CHAPTER 2

Introduction: Uncertainties in Power Generation

2.1 Introduction

This chapter explains the title of this thesis, motivation and description of the research problem, definition of the main terms and issues, and the overall agenda for the rest of the thesis. Beginning with the importance of electricity (section 2.2), this chapter introduces the structure of the industry (section 2.3) and background developments (section 2.4) that have led to the current emphasis on uncertainties. "Capacity planning" is defined in section 2.5. "Uncertainty" is defined and classified in section 2.6. Difficulties in capacity planning are then reviewed with respect to major areas or sources of uncertainty in section 2.7. The final section (2.8) discusses the use of such an extensive classification of uncertainties.

2.2 Electricity

Electricity consumption is growing faster than other energy sectors in industrialised economies (Price, 1990). 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 and borne 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 our economy. The growing number of labour-saving devices powered by electricity is another reason for our increasing dependence. We expect the electricity supply to be reliable, i.e. available when we need it, and affordable. These requirements are summarised in the words of Allan and Billington (1992, page 121): "the primary technical function of a power system is to provide electrical energy to its customers as economically as possible with an acceptable degree of continuity and quality, known as reliability."

Traditionally, centralised regulation of the electricity supply industry was considered necessary to ensure security of supply and efficiency of production. Efficiency was achieved through economies of scale. However, many countries have since restructured and deregulated their ESI to introduce competition, which was believed to improve cost efficiency, increase diversity of fuel supply, and provide additional benefits to the consumer.

In the UK, recent privatisation of public sector companies have changed the priorities of the industry and introduced new responsibilities. Companies are now concerned about profitability and maintaining a competitive edge. No longer a public sector monopoly, a private firm cannot rely on a guaranteed market or government funding. The new utilities must consider the interests of all stakeholders, the higher cost of capital, and competitive forces that did not exist before.

2.3 Industry Structure

The business of providing electricity is characterised by four independent but related functions: generation, transmission, distribution, and supply. Generation and transmission are wholesale functions while distribution and supply are predominantly retail functions. Transmission is a natural monopoly given the high fixed costs of transmission lines. Distribution is transmission at the retail level, i.e. delivery to final end-users. Supply consists of metering, maintenance, billing, and revenue-collection.

Responsibilities in the electricity supply industry vary from country to country according to the degree of deregulation and vertical integration. In Europe, for instance, it ranges from the nationalised French industry to the very fragmented private ownership in the Netherlands and Germany. The industry structure partly determines the limitations and opportunities open to power generation.

2.3.1 The Privatised UK Electricity Supply Industry

STRUCTURE OF ENGLAND AND WALES

Privatisation was possible in the UK because of favourable conditions such as political stability, total state ownership, over-capacity (removing the immediate risk of power shortages), low indebtedness (with little plant built since 1979 to the time of privatisation), and relatively high efficiency (due to the integrated grid system). Before 1990, electricity in the England and Wales was generated and transmitted by the Central Electricity Generating Board (CEGB), a monopoly wholly owned by the government, and, as a result, was able to make long-term investment decisions for the whole country. The twelve regional area boards then distributed and supplied the electricity to their respective locally monopolised geographical sectors.

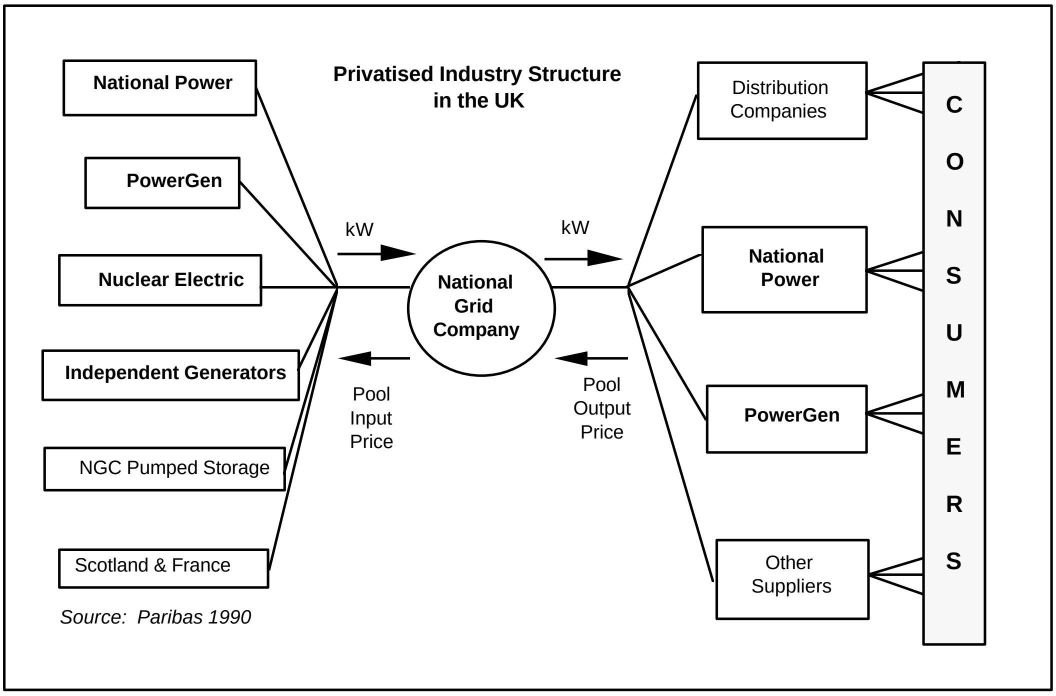
In 1990-1991, the UK ESI was restructured considerably and privatised with great emphasis on competition in generation through vertical dis-integration. The single vertically integrated public utility CEGB was split and its assets sold to the private sector as two generating companies National Power and PowerGen and twelve regional electricity companies (RECs.) The nuclear assets were transferred to a newly formed public sector company Nuclear Electric. The responsibilities for generation were separated from that of transmission and supply. An independent regulator, Office of Electricity Regulation (OFFER), was set up to look after the restructured industry. Table 2.1 and Figure 2.1 illustrate the new structure in England and Wales. Further details on the structure, organisation, and operation of this market are given in Williams (1990), EA (1992), Energy Committee (1992), and Hunt and Shuttleworth (1993).

