy* [NEA]. Those concerns need to be addressed, in particular by *informing and consulting all stakeholders and involving them in decision-making processes aiming towards reaching consensus on key issues.* The *lack of understanding and consensus between civil society and decision makers on issues related to nuclear energy may lead to conflicting situations* in some cases and will eventually result in energy policies and supply mix choices that are not optimised from the viewpoint of society as a whole.

The value of R & D that permits the launch of a new product similarly rests on the both the desires of the consumers and the success of competitive products. The technical performance of the product itself is of course essential, but this factor is only part of the equation. A research and development process that enables a country or a company to launch an industry or a product, such as the use of nuclear for electricity production, gives the sponsors the "right, but not the obligation" to do so. *Even if the R & D process is successful, the market may not be ready for the launch of the new activity.* [Neuf]

The performance of nuclear energy, based upon more than 10,000 reactor-years of experience world-wide (of which more than 80% was acquired in OECD countries), is very satisfactory. Nuclear power plants in operation compete successfully on deregulated electricity markets in several countries. The number of accidents that occurred in civil nuclear facilities and led to human fatalities, or significant health or environmental damage, remains extremely low after several decades of commercial use of nuclear energy [NEA].

Like all industries, the thermal generation of electricity produces wastes. Whatever fuel is used, these wastes must be managed in ways which safeguard human health and minimise their impact on the environment. At each stage of the fuel cycle there are proven technologies to dispose of the radioactive wastes safely. In some cases, however, they are not implemented because of public concerns or because they are not presently needed. The main objective in managing and disposing of radioactive (or other) waste is to protect people and the environment. This means isolating or diluting the waste so that the rate or concentration of any radionuclides returned to the biosphere is harmless. To achieve this, practically all wastes are contained and managed - some clearly need deep and permanent burial. None is allowed to cause harmful pollution [UIC3].

Nuclear power is the only energy industry which takes full responsibility for all its wastes, and costs this into the product. Decision-making on what to do with the waste produced by the nuclear fuel cycle, another very important social issue, is made difficult by the uncertainties concerning, among other things, the development of our societies, the pace of technological progress and the social acceptance of radiation risk in the coming centuries [Loub]. But right now, as stated by Crouail, Schneider and Sugier [Crou] "a responsible attitude implies using as best as we can all available information on the possible consequences of our present actions, even if this information does reflect the lack of knowledge in the assessment of consequences far in the future".

10.7 Final Thoughts

The world is rich and varied in its complexity. Furthermore, our society has been undergoing even more rapid change. If the reality is so complex then it is only natural that any abstraction of that reality will have to some extreme the same amount of complexity. The expression "to some extreme" is used only to emphasize that the complexity mirrored in the model will depend on the purpose of the model and how much of that complexity the modeller will have to incorporate in the model.

Uncertainty management is not possible without a clear problem definition. Reliance on empirical-scientific methods, successful applications of logic and reasoning skills, have proven to be quite effective in the understanding of dynamic systems and their controlling mechanisms, as well as the design of models, but it has not removed the factor uncertainty out of the modeling process. Modelling itself is an uncertain activity.

The modelling approach is based upon techniques, wherein complex systems are broken down into small components for analysis. By breaking the complex systems down into their functional components, it is easier to locate the source of uncertainty and try to tackle it. There is not one method that suffices in doing uncertainty analysis and model assessment is a difficult process. Sensitivity analysis and uncertainty analysis, as described in this chapter, are important tools in model assessment.

It is almost inevitable not to come across some kind of uncertainty when dealing with a problem of such importance. From the way the problem is conceived and the way the plan to move ahead is realized, to finally propose a solution.

In this chapter a try was made to identify the various kinds of uncertainty in the stages of this modeling process. This process was broken down into three main stages:

- Identification of the problem
- Modelling process
- Proposed solution

The knowledge gained throughout the research was put into test by trying to pinpoint probable problematic areas that could possibly create bottlenecks for the process. Furthermore some propositions were made in a bid to tackle those bottlenecks, with an as much as possible open minded way.Several key points during this process were identified. Some of those key points from where uncertainty is derived are emergent problems that can be found in other areas as well:

- Data collection-data mining-Knowledge acquisition. There was a need to investigate the domain of the problem, determine what concepts are important and derive clear, correct and efficient information. The problems began when some of that information was either difficult to acquire or “defective”.
- The modeling process is iterative. Models go through continual questioning, testing and refinement. The initial purpose dictates the boundary and scope of the modeling effort, but what is learned from the process of modeling may feedback to alter the basic understanding of the problem and the purpose of the effort [Ster]. Results of any step can yield insights that lead to revisions in any earlier step.
- The safety of complex systems depends not just on their physical characteristics but also quite intimately on the people and organizations operating them. Complexity creates uncertainty and uncertainty demands human judgment. Organisational reliability is just as crucial to the safety of a technology as is the reliability of the equipment. If we are to keep our “Faustian bargains” in check, we must be as clever with our organizations as we are with our machines. [Pool]

Chapter 11

Conclusions

This thesis has introduced an abstract conceptualization of the notion of the system and has examined its relations to the various issues relating to the problem of conceptual modeling and its links to the development of formal models. It has been shown that the understanding of the system goes hand in hand with the development of model conceptualization and subsequently of formal models and thus is critical for the development of subsequent control and measurement schemes. The significance of the abstract system definition and notions of conceptual models have been used to develop control and measurement architectures for the problem of "integrated operations" and subsequently used to develop decision making policies to a case study motivated by the problem of energy strategy. This work has foundational role and has revealed a large number of system and modelling issues that need further consideration. A large number of questions have been raised which form the building blocks of an open research agenda for this area of work.

The main drive behind this work has been the recognition that for the emerging areas of applications of systems and control, which go beyond the traditional engineering field, there is a need for a solid system framework that underpins the problem of conceptual modelling, development of formal models, appropriate control architectures and finally integrated solutions. The area of applications is very diverse and it is characterized by models of different nature and different forms of complexity. For the different areas of applications, the models change in nature, but behind the different forms of formal models there exists the unifying notion of “conceptual model” that takes different forms in the different disciplines where they emerge. It has been a central objective to clarify and unify the alternative notions of a “conceptual model” and thus create a basis for developing formal methods, control/information architectures and strategies in a systematic way. It has been realized that the development of a unifying notion of “conceptual modeling” requires a suitable kernel, which is provided by an appropriate definition of abstract systems. Existing “soft system theory” has remained in the conceptual and descriptive form (Checkland, Klir, etc.), it is lacking rigor and potential to provide the means for the development of methodologies empowered by analytical and synthetic tools. On the other hand abstract system theory (Mesarovic, Takahara) has a mathematical formulation, but has been rather detached from real life problem and issues of the complex system area. We have realized that the mathematical system theory developed for engineering type problems and which is based on simple formal models, is rich in structure, notions and concepts and this allows the development of techniques that provide answers to design and decision problems, as well as tools for simulation and testing of alternatives. Extending such a framework to general systems by abstracting the basic concepts and transferring notions in this abstract setup has been seen as a challenge. Our approach has been to develop an abstract and rigorous framework that is detached from the specific area of applications, but it is linked to traditional engineering concepts and issues and thus having the potential to benefit from them if the appropriate modelling tools are deployed.