Table 2.1 Privatised Structure in England and Wales

Function (estimated proportion of price to consumer*)	**Description**	**Players**
Generation (65%)	the manufacture of electricity and its sale to the electricity spot market, also known as the pool, or by contracting with large users and RECs	• National Power • Power Gen • Nuclear Power • Independent power producers (including the 12 RECs, see below) • Imports from Scotland and France via the "link"
Transmission (10%)	the bulk transportation of electricity on a national scale	• National Grid Company
Distribution (20%)	the local transportation of electricity and delivery to the individual consumers	• 12 Regional Electricity Companies (RECs)
Supply (5%)	the purchase of electricity from the pool and its sale to consumers	• generation companies (direct supply to large consumers) • RECs

Source: Williams (1990) **June 1990 estimates*

Figure 2.1 Privatised Industry Structure in the UK



After privatisation and deregulation, the new companies are commercially oriented and their responsibilities governed by contractual relationships. The obligation to serve is no longer a statutory requirement but rather a contractual one, as reflected in the supply contracts between the end-users and the distribution companies, the short-term and long-term contracts between the generators and the distributors, contracts between the National Grid Company (NGC) and the generators, contracts between the NGC and the distributors, direct sales contracts, and implied contracts with all classes of consumers. The Regulator and the NGC, rather than generators, are responsible for the reliability of the system and security of supply. The incentive to invest is contained in the wholesale pricing formula which determines the price at which electricity is traded.

THE POWER POOL

The NGC was set up to look after the operation of the bulk transmission system as well as to administer the trading of electricity through the daily power pool. The daily power pool is intended to serve three purposes. First, it determines which generating stations are run, based on bid prices rather than the former merit order ranking of costs. Secondly, the mechanics of the pool determine the cost and price of electricity traded. Finally, the pool exists to ensure that sufficient generating capacity is provided to maintain security of supply in the long-term. By means of “signals” to existing and potential generators in the form of large or small capacity credits, these financial incentives encourage generators to plan for additional capacity. Effectively, these signals supplement the traditional use of long-term demand forecasting.

The half-hourly spot market for electricity was designed to cope with the non-storability of electricity. Therefore it is run for every single day of the year. Generators tell the NGC how much electricity each of their generating units can provide and their bid prices for each half-hour period for the next day. The NGC ranks the stations in order of bid prices and selects the cheapest to meet the estimated demand per half hour.

The NGC produces three different schedules (unconstrained, operational, and out-turn) for all power stations called to run. The unconstrained schedule ranks all power stations according to ascending order of their offer prices and descending order of plant availabilities with respect to forecasted demand. This schedule is used to calculate the System Marginal Price (SMP). After taking into account transmission constraints and inflexible plant, the NGC modifies this schedule into an operational one. Since bidding occurs the day before generation, actual electricity demand and plant availability may *turn out* differently from expected. The actual order of plants called to run is the out-turn schedule. The out-turn availability is used if it is less than the declared availability in the calculation of the Pool Input Price for the generator.

The 24 hour market is governed by the fluctuations of Pool Input Price (PIP) also known as the Pool Purchase Price (PPP) and the Pool Output Price (POP) also known as the Pool Selling Price (PSP). The PIP is recalculated every half hour to reflect the changing cost of generation with the fluctuation of demand. All sellers of electricity receive the same PIP per unit of electricity, which is expressed in pence per kilowatt hour. Likewise, the buyers of electricity purchase at the current POP value. The difference between the PIP and the POP consists of a charge, called the uplift, which covers all additional costs of keeping reserve power on line, plant availability, forecasting errors, transmission constraints, and ancillary services. The size of the uplift varies through out the day but is typically around 6% of the total pool price.

There are two components of the PIP which reflect the cost of energy production (energy credit) and the provision of capacity (capacity credit). The cost of energy production, SMP, reflects the running costs of electricity generation. Intended to cover the generator's investment costs, there is a "capacity payment" equal to LOLP * (VOLL - SMP), where LOLP is the loss of load probability, VOLL the value of loss of load, and SMP the system marginal price. The price formulae for PIP and POP are as follows:

PIP = SMP + capacity payment

POP = SMP + capacity payment + uplift.

These parameters are calculated by the NGC. The schedule of plants and SMPs also indicate the level of market activity.

The LOLP is the probability within any half hour of demand exceeding available generating capacity. It accounts for demand uncertainty and the probabilistic reliability of individual plants in meeting the load as planned. It reflects the balance of supply and demand. For any half hour, if demand is significantly higher than available capacity, LOLP will be high. LOLP will be higher during the winter peak than the summer trough. LOLP is intended to give the incentive to invest in future plant capacity.

VOLL (or VLL) is the price that pool members have to pay to ensure that no supply is lost. This has been initially set at £2/kWh. VOLL is closely related to the planning margin. Excess capacity causes planning margins to rise. To reduce the margins, the NGC can set a lower VOLL so that capacity credit will be low even if LOLP is high at certain times, thereby discouraging new capacity investment. Similarly, a high VOLL provides an incentive to invest in new capacity. Unlike in the former CEGB days, the planning margin is not pre-determined but market dependent.

The SMP is the offer price of the most expensive station in operation in each half hour, expressed in pence/kWh. Power stations that are bid into the operational schedule will receive the SMP. The difference between this SMP and its own marginal cost of production is the profit. To maximise profit on energy credits, a utility will bid as many power stations into the merit order as it can while keeping down costs of generation. To remain profitable, a generator's marginal cost of production should be lower than the SMP. The merit order is also determined by plant characteristics such as black-start capability, load following, and geographic location.