We have, thus, considered the development of this abstract system framework as the pivotal stone on which we can develop modelling, control and decision making design. The process of modelling has been considered in its most general form as the effort to bridge the real life system with our understanding of it in the form of a model. Most of the effort in modelling is invested nowadays into formal methods and the part of the modelling that bridges our understanding of the system with control and decision making applications that is the process of conceptualisation, is in general underestimated. The stage of modeling that is referred to as "conceptual modeling" has been used in different domains in an unstructured way. Most of the current work has been done from the viewpoint of specifications and although this brings important notions, it has an informatics flavor that may be rather restrictive. Our viewpoint of conceptual modelling that has been developed here is closer to the description of objects, topologies and process features which in other terms is an expression of our understanding of what is the system. Our view has been that from the different engineering disciplines Chemical Engineering has addressed the problem of model conceptualization, conceptual design and decision making on conceptual models in the most structured way. Thus, our thinking has been influenced by developments in Chemical engineering (Douglas) where design of new processes has to go through stages of early conceptualisation, in terms of viewing its topology and deciding the nature of basic processes; in fact, the overall design involves is part of a larger cycle where successive evaluations lead to progressively more detailed and richer models, which in turn have variable capabilities as far as predictions of system behaviour. The role of the observer, measurements, setting up of the experiments and data analysis have been discussed, but not elaborated at the level of highlighting the transition to formal models.

The thesis contributes to the development of a relevant general system framework understanding the process of development of conceptual models, develops control architectures for a specific problem on the basis of system conceptualisation and finally demonstrates the use of the latter in the study of a specific problem that acts as a case study. In the specific case study we have examined the problem of electricity production from different energy sources. We have identified the main provider as natural gas and from that point and on, we have developed an approach that has involved the collection of data to demonstrate that for various reasons, at some point in the future it would be more economically viable to substitute the percentage of natural gas in the production of electricity with another energy source. The various options were identified and we have proposed nuclear energy as the most competitive, according to the specifications of the given problem. The problem was looked from a purely economic point of view, and the various modeling issues were formed around that assumption. This point of view prompted the use of an economic forecasting model, and the use of Real options analysis.

The importance of having a suitable abstract systems framework that can act as a platform for developing appropriate modeling and subsequently a successful analysis and design methodology, has been demonstrated in the thesis. So far, the problem of system conceptualization, dominating the early stage activities in the work of general system applications, has been a rather vague and unstructured activity; this has led to solutions which were narrowed down to building a 'nice' picture of the problem; on the basis of that construction decision-making was performed, based wholly on heuristics and the intuition of the people involved. Here, an effort was made to address the problem in a more systematic and formal way by introducing the need to understand the abstract system and then use it as the core in the process of development of the conceptual model; the identification of the abstract system as kernel to the problem is the first step in the process of modeling. Based on that understanding, the development of a conceptualization-identifying the specifics of the system and providing a modeling support for the process to come-is realized and from there the basis for decision making is built. The importance of that chain of processes was established and their necessity in the whole modeling process was stressed.

The relevant issues and areas related to a system, its objects, environment and the relations between them, were approached in a systematic way. Furthermore, the modeling process was broken down into, what was thought coherent and strongly related, stages. A basis for thinking about and creating a conceptual model was given. This approach came to bridge the gap that is created from the identification of the problem to the system definition. The significance of having a well structured conceptual model stems from that this can provide the basis for developing formal methods that may permit the use of powerful analytic techniques for study of problems and decision making on the general process under study. A well defined conceptual model also provides the basis for developing an activity that has been very vague and unstructured so far and may be referred to as "conceptual analysis" and "conceptual decision making". These last two activities are performed now-days by the experienced researcher, but are entirely unstructured mental processes. The development of control and information architectures is part of this new challenging process and this has been demonstrated here for the case of systems integration of operations in the continuous process manufacturing under a hierarchical system organization.

The case study that has been considered in the thesis has served as a demonstration on how to develop decision strategies on systems that are not well structured. The simple version based on one option may be extended to a multi-option decision problem that may include more than one alternative to gas. This is a topic of future work.

In this thesis, the emphasis has been on developing the fundamentals of a conceptual framework, rather than addressing the methodology for evolving formal models on the basis of developed conceptualizations. An open issue that requires attention in the future is the development of a formal mathematical set up that supports the understanding of the abstract system. The description of concepts and properties are linked to formal methods which enable the systematic study of analysis and design/synthesis problems. The development of that relevant mathematical framework is a future task that can be undertaken when the relevant concepts have been appropriately defined. The expansion of the framework by generalizing the fundamental notions and concepts involved to suit other paradigms of interest and where it is needed to introduce additional new concepts and notions to serve the new paradigms, is something of immense value. A major challenge in this area is the transition from the conceptual to the formal model. We see the process of development of successively more detailed and complex models with varying capabilities to predict aspects of behaviour and emergence properties as a "model evolution"; the abstract system and the development of a well structured conceptual model are central to this evolutionary process. Such activities are subjects for future research.

In recent years, an increasing attention has been paid to the development of domain-specific modeling languages. It is believed that using the conceptual model as the "kernel" of the modeling process and having the means to make the transition from the conceptual to specific, these languages can contribute to the production of models that are more flexible, reusable and easier to maintain than models produced by using general-purpose modeling languages. Notwithstanding, in order to be effective, a domain specific modeling language must be defined taking into account the needs of its client users. From their perspective, the use of the language should be intuitive and satisfactory in the following terms:

- The semantics of the produced models should be clear, i.e., it should be easy for a model designer to recognize what language constructs mean in terms of domain concepts;
- The language should be sufficiently expressive to represent all domain concepts that should be captured by the intended models.

For these reasons, it is very important to develop concepts, techniques and methodology that support the construction of explicit models of domain conceptualizations. Additionally, there is a need for concrete and precise guidelines for selecting which domain concepts should be represented as language constructs and how.

Further to the unifying language that is necessary for interdisciplinary work, other issues arise, that are more focused on the actual modelling process rather than the semantics of it. The following are just few of the areas identified for which thorough understanding and clarification is needed by development of further research:

- Question regarding the nature of the building blocks of a model have been raised. These relate to the knowledge we have for the objects, their relationships, their attributes. The knowledge we acquire and the way this knowledge is acquired relevant questions to be investigated. Model definition that fits the existing data and the knowledge of the objects/relations is another issue. From model definition different kinds of questions come into the surface regarding model "Minimality", as well as model simplification and expansion and how these are achieved. The questions formed provide a framework of problem areas; areas for which little has been done to provide concrete solutions or step-by-step approaches, and thus form open problem areas. These open problem areas have been identified as: *Knowledge extraction, Systems conceptualisation, Design of experiments, Model construction,* *Model minimality, Model expansion, Model reduction* and *Model simplification*. Developing modelling approaches requires tackling problems of the above classes in a rather substantial way.

- The need of data mining and knowledge management has been stressed and the importance of a concrete process of data collection, as well as the extraction of knowledge in a systematic way. The transition from data to information and eventually knowledge is still an open and major challenge. There is a need for a generic framework that should provide the basis for an understanding by answering key questions. Specifically:
    - How is data transformed into information? Issues of data mining and the knowledge brought by the modeller related with the modelling process. A question closely related with the Knowledge extraction problem previously identified, as well as the observer and his previous knowledge.
    - What is the role of data in shaping the structure of the model? Here again, we identify a question that if clearly answered could provide an insight in the model expansion, reduction, as well as simplification problem.
    - Is the role of data purely for quantitative reasons, that is, for providing measures for the variables, constraints, limitations, etc?

An agenda for long term research is to develop a systemic approach summarizing the above needs that aims at:

(i) Providing a conceptual framework that explains the interrelationships between the different actors of the system notion (objects, interconnection topology, inputs, outputs, environment).