While it was intended for the "bulk" of trading to be transacted through the pool, initially buyers and sellers actually entered into "contracts for differences" to reduce the exposure to pool price volatility. The risk averse attitude that prevails in an unfamiliar business environment drives the buyers and sellers of electricity to enter into these contracts which effectively stabilise the price of electricity for both parties. In the first year of privatisation, 95% of all electricity supply was covered by such contracts so that less than 5% of electricity was actually "traded" through the pool. "Back-to-back" contracts can also provide the necessary security to raise funds for independent power producers if gas supplies are similarly hedged by long-term contract. In the direct sales market, generation companies have direct contracts with large industrial consumers. The ancillary services market is beginning to enable generators to sell products generally associated with facilitating electricity supply, such as keeping plant on standby to start at short notice.

STATE OF THE INDUSTRY

The following summarises the state of the UK ESI four years after privatisation (Reuters, May 1994.) The market shares of the two major generators (duopolists) National Power and PowerGen have fallen from a total of 73% at vesting to 61% due to the entry of independent power producers, who own a total of 3,225 MW of new CCGT plant. The total capacity ratio of National Power and PowerGen has stayed at roughly two to one (40%: 22%). Nuclear Electric's market share has increased to 25%. Behaving like wholesale companies, the generation companies have found lucrative business in supplying large energy consumers through direct sales, thus taking business from the distribution companies. On the other hand, any of the distribution companies (RECs) can generate up to 20% of their power needs and sell it through the grid. They are keen to purchase electricity more cheaply, reduce business risk, promote competition in generation, and produce profits in their own right. Likewise, non-energy producers can generate electricity for their own use, provided they have a licence or exemption as stipulated by the Electricity Act 1989. Deregulation has paved the way for more diverse solutions and alternative ways of doing business.

While the effects of privatisation are still being felt, some obvious concerns face the UK industry today: public awareness of the environment, the cost of cleaning up, fuel switching from coal to gas, new entrants to the market, electricity trade in the EC, potential over-capacity, and the future of nuclear power. The definition of economic plant now includes greater consideration for the environment and thermal efficiency as well as shorter lead-time and modular units. While it was intended that competition leads to greater efficiency and security by diversity of supply (or suppliers) and greater sensitivity to changing markets (Grimston, 1993), privatisation has also introduced considerable market uncertainties and higher cost of capital. In their analysis of the UK market structure, Vickers and Yarrow (1991) identify several sources of possible problems for potential market failure: the non-storability of the product (electricity) coupled with fluctuating levels of demand; vertical coordination among generation, transmission, distribution, and supply to final customers; dependence of supply on the maintenance of electrical equilibrium in the network; industry's capital intensity and level of sunk costs, investment lead times and short run capacity constraints; natural monopoly conditions in transmission and distribution; and major environmental externalities. Since 1991, a number of new issues have surfaced: over-contracting for new gas plants, protective contracts for British Coal, instability of the LOLP and the "capacity payment system." In an industry involving long-term investments and long-term fuel supply contracts, it remains to be seen how such long-term decisions can be driven by the short-term bid prices. The fact that only a portion of all electricity is actually traded through the pool gives an element of artificiality about the pool prices that is unsettling for customers and generators. Furthermore, the pool is only half a market, that is, supply-side bidding only. These weaknesses and potential problems reflect market and regulatory uncertainties that have to be managed through the intervention of the Regulator.

2.3.2 ESI of Other Countries

There are currently three types of ESI structures in the world: unitary integrated state-owned system, mixed dominant state incumbent systems, and decentralised mixed ownership system. The degree of fragmentation and competition in the electricity supply industry varies greatly from country to country. Table 2.2 shows the industry structures of six high electricity consumption countries.

Table 2.2 Comparison of Industry Structures

Source: Paribas (1990)	**UK**	**France**	**W.Germany**	**USA**	**Spain**	**Japan**
Privatised?	yes	no	yes	yes	yes	yes
Vertically-Integrated companies?	no*	yes	yes	yes	yes**	yes
Pool system?	yes	no	yes	several	yes	no
Competition in generation?	yes	no	yes	yes***	yes	some
Fragmentation?	average	little	highly	highly	average	average
Regulation style	RPI-X	n/a	fixed tariff	Return on Equity	fixed tariff	fixed tariff

* except Scotland ** except ENDESA *** depends on region

In a vertically integrated industry, demand-side management is promoted as an alternative to supply-side planning. Options such as time of use pricing, interruptible supply, and real time pricing are designed to change consumer's utilisation behaviour so that the utilities can better manage load distribution. These demand-side alternatives along with energy efficiency practices appeal to American utilities who may generate and import power as well as supply to the end-user. With separate ownership of and responsibility for generation and distribution, the UK companies do not have such incentives and run the risk of over-capacity.

In the US, the price of electricity is monitored by regulatory agencies and consumer bodies. Operating a rate-of-return regulation, the regulators ensure a fair return to investors. In the UK, the price of electricity is governed by competitive forces in the electricity market, with the independent regulator OFFER acting as the watchdog for the industry. The merit order dispatch principle, where power stations are scheduled to generate electricity in order of lowest operating cost, still applies. However, unlike the US and most other countries where the merit order is based on cost, the National Grid Company sets out the order based on the cheapest offer price quoted in the UK spot market.

The imbalance of electricity needs in Europe is one reason for the cross border trade in electricity. Excess generation capacity makes France a net exporter of electricity, to Germany which faces a high cost of domestic power and to Italy a shortage of capacity. The UK buys electricity from France through the cross-channel link. The transitions of the economies of Eastern and Central Europe offer potentially more opportunities for trade. In theory, the European Commission would like to see the industry broken up in each country into a generating sector, a supply sector, and a transmission sector, the latter being open to third-party access. However, complex issues such as ownership of the grid and legislative mechanisms have to be ironed out, not least to alleviate opposition from member countries and special interest groups. The growing number of privatisations[1] around the world support the relevance of this thesis. Electricity supply industries in other countries are described in Helm and McGowan (1989) and Joskow and Schmalensee (1983).

2.4 Background Developments

History suggests that we are more capable of reacting to and dealing with short-term uncertainties than long-term ones (Senge, 1990.) Indeed, gradual changes over a long period of time seem to have less impact than sudden changes. While we may react immediately to a price spike, we seldom react to slow and minor increases in price. Similarly, while we may be aware of the the hazards of pollution, as long as we are healthy we are not too concerned. We run the risk of being too reactive to short-term events and too inert to long-term trends. The history of power generation is full of such tales, and these have determined the attitudes that power companies have taken to capacity planning and uncertainty.

Before the oil shock of the 1970's, fuel prices and electricity demand were relatively stable and predictable. For planning purposes, demand was easily forecast by trend analysis using compounded rates of past growth. There was no reason to expect the future to depart from this stable pattern.

In 1973 and 1974, oil prices quadrupled and led to unprecedented leaps in related fuel prices. The resulting energy crisis combined with the effects of a world-wide recession led to a down-trend in electricity demand. Scheduled investments and installations in new capacity, which had been planned in anticipation of continued growth in demand, had to be cancelled or postponed. Short-term measures, such

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1 During the period from February to August 1994, the following countries have privatised, started privatising, or announced intentions of privatising full or parts of their electricity supply industries: Argentina, Australia, Austria, Brazil, Canada, Chile, Congo, Czech Republic, Germany, Hungary, India, Indonesia, Italy, Kuwait, Mexico, Morocco, New Zealand, Pakistan, Peru, Portugal, Slovakia, Spain, Sweden, and Thailand. (Reuters, 1994)

as cutting back by cancelling new orders or deferring construction, were costly to cope with deviations from predictions. Over-supply in the 1970's led to caution in the 1980's. Henderson et al (1988) outline the historic trends in capacity and load and the resulting problems faced by some of the utilities in the US at the time.

Another disruption to the stable scene was the series of nuclear accidents which led to a dramatic cancellation of new orders and cast serious doubt on the future of nuclear power. The Three-Mile Island accident and the Chernobyl disaster caused negative public reaction and government response. Public concern for health and safety rose above the minimum cost objective of capacity planning. The promise of cheap electricity from nuclear power was questioned as countries like Sweden put a moratorium on their nuclear programme. The anti-nuclear sentiment was partly a result of the influential green movement that originated in the United States and Germany. Special interest groups such as Greenpeace and Friends of the Earth voiced their disapproval of nuclear power and actively campaigned for legislative action. Detailed historic accounts of environmental and anti-nuclear movements are given in Holmes (1987) and Price (1990).

Meanwhile, scientific evidence of global warming and ozone depletion brought attention to the environmental aspects of power generation, especially the consequences of fossil-fuel burning. These environmental concerns have been voiced at national and international levels. International collaboration led to the 1987 Montreal Protocol on chlorofluorocarbons (CFC) production controls for the protection of the ozone layer, the 1988 Toronto Treaty on the reduction of carbon dioxide emissions, and the 1992 Rio Summit on global environmental concerns. As emission limits are being discussed at the global level, individual countries are translating the targets into national legislation. Talk of carbon tax and emissions trading permits, for example, has made coal-fired plants potentially less competitive. Squeezed from both sides by the hazards of nuclear and the adverse environmental effects of fossil fuels, companies are turning to other forms of energy.

Environmental legislation in the form of emission limits and fuel taxes favours cleaner and more efficient plant. 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 Magnox 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 high availability of cheap gas from the North Sea and the new 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. In addition, both extra capacity in Scotland and cheap electricity from France threaten potential over-capacity in England and Wales. The industry has responded with announcements of early closure of uneconomic plant and cancellation of new projects.

2.5 Capacity Planning

Capacity planning has always been necessary because of long lead times and other characteristics of the power generation business. Traditionally, such planning was mainly undertaken to ensure sufficient capacity to meet future demand. It is even more important now to anticipate and prepare for surprises. For example, ten years ago, there was no uncertainty surrounding the "cost of capital", which was set at 5% in the UK public sector. However, in the run up to privatisation it became a big issue. The companies are now "at risk" of business failure and indeed hostile take-overs in a way that the CEGB was not.

In times of growth, capacity planning is also known as capacity expansion planning. Planning to determine the right level of capacity to have at any time is necessary for the replacement of retiring, uneconomic, or unfavourable plant. In the UK, a number of uneconomic and environmentally unfriendly plant have been retired prematurely or sold in favour of new gas-fired plant.

Capacity planning in the electricity supply industry is largely governed by three types of decisions about power plant investment: 1) what to build (choice and mix of technology), 2) how much to build (capacity), and 3) when to build (timing and sequencing). The choice of technology depends upon available technologies, their performance levels, expected operating lives, construction time and cost, fuel cost, and other external factors. How much and when to build depend on demand projections, existing capacity, and the retirement schedule. Combined together, the three decisions constitute what is otherwise known as power system expansion planning, which is defined by the International Atomic Energy Agency (IAEA, 1984) as "the process of analysing, evaluating, and recommending what new facilities and equipment must be added to the power system in order to replace worn-out facilities and equipment and to meet the changing demand for electricity."

The resulting schedule of investment decisions indicates the dates for installing new capacity and the dates for retiring old plants over a period of forty to fifty years. In capacity planning, it is often required to focus on specific issues and decisions, such as making a choice between a known technology as opposed to a new one, evaluating the costs and benefits of over- and under-capacity, and assessing whether or not to invest in anticipation of regulatory changes.

Changing business environments have shifted the planning emphasis over the years, leading to the development of more suitable planning methods, e.g. table 2.3 for the US. The techniques used for planning purposes have evolved with the needs of the industry. The dramatic restructuring of the UK ESI implies a similar evolution.