(ii) Select the appropriate modeling tools that describe particular problems and provide qualitative and quantitative means enabling the understanding of hierarchical nesting and system properties emerging at different levels,

(iii) Study control, optimisation and state assessment problems in the integrated overall set up; this involves the development of both top-down and bottom-up approaches and related diagnostics-prognostics-control aspects.

(iv) Develop criteria, modelling concepts and methodologies that explain the evolution of physical system structure through the different stages of the cascade design process.

(v) Develop methodologies for redesigning existing systems to meet new operational requirements.

(vi) Explore the system aspects of data merging and transformations which may provide useful tools that may support the operational and design aspects of integration.

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Appendices

Appendix 1: Calculations of Volatility of Natural gas

- The conversion of the prices from p/therm to £/MWh are based on the fact that 1therm=29.3071 kWh.
- For the adjustment of the prices to 2003 prices the paper "Consumer price Inflation since 1750", available from the website of National Statistics, was used. The method as described in the paper uses this formula:
-

$$\text{Price of gas} = \frac{\text{Average of 2003 (Table 4)}}{\text{Average of the year trying to adjust (Table 1)}}$$

The tables are not provided in this report but can be found as appendices in the paper.

- The calculations of the future cash flow estimates and their corresponding logarithmic returns, the method used to calculate volatility, were carried out using excel. The table of the results is given below:

Year	cash flow £/MWh	cash flow relative return	ln of cash flow return
1976	2.795	0	
...	2.815	1.007155635	0.007130155
	3.839	1.363765542	0.310249654
	4.15	1.08101068	0.077896418
	4.532	1.092048193	0.088055009
	5.378	1.186672551	0.171153215
	5.631	1.047043511	0.045970488
	6.109	1.084887231	0.081476047
	6.928	1.134064495	0.125808078
	7.781	1.123123557	0.116113693
...	7.969	1.024161419	0.02387415
	7.508	0.942150834	-0.059589896
	7.576	1.009057006	0.009016237
	7.624	1.006335797	0.00631581
	7.013	0.919858342	-0.083535597
	7.412	1.056894339	0.055334739
	7.058	0.952239611	-0.048938583
	6.587	0.933267215	-0.069063716
	6.996	1.062091999	0.060240547
	6.638	0.948827902	-0.052527844
...	6.723	1.012805062	0.01272377
	6.552	0.974564926	-0.025764137
	6.143	0.937576313	-0.064457124
	5.119	0.833306202	-0.182354115
	5.733	1.119945302	0.113279846
	6.638	1.157858015	0.146571759
	6.177	0.930551371	-0.071977997
2003	5.938	0.961308078	-0.03946034
		Sum	**0.75354027**
		mean value of sum	**0.026912152**
		variance	**0.01013746**
		volatility	**0.100684956**

Appendix 2: Calculations of Volatility of U_3O_8

- For the conversion of \$ to £ the conversion factor 0.575 was used.
- For the adjustment of the prices to 2003 prices the paper "Consumer price Inflation since 1750", available from the website of National Statistics, was used. The method as described in the paper uses this formula:

$$\text{Price of gas} = \frac{\text{Average of 2003 (Table 4)}}{\text{Average of the year trying to adjust (Table 1)}}$$

  The tables are not provided in this report but can be found as appendices in the paper.
- The calculations of the future cash flow estimates and their corresponding logarithmic returns, the method used to calculate volatility, were carried out using excel. The table of the results is given on the next page:

Year	cash flow (£/pound)	cash flow relative return	ln of cash flow return
1987	9.71	0	
	8.4	0.865087539	-0.144924576
	5.73	0.682142857	-0.382516175
	5.6	0.977312391	-0.022948933
	5.03	0.898214286	-0.107346614
	4.9	0.97415507	-0.026184779
	5.8	1.183673469	0.168622712
	5.4	0.931034483	-0.071458964
	6.6	1.222222222	0.200670695
	9	1.363636364	0.310154928
	6.92	0.768888889	-0.262808808
	5.92	0.855491329	-0.156079321
	5.9	0.996621622	-0.003384098
	4.7	0.796610169	-0.227389842
	5.06	1.076595745	0.073803975
	5.68	1.122529644	0.115584749
	6.63	1.167253521	0.154653571
2004	10.66	1.607843137	0.474893615
		Sum	**0.093342136**
		mean valueof sum	**0.005490714**
		variance	**0.047684062**
		volatility	0.218366806

Appendix 3: Binomial Lattice of valuation of the cost of natural gas as fuel in the production of electricity

S=12.62	12.62	u=e^s(dt)^1/2	1.105928
s=0.100684	0.10068	d=-e^s(dt)^1/2	0.904218
dt=1	1		

Calculated using gas price 20.1 p/therm as fuel in a CCGT with 55% plant efficiency

2.7182818
1 therm= 0.0293 MW
Prices till 2033 (30 years from 2003 prices)

																														258.782
																													233.9892	
																												211.5501		211.5501
																											191.2873		191.2873	
																										172.9654		172.9654		172.9654
																									156.3984		156.3984		156.3984	
																								141.4182		141.4182		141.4182		141.4182
																							127.8729		127.8729		127.8729		127.8729	
																						115.625		115.625		115.625		115.625		115.625
																					104.5502		104.5502		104.5502		104.5502		104.5502	
																				94.53612		94.53612		94.53612		94.53612		94.53612		94.53612
																			85.48125		85.48125		85.48125		85.48125		85.48125		85.48125	
																		77.29367		77.29367		77.29367		77.29367		77.29367		77.29367		77.29367
																	69.89032		69.89032		69.89032		69.89032		69.89032		69.89032		69.89032	
																63.19607		63.19607		63.19607		63.19607		63.19607		63.19607		63.19607		63.19607
															57.14302		57.14302		57.14302		57.14302		57.14302		57.14302		57.14302		57.14302	
														51.66974		51.66974		51.66974		51.66974		51.66974		51.66974		51.66974		51.66974		51.66974
													46.7207		46.7207		46.7207		46.7207		46.7207		46.7207		46.7207		46.7207		46.7207	
												42.24569		42.24569		42.24569		42.24569		42.24569		42.24569		42.24569		42.24569		42.24569		42.24569
											38.19931		38.19931		38.19931		38.19931		38.19931		38.19931		38.19931		38.19931		38.19931		38.19931	
										34.5405		34.5405		34.5405		34.5405		34.5405		34.5405		34.5405		34.5405		34.5405		34.5405		34.5405
									31.23213		31.23213		31.23213		31.23213		31.23213		31.23213		31.23213		31.23213		31.23213		31.23213		31.23213	
								28.24065		28.24065		28.24065		28.24065		28.24065		28.24065		28.24065		28.24065		28.24065		28.24065		28.24065		28.24065
							25.5357		25.5357		25.5357		25.5357		25.5357		25.5357		25.5357		25.5357		25.5357		25.5357		25.5357		25.5357	
						23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984		23.08984
					20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824		20.87824	
				18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848		18.87848
			17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026		17.07026	
		15.43523324		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523		15.43523
	13.95681352		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681		13.95681	
12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62		12.62
	11.41122936		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123		11.41123	
		10.31823734		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824		10.31824
			9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934		9.329934	
				8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293		8.436293
					7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247		7.628247	
						6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587		6.897587
							6.236931		6.236931		6.236931		6.236931		6.236931		6.236931		6.236931		6.236931		6.236931		6.236931		6.236931		6.236931	
								5.639544		5.639544		5.639544		5.639544		5.639544		5.639544		5.639544		5.639544		5.639544		5.639544		5.639544		5.639544
									5.099376		5.099376		5.099376		5.099376		5.099376		5.099376		5.099376		5.099376		5.099376		5.099376		5.099376	
										4.610947		4.610947		4.610947		4.610947		4.610947		4.610947		4.610947		4.610947		4.610947		4.610947		4.610947
											4.169301		4.169301		4.169301		4.169301		4.169301		4.169301		4.169301		4.169301		4.169301		4.169301	
												3.769958		3.769958		3.769958		3.769958		3.769958		3.769958		3.769958		3.769958		3.769958		3.769958
													3.408862		3.408862		3.408862		3.408862		3.408862		3.408862		3.408862		3.408862		3.408862	
														3.082354		3.082354		3.082354		3.082354		3.082354		3.082354		3.082354		3.082354		3.082354
															2.787118		2.787118		2.787118		2.787118		2.787118		2.787118		2.787118		2.787118	
																2.520163		2.520163		2.520163		2.520163		2.520163		2.520163		2.520163		2.520163
																	2.278776		2.278776		2.278776		2.278776		2.278776		2.278776		2.278776	
																		2.06051		2.06051		2.06051		2.06051		2.06051		2.06051		2.06051
																			1.86315		1.86315		1.86315		1.86315		1.86315		1.86315	
																				1.684694		1.684694		1.684694		1.684694		1.684694		1.684694
																					1.52333		1.52333		1.52333		1.52333		1.52333	
																						1.377422		1.377422		1.377422		1.377422		1.377422
																							1.24548		1.24548		1.24548		1.24548	
																								1.126194		1.126194		1.126194		1.126194
																									1.018326		1.018326		1.018326	
																										0.920787		0.920787		0.920787
																											0.832592		0.832592	
																												0.752846		0.752846
																													0.680736	
																														0.615534

Appendix 4: Binomial Lattice of valuation of the cost of producing electricity from gas (with volatility in fuel)

S=12.62 12.62 u=e^s(dt)^1/2 1.105928
s=0.1006849 0.1007 d=-e^s(dt)^1/2 0.904218
dt=1 1

CAP=5.5 5.5

Cost of electricity produced by gas with volatility applied in fuel

Notes:
Calculated using gas price 20.1 p/therm as fuel (price in 2004) in a CCGT with 55% plant efficiency
Which means gas price of £18.12 with fuel £12.62 and capital+OM+overhead=£5.5
CAP is the capital cost of gas price(= £5.5) which will be presented as a constant and added up on every cell.
1 therm= 0.0293 MW
Prices till 2034 (30 years from 2004 prices)

																														264.242
																													239.4592	
																												217.0601		217.0601
																											196.7673		196.7673	
																										178.4654		178.4654		178.4654
																									161.8964		161.8964		161.8964	
																								146.9162		146.9162		146.9162		146.9162
																							133.3729		133.3729		133.3729		133.3729	
																						121.126		121.126		121.126		121.126		121.126
																					110.0502		110.0502		110.0502		110.0502		110.0502	
																				100.0361		100.0361		100.0361		100.0361		100.0361		100.0361
																			90.98125		90.98125		90.98125		90.98125		90.98125		90.98125	
																		82.79347		82.79347		82.79347		82.79347		82.79347		82.79347		82.79347
																	75.39032		75.39032		75.39032		75.39032		75.39032		75.39032		75.39032	
																68.69607		68.69607		68.69607		68.69607		68.69607		68.69607		68.69607		68.69607
															62.64302		62.64302		62.64302		62.64302		62.64302		62.64302		62.64302		62.64302	
														57.16974		57.16974		57.16974		57.16974		57.16974		57.16974		57.16974		57.16974		57.16974
													52.2207		52.2207		52.2207		52.2207		52.2207		52.2207		52.2207		52.2207		52.2207	
												47.74569		47.74569		47.74569		47.74569		47.74569		47.74569		47.74569		47.74569		47.74569		47.74569
											43.69931		43.69931		43.69931		43.69931		43.69931		43.69931		43.69931		43.69931		43.69931		43.69931	
										40.0405		40.0405		40.0405		40.0405		40.0405		40.0405		40.0405		40.0405		40.0405		40.0405		40.0405
									36.73213		36.73213		36.73213		36.73213		36.73213		36.73213		36.73213		36.73213		36.73213		36.73213		36.73213	
								33.74065		33.74065		33.74065		33.74065		33.74065		33.74065		33.74065		33.74065		33.74065		33.74065		33.74065		33.74065
							31.0357		31.0357		31.0357		31.0357		31.0357		31.0357		31.0357		31.0357		31.0357		31.0357		31.0357		31.0357	
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				24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846		24.37846
			22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026		22.57026	
		20.93523324		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523		20.93523
	19.45661362		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661		19.45661	
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		15.81823734		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824		15.81824
			14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993		14.82993	
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Appendix 5: Binomial Lattice of valuation of the option to abandon the production of electricity from gas

S=12.62	12.62	u=e^s(dt)^1/2	1.1
s=0.100684956	0.101	d=-e^s(dt)^1/2	0.9
dt=1	1		
rf=0 025	0 003		
CAP=5 5	5 5		
p=((e^rf*(dt))-d)/(u-d)	0 487		
k=32 4	32 4		

Evaluation of the option lattice - PART (I)- calculation of option value at each final node

Notes:

Calculated using gas price 20.1 p/therm as fuel in a CCGT with 55% plant efficiency
Which means gas price of £18.12 with fuel £12.62 and capital+OM+overhead=£5.5
CAP is the capital cost of gas price(= £5.5) which will be presented as a constant and added up on every cell.
Furthermore, the backward model is calculated by subtracting from the last column the strike price. If the difference is negative we put ZERO in the cell. For the inside columns we use the p formula.
At this stage the risk free rate is 2.5%
K is the strike price, that was chosen to be the electricity price produced by nuclear.
1 therm= 0.0293 MW
prices till 2034 (30 years from 2004 prices)

S=12.62 12.62 u=e^s(dt)^1/2 1.1
s=0 100684956 0.101 d=-e^s(dt)^1/2 0.9
dt=1 1
rf=0 025 0.003
CAP=5.5 5.5
p=((e^rf*(dt))-d)/(u-d 0 487
k=32 4 32.4

Evaluation of the option lattice - PART (II)- progressive calculation of option value at each earlier node

Notes:
Gas price of £18.12 with fuel £12.62 and capital+OM+overhead=£5.5
CAP is the capital cost of gas price(= £3.3) which will be presented as a constant and added up on every cell.
Furthermore, the backward model is calculated by subtracting from the last columnthe strike price. If the difference is negative we put ZERO in the cell For the inside columns we use the p formula.
At this stage the risk free rate is 2.5%
K is the strike price, that happens to be the electricity rice produced by nuclear.
1 therm= 0.0293 MW
prices till 2034 (30 years from 2004 prices)

Appendix 6: Further reading on energy related fact related to Chapter 8

8.1 Energy consumption

Poised at the brink of the twenty-first century, nearly 6 billion people are consuming 10 Gtoe of energy. However, that consumption is spread extremely unevenly. Indeed for a very large number of people - some two billion, or approximately one in three people - the energy revolution has not yet begun. These people, the majority of them in the rural areas of developing countries, still use traditional fuels. Meanwhile, as the richest 20% of the population use 55% of the energy consumed the poorest 20% use 3%. The disparities are even greater with respect to electricity. The richest 20% use 75% of all electricity, while the poorest 20% use less than 3%. [Mur]