Table 2.3 Evolution of Electricity Planning in the USA

Time Period	Business Environment: Supply	Business Environment: Markets	Business Environment: Regulation	Planning Emphasis	Planning Method
Before 1960's	Declining cost	Strong growth	Favourable and stable	Supply reliability; Revenue requirement minimisation	Optimisation; Probabilistic analysis of production
1960's - 1970's	Gradual cost increase	Continued growth	Emerging environmental concerns	Economic, reliability and environment trade-offs	Cost-benefit analysis of capacity planning margin
1970's - 1980's	Sharp cost increases	Slowdown	Conservation and PURPA*	Demand-side and renewable options; Risk management	Integrated resource planning; Decision analysis
1990's and beyond	High and uncertain cost; Adoption of information technologies	Moderate growth; Increasing heterogeneity and uncertainty	Increasing competition; Changing structure; Global environmental concerns	Enhancing value of utility services and business to shareholders, customers, and the public-at-large; Transaction-based resource options	"Integrated value-based planning"

Source: Yu and Chao (1989) *Public Utility Regulatory Policies Act 1978

The traditional approach to capacity planning under uncertainty has been that of fitting plans to forecasts. As described in Nicholson (1971) and others in Chapter 3, this modelling approach primarily consists of running an optimisation algorithm against a forecast of future electricity demand and fuel supply. Accurate, reliable forecasts of demand and timely delivery of supply are needed otherwise costly consequences such as rationing, forced interruptions of power supply, and possible import of expensive foreign fuel result. On the other hand, over-estimates of demand and over-capacity tie up capital. The cost of investment must be spread over less output, resulting in higher unit costs. As a result of these uncertainties, the effects of over- and under-investment are much greater. [See Munasinghe 1990, Ford and Yabroff 1980.]

A compromise has to be made somewhere as accurate forecasting is now far more difficult than before. Historic accounts of forecasts based on proven methods demonstrate their inability to predict shocks to the system and the resulting impacts. In the absence of an ability to hold "stocks" of electricity, one way to ensure the security of supply is to keep a reserve margin. This excess of installed capacity is required to cater for unexpected peaks in demand. The installed capacity must be greater than expected peak capacity to cater for planned maintenance of plants as well as to cover unforeseen plant breakdowns and variations in peak demand. Since capacity decisions have to be made years in advance, the reserve margin is intended to close the gap between actual and forecast peak demand. More sophisticated approaches (Eden et al, 1981) use probabilistic concepts such as loss of load probability and expected unserved energy.

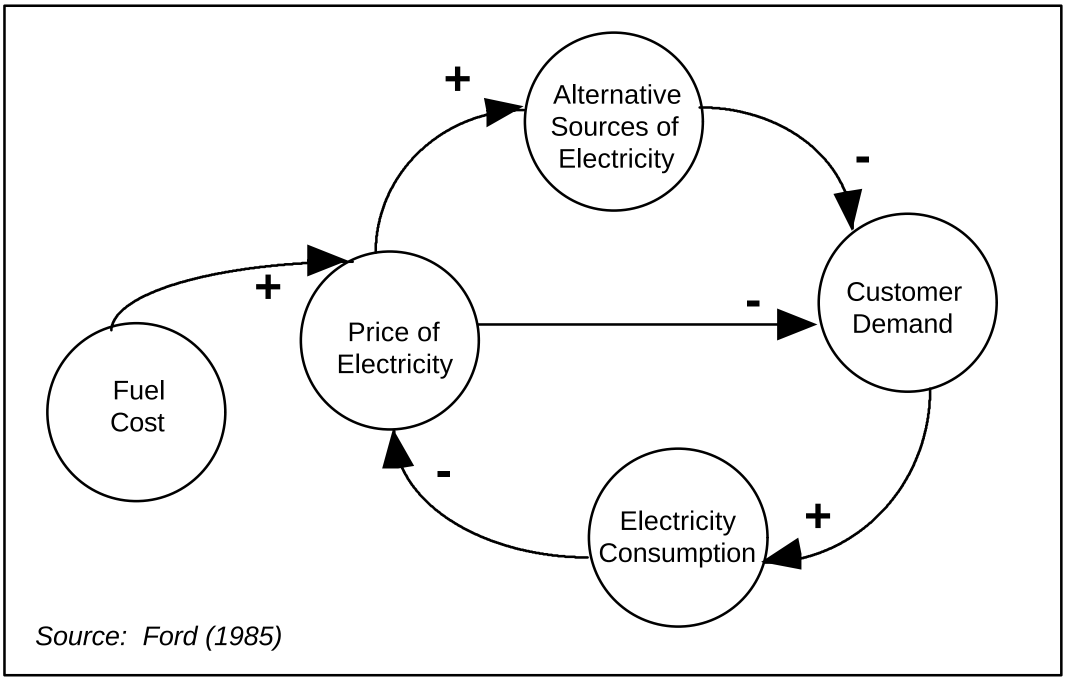
2.6 "Uncertainty" and Types of Uncertainty

Uncertainties are the reasons why planning is difficult and why plans are not optimal (Dowlatabadi and Toman, 1990). Others view the acute areas of uncertainty as being floating exchange rates, changing social and political values, growing environmental awareness, government regulation, technological change, pollution control regulation, energy cost, and raw material availability. Volatility and instability of fuel prices lead to more uncertainties. The complex interactions between different sources of uncertainty require multi-disciplinary considerations (Berrie and McGlade 1991 and Merrill et al 1982), such as engineering, environmental, economic, and political trade-offs.

It is important to identify and understand uncertainties, especially the major ones, because they have potentially negative consequences. Too much or too little capacity translates to higher costs, as over investment raises electricity prices and under investment risks black-outs. Based on the information available today, companies may invest in technologies which under-perform tomorrow due to the changing circumstances caused by new fuel supplies and new competitive technologies.

It is also necessary to evaluate the relationships between various sources of uncertainty as they may lead to further uncertainty and undesirable effects. For example, Ford (1985) has identified a “spiral of impossibility” in figure 2.2, where the plus signs indicate a positive relationship. As higher prices discourage demand, a utility’s capital costs must be spread over a smaller number of kilowatt hours which in turn leads to still higher prices, inducing a loss of customers. Some of them turn to building their own power plants; others switch to alternative forms of energy.