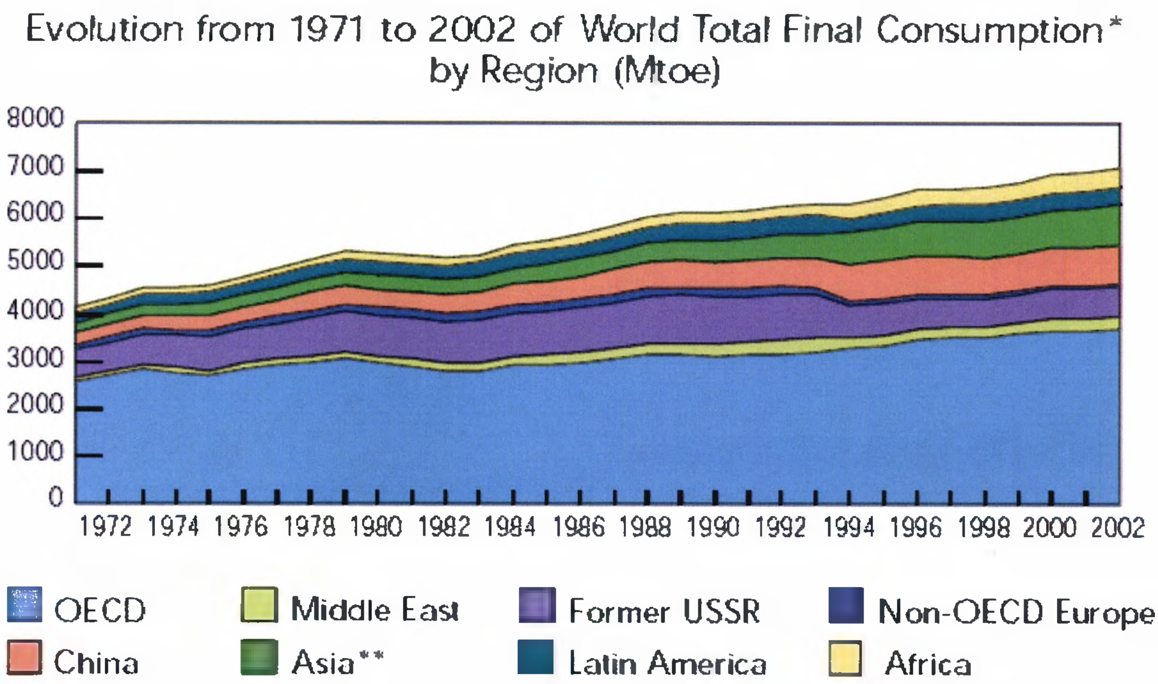


Figure 8.1: World total final consumption by region [IEA1].

Turning to the supply of energy, oil makes the biggest contribution with a share of approximately one third of our primary energy. It is followed by coal which supplies about one quarter and gas at one fifth, highlighting our dependence on fossil fuels for over three quarters of all our energy needs today.

Next in the primary energy pecking order come traditional fuels - fuelwood, dung, crop residues and so forth - at about 10% and then hydroelectricity and nuclear electricity at 8% and 7% respectively. So-called new renewables - for example, solar, wind, tidal, geothermal - do not yet show up on this scale. All of the photovoltaic cells ever made up to the end of 1997 amount to 0.007% of world electricity generating capacity!

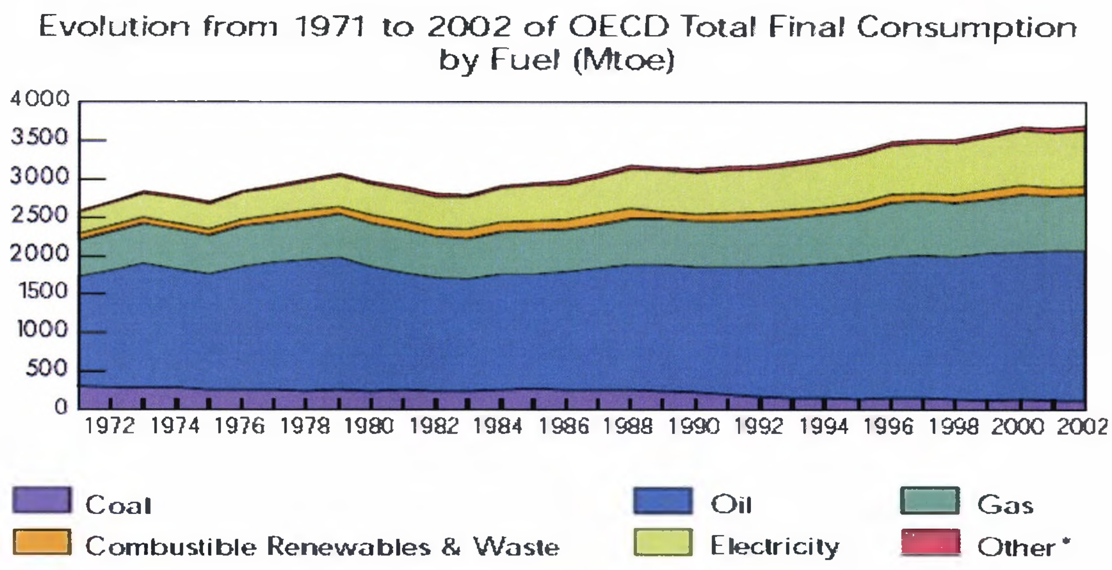


Figure 8.2: Total final consumption of OECD by fuel. [IEA1]

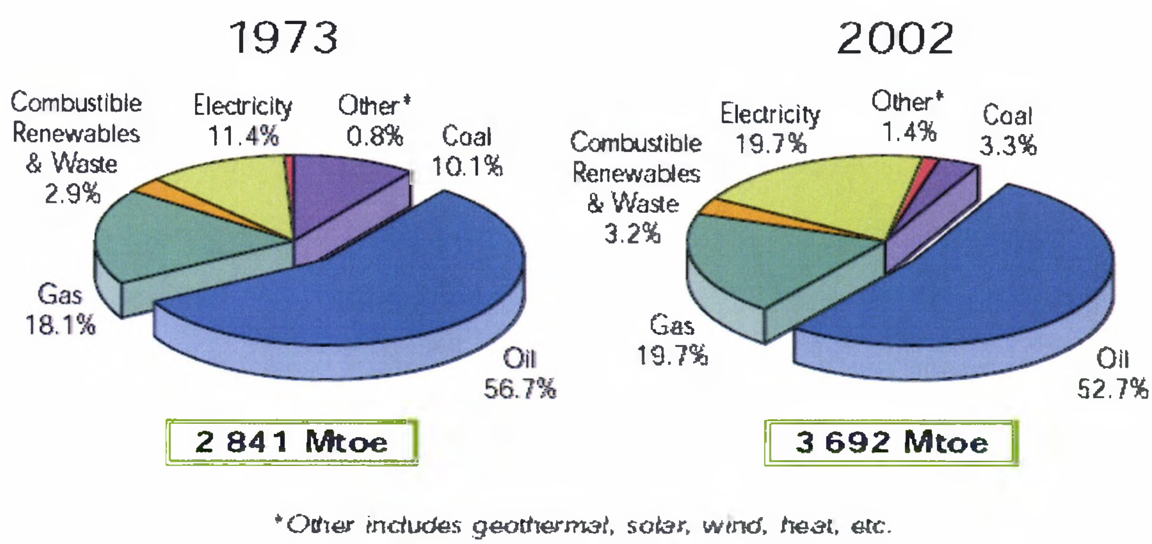


Figure 8.3: 1973 and 2002 OECD Fuel Shares of Total Final Consumption [IEA1].

Once again, there are considerable differences in the shares of these energy sources in the different regions. Not surprisingly, woodfuel predominates in the developing world. While woodfuels represent about 7% of primary energy consumption (about the same as nuclear), 76% of woodfuels are used in developing countries, where their share is 15%. In some individual countries the share exceeds 80%. By contrast, the lion's share of oil (63%) is consumed in the developed countries. The developed countries' share of gas consumption falls to 56% thanks to the relatively high use of gas in the CIS. With coal the developed country share falls still further to 46%, largely because of China, which is the world's biggest single consumer of coal. China uses some 20% more than the USA, the second biggest user. Of course, even here, the developed countries are the dominant consumers in per capita terms. [Mur]

It will probably not come as any surprise to the reader to learn that nuclear energy is, to an even greater extent, the preserve of the developed world. Around 83% of nuclear electricity is produced in a dozen developed countries. The remaining production is shared between Eastern Europe and the CIS (11%) and developing countries including China (6%). There are currently 430 reactors operating, amounting to 345 GW of installed generating capacity. [Mur]

8.2 Energy Crisis: A summary

"Energy is vital to a modern economy. We need energy to heat and light our homes, to help us travel and to power our businesses. Our economy has also benefited hugely from our country's resources of fossil fuels -coal, oil and gas. However, our energy system faces new challenges. Energy can no longer be thought of as a short-term domestic issue. Climate change –largely caused by burning fossil fuels - threatens major consequences in the UK and worldwide, most seriously for the poorest countries who are least able to cope. Our energy supplies will increasingly depend on imported gas and oil from Europe and beyond. At the same time, we need competitive markets to keep down costs and keep energy affordable for our businesses, industries, and households…."

Tony Blair (ENERGY WHITE PAPER Our energy future - creating a low carbon economy)

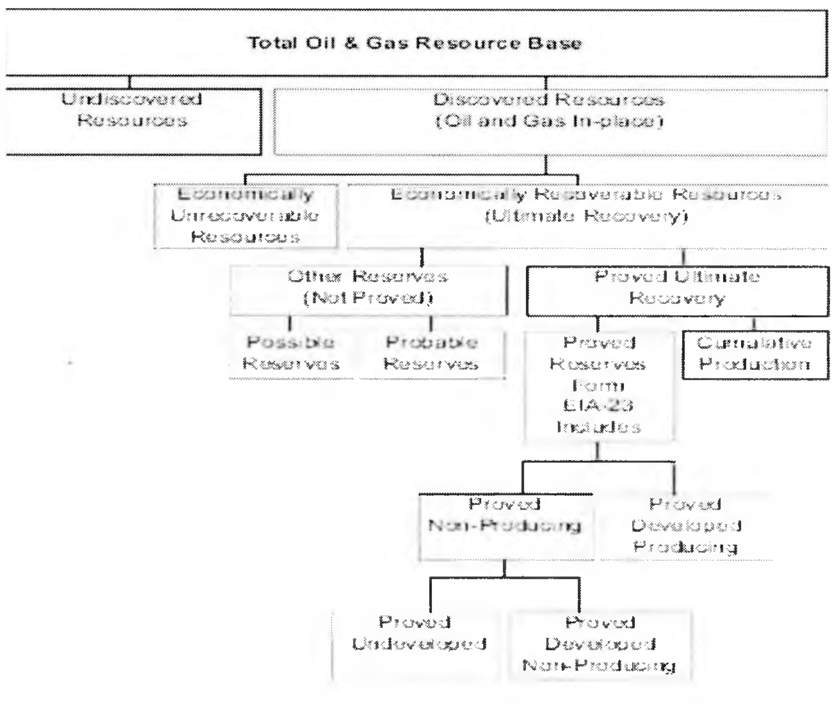
2004 was the second consecutive year of high growth in global energy markets. An upbeat world economy contributed to the strongest growth rate in global primary energy consumption since 1984. In 2004, consumption of all fuels grew at above 10-year average rates. This strength in turn pushed prices for oil, natural gas and coal to record (nominal) levels. [BP]

8.2.1 Resources coming to a deadlock

In the 1959 film of Jules Verne's 1864 novel "Journey to the centre of the Earth", James Mason and his companions found themselves sailing on a dark sea in a mighty cavern, miles down in the earth's crust. This was, of course, just science fiction, not science fact. Unfortunately, it is still a misconception that oil is found in such "caverns" forming black lakes deep beneath our feet. While such images may be romantic and wishful, reality is far more intricate. For the most part oil and gas are found in the microscopic pore spaces present between individual grains making up the rock. So not only do we need a rock that contains oil or gas but also the oil or gas must be trapped somehow ready for exploitation. [Mun]

Universally accepted definitions have not been developed for the many terms used by geologists, engineers, accountants and others to denote various components of overall oil and gas resources. In part, this is because most of these terms describe estimated and therefore uncertain, rather than measured, quantities. The lack of standardized terminology sometimes leads to inaccurate understanding of the meaning and/or import of estimates. Particularly common is an apparently widespread lack of understanding of the substantial difference between the terms "reserves" and "resources", as indicated by the frequent misuse of either term in place of the other. The total resource base of oil and gas is the entire volume formed and trapped in–place within the Earth before any production. The largest portion of this total resource base is nonrecoverable by current or foreseeable technology. Most of the nonrecoverable volume occurs at very low concentrations throughout the earth's crust and cannot be extracted short of mining the rock or the application of some other approach that would consume more energy than it produced. An additional portion of the total resource base cannot be recovered because currently available production techniques cannot extract all of the in–place oil and gas even when present in commercially viable concentrations. The inability to recover all of the in–place oil and gas from a producible deposit occurs because of unfavorable economics, intractable physical forces, or a combination of both. Recoverable resources, the subset of the total resource base that is of societal and economic interest, are defined so as to exclude these nonrecoverable portions of the total resource base [EIA1].

The structure presented in Figure 8.4 outlines the total resource base and its components. The total resource base first consists of the recoverable and nonrecoverable portions discussed above. The next level down divides recoverable resources into discovered and undiscovered segments. Discovered resources are further separated into cumulative (i.e., all past) production, and reserves. Reserves are additionally subdivided into proved reserves and "other reserves".



Source: Energy Information Administration, Office of Oil and Gas.

Figure 8.4: Components of the oil and gas resource base. [EIA1]

Giving an insight in the components of oil and gas resource base the Energy Information Administration [EIA1] gives the following definitions:

Discovered recoverable resources are those economically recoverable quantities of oil and gas for which specific locations are known. While the specific locations of estimated undiscovered recoverable resources are not yet known, they are believed to exist in geologically favorable settings. The USGS (United States Geological Survey) defines ***undiscovered recoverable conventional resources*** as those expected to be resident in accumulations of sufficient size and quality that they could be produced using conventional recovery technologies, without regard to present economic viability. Therefore, only part of the USGS undiscovered recoverable conventional resource is economically recoverable now.

In addition to ***cumulative production,*** which is the sum of current year production and the production in all prior years, estimates of discovered recoverable resources include estimates of reserves. Broadly, ***reserves*** are those volumes that are believed to be recoverable in the future from known deposits through the eventual application of present or anticipated technology.