Figure 2.2 Spiral of Impossibility



To clarify the meaning of "uncertainty," we discuss the literature definition and view of uncertainty. Then we list different "types" of uncertainty as viewed from the literature. We distinguish between "types" and "areas" of uncertainty, which parallel closely with Morgan and Henrion's (1992) distinction between types and sources of uncertainty. Sources of uncertainty refer to the areas or variables which are unknown or uncertain, while types of uncertainty refer to the nature, characteristic, or extent of uncertainty itself. Types of uncertainty give insight to the modelling treatment, i.e. "how to model", while areas of uncertainty give insight to the variables that must be included, i.e. "what to model." Finally, to summarise the above, we give our interpretation of uncertainty and classifications, for the context of this thesis.

LITERATURE DEFINITIONS

"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, although it is not necessarily the "unknow-able." 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. Schweppe et al (1989) define uncertainties as quantities or events that are beyond the decision maker's foreknowledge or control. Paraskevopolous et al (1991) attribute the origins of uncertainties to errors in specification, statistical estimation of relationships, and assumptions of exogenous variables. 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 sometimes refers to randomness in nature or variability in data.

In the literature, "uncertainty" and "risk" are often used interchangeably. Knight (1921) was the first to distinguish between measurable risk and unmeasurable uncertainty. Strangert (1977, p. 35) 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." Strangert's concept of pure uncertainty was introduced around 1950 where different outcomes are stated without reference to probabilities. Building upon Knight's definitions, Barbier and Pearce (1990) note that risk denotes broadly quantifiable probabilities while uncertainty refers to contexts in which probabilities are not known. Hertz and Thomas (1984) 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 about all elements of the problem structure. Chapman and Cooper (1983) consider risk to be the undesirable implication of uncertainty. Risk may also tend to focus on just bad outcomes, i.e., what can go wrong. Choobineh and Behrens (1992) consider uncertainty as the manifestation of unknown consequences of change and risk as the consequence of taking an action in the presence of uncertainty. From an engineering perspective, Merrill and Wood (1991) 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.

TYPES OF UNCERTAINTY

Factors within an organisation's control are considered internal factors related to planning, while those outside are external. Hirst and Schweitzer (1990) describe ***internal uncertainties*** surrounding the type, availability, and costs of new generating facilities, availability and costs of existing generating facilities, availability and/or costs of power from life-extension projects, demand-side management capability, and the availability of renewable energy resources. ***External uncertainties*** apply to load growth, fuel prices, availability and costs of purchased power, actual savings from demand-side management, regulatory policies, inflation, interest rates, and environmental constraints.

Generation technologies with different lead times face demand forecasts with different levels of uncertainty, which Boyd and Thompson (1980) distinguish as "short term" and "long term." ***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, giving inertia to a substantial component of demand. The latter type belongs to ***long-term uncertainties***. The difference between the two types of uncertainties depends upon the extent to which uncertainty in demand changes during the time necessary to construct a power plant. Some performance indicators, such as reliability constraints, reserve margin, and loss of load probability should also be taken into account.

Not all factors are measurable, especially in relation to the way uncertainties are expressed. The International Energy Agency (IEA, 1987) 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 (Merrill and Wood, 1991).

Barbier and Pearce (1990) 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.

IEA (1987) 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. Zadeh’s fuzzy set theory, described in Dhar (1979), is concerned with ambiguity resulting from lack of knowledge. System imprecision due to unavailable information, imprecise data, or simply linguistic ambiguity gives rise to fuzziness. Choobineh and Behrens (1992) argue that the principal sources of uncertainty are often non-random in nature and relate to fuzziness rather than to data frequency.

Gerking (1987) 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*** (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. There are four types: ***static uncertainty*** (several alternatives are recognised as possible when there is no indication that the uncertainty may change over time or that it can be affected or diminished), ***quasi-static uncertainty*** (can be reduced in a negligible period of time relative to the decision alternatives), ***dynamic uncertainty*** (as time passes, certain developments of external inputs can be successfully removed from further discussion, i.e. resolution of uncertainty over time), and ***unspecified uncertainty*** (cannot be met with programmed planning measures.)

THESIS DEFINITION AND CLASSIFICATION

In this thesis, "uncertainty" refers to factors, that affect the outcomes of decisions but which are not known at time of planning. There are two kinds of factors: 1) variables that enter into the planning model, and as such, can be specified, approximated, or predicted beforehand although the actual "resolution of uncertainty" may be quite different from its estimate; 2) variables or events that do not enter into the planning model, and as such, cannot be predicted or even foreseen at all. For example, the restructuring of the UK ESI and its implications could not be foreseen two decades ago and therefore would not have been treated as an uncertainty at that time.

This definition of uncertainty broadly captures the distinctions between types of uncertainty, as reviewed above.

We propose a more useful classification of uncertainty, by data, model, the user, and area of uncertainty, i.e. factors that affect capacity planning.

Data uncertainty refers to the availability and accuracy of data. For example, although pricing information is freely available in the UK power pool, individual plant details are often inaccessible due to commercial reasons. Data for modelling purposes is incomplete, insufficiently detailed, untimely, and possibly unreliable as there is no requirement to publish or supply such information. Furthermore, announcements of new plant may be strategically motivated as frequently these are followed by deferrals or cancellations. These market signal distortions present uncertainties in the data.

Uncertainty in the model concerns the "right" structure, techniques, etc. ***Uncertainty in the user*** refers to that hidden agenda the user has not communicated to the model builder, i.e. what the final decision maker has not told the developer of the planning model. It also refers to the gap between the model and the user, i.e. what is not captured by the model but desired by the user.

Areas of uncertainty are classified in the next section.

2.7 Areas of Uncertainty

Factors that are important to capacity planning such as determinants of electricity prices (variables and alternatives) are listed in table 2.4. These factors differ in degree of sensitivity and uncertainty. For example, capital cost has a high impact on electricity prices, but for a well-known technology, it is highly predictable. In modelling uncertainty, it is not only important to focus on highly sensitive variables but also highly uncertain ones. Too many existing techniques focus on the former, as evident in Chapter 3. Here, we discuss those factors that have potentially high and uncertain impact. Relationships between factors are also important in the subsequent analysis of uncertainty albeit only briefly mentioned here.

Table 2.4 Important Factors in Capacity Planning

Variables (attributes)	**Alternatives (by type of fuel and technology)**
DIRECT Capacity size (total, unit) Heat rate (efficiency, conversion rate) Discount rate Life Fuel cost O&M cost (fixed, variable, escalation rate) Capital cost (fixed, variable) FGD and other add-on capital equipment Decommissioning (cost or provision) Interest during construction Tax (corporate, carbon, etc) Load factor (utilisation rate) Load duration curve (merit order) Emission factors (CO2, SO2, NOx) Non Fossil Fuel Obligation Nuclear Fuel Levy Construction time (lead time, delays) Availability Performance External costs (environmental, social) INDIRECT Accounting methods Heath and safety Regulatory Competition Environmental Public Attitudes	FOSSIL FUEL - coal (lignite, anthracite; FBC, IGCC) - oil - natural gas (CCGT) --diesel (OCGT) - orimulsion NON-FOSSIL FUEL - nuclear (AGR, MAGNOX, PWR) - renewables -- hydroelectricity -- solar -- wind -- wave -- tidal -- geothermal -- biomass -- waste incineration DEMAND SIDE MANAGEMENT - time of use - spot pricing - interruptible power supplies - energy efficiency - conservation schemes Import or export of power Combined heat and power Contractual options

The next sub-sections are grouped into factors that directly contribute to capacity planning (plant economics, demand, fuel, and technology) and indirect (financing requirements, market, regulatory, environment, public opinion) uncertainties. These areas of uncertainties are by no means exhaustive but provide an insight into their impacts on capacity planning.

2.7.1 Plant Economics

Central to capacity planning are the components that directly determine the cost of electricity generation. Each major cost category contains fixed and variable components, with the variable element tied to utilisation. Fixed cost is composed mostly of capital cost incurred during the construction phase. Variable costs are the running costs due mainly to fuel and operations and maintenance (O&M). Within each type of plant or fuel, the range of technologies varies considerably. The final costs are also highly affected by load factor, life, plant efficiency, and discount rate. Factors that are highly variable and need to be considered include inflation rates, interest rates, technical and regulatory conditions in the electric utility environment, and the way they change over time.

Capital costs, which are committed years before a power plant begins operating, must be recovered during its lifetime. Capital costs are sensitive to discount rates and construction lead times.

Most technologies exhibit an inverse relationship between their capital and generation costs. Baseload plants have high capital cost and low generating cost as compared to peaking or peakload plants which have relatively low capital cost and high generating cost. Because demand fluctuates throughout the day and year, baseload plants are scheduled to supply the bulk of demand and peakload plants brought in to meet short-duration peaks in demand. The order in which the different plants are brought on-line depends on capital and operating costs as well as technical characteristics of plants. Those plants with high capital costs are also often difficult to switch on and off quickly, and therefore more suited for baseload. To meet the restrictions on certain emissions, the less polluting plants tend to get ordered first.

Uncertainties in construction costs and lead times are a major source of concern because delays are common, often due to licensing complications, public intervention, financing difficulties, project miscalculation, accidents, or over-capacity. If additional funding is needed but not available, it could lead to the undesirable result of project abandonment. The longer the time to commission, the higher will be the interest during construction (interest on funds provided during construction period).

Many uncertainties arise during the long planning horizon. Peck et al (1988) mention the importance of assessing equipment life, which is affected by the cost of maintenance and new technologies. When certain fuels become less favourable because of poor environmental performance, unreliable supply, steep cost escalations, or competition from alternative technologies, the associated power plants will have to be retired early. Capital costs would then spread over a shorter lifespan thereby effectively increasing the generation cost. This is especially true of new untried technologies, where the initial learning curve is steep.

Power stations are function-specific infrastructure. Once the maximum useful life is reached, a plant must be decommissioned. Hopefully all of its capital and decommissioning costs can be recovered during its operating lifetime. Nuclear plants in particular have the burden of end of life uncertainty which translates into costs and risks of safety. These concerns are not easily converted into monetary units even though the common practice is to set aside a provision for decommissioning. Problems with radioactive waste, safe containment, dismantling, and reprocessing of spent fuel present uncertainties in the operation of nuclear plants. Together with the heavy burden of decommissioning costs, these uncertainties made the privatisation of the UK nuclear power industry too expensive and risky in 1990.

The capital intensive and function-specific nature of power plants is offset by the lower costs achieved through economies of scale. In the past, the emphasis was on building big to achieve economies of scale; but against a background of fluctuating demand and unstable conditions, the downside risk is expensive. It is more difficult to achieve economies of scale in a fragmented industry. Such "big" commitments tie up capital in presence of rapidly changing technology and competitive forces. These commitments can be very costly over a long period of time. [For further discussion, see Merrill et al 1982, Krautmann and Solow 1988, and Hobbs and Maheshwari 1990.]

2.7.2 Fuel

Uncertainties that affect fuel price and supply are important as fuel related costs make up the majority of the running costs of fossil fuel plants. National Power (1992) attributes 53% of their operating cost to fuel, while PowerGen (1992) claims close to 70%. Adverse shifts in relative fuel prices have a direct impact on running costs, possibly changing the technology mix and the merit order of power plants over time.

The oil shocks of the 1970's warned electricity generators of the risks of over-dependence on a single fuel source. The uncertainty associated with fuel has to do with political and economic risks of the supplying countries. Price instability, supply and transportation interruptions , and disruption of strikes all contribute to uncertainty of supply (Merrill et al, 1982.) Even if self-sufficient in supply, domestic primary fuel suppliers are not insulated from price, as the privatised generators can choose to import from abroad. After several oil shocks and continued unrest in the oil-producing countries, the world's oil reserves are still concentrated in the politically unstable areas of the Middle East (65%) and South America (13%). Gas reserves are distributed unevenly as well, with 38% in the Soviet republics and 31% in the Middle East. Most countries have their own reserves of coal with the majority in the USA (24%), Soviet republics (22%), and mainland China (15%). Secure fuel supplies are necessary for the reliable provision of electricity at stable and predictable prices. Unfortunately effort to maintain this through long-term contracts with fuel suppliers cannot prevent disruptions due to war, strike, embargoes, etc. Fuel diversity is a way to spread the risks and to avoid over-dependence on one country. Sizewell B, being the first PWR (Pressurised Water Reactor) to be built in the UK, was approved on grounds of fuel diversity.