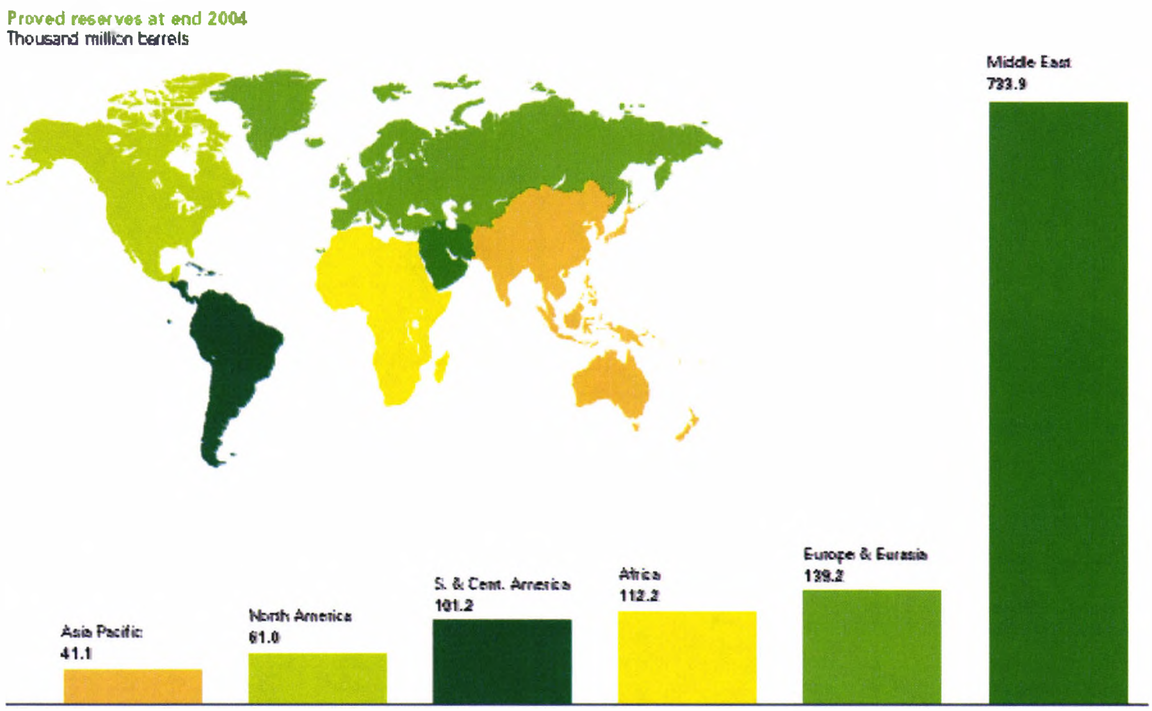


Figure 8.5: Proved reserves of oil at the end of 2004 [BP].

Some thoughts:

"There is strong evidence that World oil production has nearly reached its peak. When the rate at which it can be extracted peaks – in other words we are unable to increase World supplies – we will have to make do with less year-on-year." [Laug]

"Given that most fields decline at a rate of 5% per year, this means that given an additional 4.3 million barrel per day demand, and a decline of 4 million barrels, we need to find another Saudi Arabia in production IN THE NEXT 15 MONTHS!" [Laug]

"Hubbert's peak is at hand. It isn't tomorrow, or next week, but it is NOT 2015 or 2037. It is within the next couple of years." (Society of Exploration Geophysicists Oct 15 2004) [Laug]

"Will the world ever physically run out of crude oil? No, but only because it will eventually become very expensive in absence of lower-cost alternatives." [Wood]

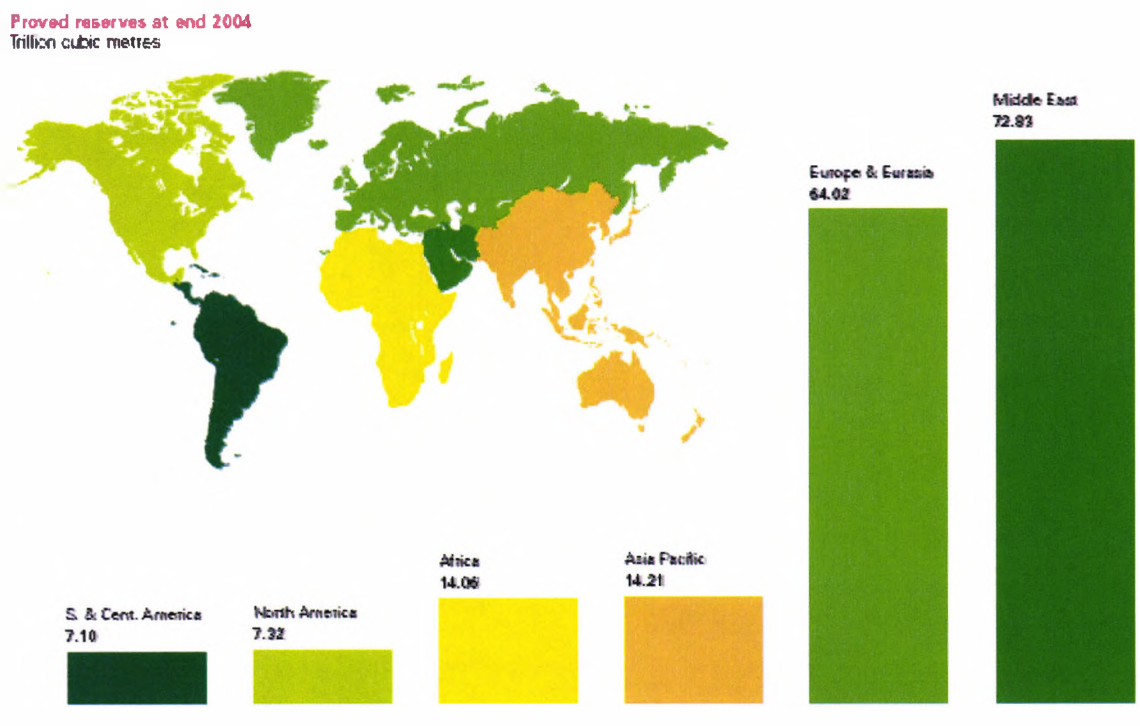


Figure 8.6: Proved reserves of natural gas at the end of 2004 [BP]

Some thoughts:

"Natural gas discoveries peaked in 1973 and we have burned 1/3 of the world's natural gas." [Laug]

"The Earth's energy resources are more than adequate to meet demand until 2030 and well beyond. Less certain is how much it will cost to extract them and deliver them to consumers. Fossil-fuel resources are, of course, finite, but we are far from exhausting them. The world is not running out of oil just yet. Most estimates of proven oil reserves are high enough to meet the cumulative world demand we project over the next three decades. Our analysis suggests that global production of conventional oil will not peak before 2030 if the necessary investments are made. Proven reserves of gas and coal are even more plentiful that those of oil." [WEO]

8.2.2 The Kyoto Protocol

To add up to the problem of resources-reserves comes the Kyoto agreement. One of the challenges that today's society is faced with is the environmental climate change. Levels of carbon dioxide (CO_2) in the atmosphere, one of the main causes of climate change, have risen by more than a third since the industrial revolution and are now rising faster than ever before. This has led to rising temperatures: over the 20th century, the earth warmed up by about 0.6°C largely due to increased greenhouse gas emissions from human activities. The 1990s were the warmest decade since records began.

The UNFCCC (United Nations Framework Convention on Climate Change) and its Kyoto Protocol demonstrate that it is possible to reach global agreement on action, but far more needs to be done. The Protocol contains legally binding emissions targets for Annex I Parties, requiring them to reduce their collective emissions of six key greenhouse gases 5 by at least 5.2% up to the period 2008-2012 (the "commitment period"), with the emissions being calculated as an average over the 5-year period. The six gases are to be combined in a "basket", with reductions in individual gases translated into "CO2 equivalents" that are added up to produce a single figure. The Protocol does not contain emissions targets for non-Annex I Parties. The global target for the Annex I group of countries is to be achieved through cuts of: 8% by Switzerland, most Central and East European states, and the European Union (the EU group target will be met by distributing different reductions among its member states); 7% by the USA; 6% by Canada, Hungary, Japan and Poland. Russia, New Zealand and the Ukraine are to stabilize their emissions at the 1990 levels, while Norway may increase emissions by up to 1%, Australia by up to 8%, and Iceland by up to 10%.

The new projections for CO2, combined with separate projections of other greenhouse gases, suggest that, with allowance for the impact of policies that have already been announced, the UK is broadly on course to meet its Kyoto commitment for the period 2008-12. The domestic goal to reduce emissions of CO2 alone by 20% is more challenging. The projections suggest that on existing policies, prior to consideration of new measures within the Climate Change Programme, CO2 emissions will be around 19 million tonnes of carbon above the domestic goal in 2010. [En.F]

The reduction in CO2 from now to about 2005 to 2010 reflects mainly a reduction in emissions from the power generation sector. It is associated with a continued shift into generation from gas. Emissions from other sectors generally increase – most strongly from road transport and the domestic sector. Beyond around 2005 to 2010 growth from these sectors, combined with reducing scope for reductions in emissions from generation, mean that overall CO2 emissions for the UK resume an upward path. In 2020 CO2 emissions are projected to be 4-7% above the level projected for 2010. [En.F]

What the Kyoto agreement suggests in fuels use is that somehow the energy sources must be efficient and sustainable enough to power the world without them being a carcinoma for the environment. While this seems like a fair and logical argument one stops to ponder the "technicalities" of taking on such a huge challenge. This action entails:

- the reduction of use of fossil fuels-since those have more emissions (this action can not go forward if there is no other energy source to balance this reduction)

- **or** the use of new technologies to produce maximum power with minimum emissions (which means that these new technologies should be already something feasible and not only found in the state of proposals or laboratories, due to the urgency of the protocol-clean coal and fuel cell technologies are "here" but their appearance will not be noticed until later this century)
- **or** increase the output power of renewables to an amount that can be considered of real importance towards the overall output (a quite unrealistic action with today's technologies-wind, which is considered the most valuable of renewables can only produce 7% towards the overall energy production)
- **or** not abandon the option of nuclear power (UK and Northern Ireland have 22 nuclear reactors that are already shut down, 23 operational but with dates to be shut down in the next decade or so-the government understand the importance of nuclear for the future as well as acknowledge the "general disapproval" for nuclear and thus in the Energy White Paper Our energy future - creating a low carbon economy have kept the option of nuclear *open*)

"We have got to start from the brutal honesty about the politics of how we deal with it. The truth is no country is going to cut its growth or consumption substantially in the light of a long-term environmental problem. To be honest, I don't think people are going, at least in the short term, to start negotiating another major treaty like Kyoto."

Mr. Tony Blair (international meeting in New York, Sunday Times 25th of September 2005)

(The prime minister's comments were made on September 15 at the Clinton Global Initiative, hosted by the former American president at the Sheraton New York hotel. In his comments, Mr. Blair suggested he no longer had faith in global agreements as a way of reversing rising greenhouse gas emissions. **Instead he appeared to place his faith in science, technology and the free market — a position that President George W Bush adopted when he repudiated the Kyoto treaty in 2001**.)

8.2.3 Sustainable Energy

The term *sustainability* originally applied to natural resource situations, where the long term was the focus. Today, it applies to many disciplines, including economic development, environment, food production, energy, and lifestyle. Sustainability refers to doing something with the long term in mind, the ability to provide for the needs of the world's current population without damaging the ability of future generations to provide for themselves. When a process is sustainable, it can be carried out over and over without negative environmental effects or impossibly high costs to anyone involved [Sust].

Until the last ten or twenty years sustainable energy was thought of simply in terms of availability relative to the rate of use. Today, in the context of the ethical framework of sustainable development, other aspects are equally important. These include environmental effects and the question of wastes, even if they have no environmental effect. Safety is also an issue, as well as the broad and indefinite aspect of maximising the options available to future generations [UIC1].

There are many who see no realistic alternative to pushing Sustainable Development criteria into the front line of energy policy. In the light of concerns about global warming due to human enhancement of the greenhouse effect, there is clearly growing concern about how we address energy needs on a sustainable basis [UIC1]:

Energy demand

A number of factors are indisputable. The world's population will continue to grow for several decades at least. Energy demand is likely to increase even faster, and the proportion supplied by electricity will also grow faster still. The key question is how we generate that electricity. Today, worldwide, 64% comes from fossil fuels, 16% from nuclear fission and 19% from hydro, with very little from other renewables. There is no prospect that we can do without any of these.

Sources of energy

Harnessing renewable energy such as wind and solar is an appropriate first consideration in sustainable development, because apart from constructing the plant, there is no depletion of mineral resources and no direct air or water pollution. In contrast to the situation even few decades ago, we now have the technology to access wind on a significant scale, for electricity. But harnessing these "free" sources cannot be the only option. Renewable sources other than hydro - notably wind and solar, are diffuse, intermittent, and unreliable by nature of their occurrence. Similarly, bad weather and night-time underline its short-term unreliability. These two aspects offer a technological challenge of some magnitude. It requires collecting energy at a peak density of about 1 kilowatt (kW) per square metre when the sun is shining to satisfy a quite different kind of electricity demand, - one which requires a relatively continuous supply.

Wind is the fastest-growing source of electricity in many countries, albeit from a low base, and there is a lot of scope for further expansion. While it has been exciting to see the rapid expansion of wind turbines in many countries, capacity is seldom more than 30% utilised over the course of a year, which testifies to the unreliability of the source and the fact that it does not and cannot match the pattern of demand. The rapid expansion of wind farms is helped considerably by generous government-mandated grants, subsidies and other arrangements ultimately paid by consumers. But there is often a strong groundswell of opposition on aesthetic grounds from the countryside where the turbines are located.

The criteria for any acceptable energy supply will continue to be cost and safety, as well as environmental considerations. Addressing environmental effects usually has cost implications, as the current greenhouse debate makes clear. Supplying low cost electricity with acceptable safety and low environmental impact will depend substantially on developing and deploying reasonably sophisticated technology.

The Hydrogen economy

Hydrogen is expected to come into great demand as a transport fuel which does not contribute to global warming. It may be used in fuel cells to produce electricity or directly in internal combustion motors. Fuel cells are at an early stage of technological development and still require substantial, research and development input, although they will be an important technology in the future.

Hydrogen may be provided by steam reforming of natural gas (in which case CO_2 has to be taken into account), by electrolysis of water, or by thermochemical processes using nuclear heat. Large-scale use of electrolysis would mean a considerable increase in electricity demand. However, this need not be continuous base-load supply, as hydrogen can be accumulated and stored, and solar or wind generation may well serve this purpose better than supplying consumer electricity demand.

Wastes

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

Energy security

From a national perspective, the security of future energy supplies is a major factor in assessing their sustainability. Whenever objective assessment is made of national or regional energy policies, security is a priority. France's decision in 1974 to expand dramatically its use of nuclear energy was driven primarily by considerations of energy security. However, the economic virtues have since become more prominent. The EU Green Paper on energy security in 2000 put forward coal, nuclear energy and renewables as three pillars of future energy security for Europe.