Nuclear fuel cycle has its own uncertainties, particularly in the back-end. Reprocessing of spent fuel is a highly controversial issue, as the risks of fuel transportation present a fear of possible nuclear weapon proliferation. These concerns show that fuel cost and availability are not the only determinants of technology choice.

The volatility of fuel price as illustrated in Stoll (1989) makes it difficult to predict accurately. Oil prices quadrupled in 1974, doubled in 1979, and plummeted by one-half from 1982 to 1986. Natural gas, as a derivative of oil, followed similar patterns.

One way to reduce fuel-related uncertainty is to maximise the accuracy of supply-side forecasts. However, experience (Balson and Barrager 1979 and Energy Business Review 1991) shows that accuracy varies greatly among the different types of fuels, as follows.

> ***Forecasts for hydro-electric power supply and consumption are by far the most accurate.*** This is probably due to the "counting element." That is, sites are identified and schemes are planned for many years ahead. But this may no longer hold if adverse shifts in weather patterns are expected from global warming.
>
> ***Nuclear power forecasts are highly unreliable*** for several reasons. Many are politically motivated. There are great political and social uncertainties. Costs of R&D, operations, and especially dismantling and decommissioning are either badly estimated or ignored.

Little is allowed for environmental problems and the NIMBY (Not In My Back Yard syndrome) attitude that prevails.

Forecasts for natural gas are also unreliable. Until gas discoveries are made, these supplies are simply not included. Similarly with Liquid Natural Gas (LNG) imports, unless contracts have been signed, it is considered too speculative to include it. These event-driven uncertainties cause great discrepancies in forecasts.

Forecasts for coal vary. In the fifties and the sixties, the picture for Europe was over optimistic due to the failure to anticipate the high cost of production in Germany and the UK. There was also a panic response to the oil crises of 1973 and 1974. Increased use of coal in the future depends on the successful development and acceptance of clean fuel technologies.

Estimates of future oil prices must be guided by careful economic and geological analysis as they are ***highly uncertain and subjective***. The uncertainties are dependent on reserves, recovery costs, world demand, and politics at the national and international levels. As a result, the forecasts are revised almost as soon as new reserves are discovered.

In general, uncertainty in supply forecasts is associated with uncertainties in technological, environmental, political, and economic forecasts. Traditional forecasting methods are strong in analysing and using historic trends but weak in predicting event-based "shocks" to the system. As seen from the above discussions, forecasting methods can no longer rely on historic relationships between electricity consumption and economic and demographic factors such as prices, GNP, population, growth, and weather, because the relationships are not clear or stable.

2.7.3 Electricity Demand

Demand uncertainty is one of the major determinants of future capacity need. The demand for electricity varies throughout the day, the week, and the year. Since electricity cannot be stored, there must be sufficient capacity to generate the power demanded at any time. The traditional appoach of fitting plans to demand forecasts relies on the accuracy of predicting the shape and growth of demand.

At the macro-level, electricity demand growth has been closely correlated with GNP growth. Other factors that affect uncertainties in demand are given in Henderson et al (1988) as follows: the relationship between peak load and economic activity, the price of electricity, technology, specific incentives, usage, the fundamental growth of demand, forecasts, and baseline projections of supply and demand.

Other aspects of demand uncertainty (Schroeder et al, 1981) include the demographic bulge, i.e. whether the next generation will have greater or less electricity consumption. Demand is also greatly influenced by new technologies, so-called phantom appliances, the electricity intensities of which are difficult to predict. The strength and persistence of the energy conservation movement may counter the effects of greater energy consumption.

Forecasts of long-term electricity demand are translated into load distribution curves and more commonly shaped into load duration curves which are useful in "merit ordering". Load distribution curves map daily demand against time, e.g. hours of the day, days of the week, months of the year, etc. Load duration curves are aggregated and averaged from load distribution curves and are represented as percentage of demand (or load) against percentage of time. The short-term scheduling of plants to operate depends on their controllability. Some plants are better at following the rises and falls of demand. Load demand changes are difficult to adapt to because of the long lead times in construction. These issues relating to uncertainty of load growth and shape, and their impacts are discussed in Stoll (1989) and Ford (1985).

2.7.4 Technology

The choice of technology, i.e. type of plant, is determined by the type of fuel used and technical performance characteristics like heat rate, emission factors, operating life, and black-start capability. Table 2.5 lists the benefits and costs of the main technologies.

Plants with greater thermal efficiency, lower emission levels, better designs, and improved cost-effectiveness are able to cope with the tougher environmental standards today. New coal-fired technology, such as AFBC (Atomospheric Fluidised Bed Combustion), PFBC (Pressurised Fluidised Bed Combustion), and IGCC (Integrated Gasification Combined Cycle) as described in OECD/NEA (1989) outperform existing coal-fired plant. Advanced nuclear reactor technologies promise potential improvements in simplicity, safety, and economy. AWCR (Advanced Water-Cooled Reactor) and HTGR (High-Temperature Gas Cooled Reactor) demonstrate greater reliance on passive safety features and increased use of modularisation to reduce construction costs and schedule. Moreover, their designs are the results of optimisation in plant size, multi-unit sizing, standardisation of design and component, and improvement in construction efficiency. Modularity, instead of economies of scale, is one way of coping with the uncertainties in electricity demand and fuel supply (Hirst 1990, Ford 1985).

Table 2.5 Fuel/Technology Comparisons

Fuel/ Technology	Benefits	Costs
nuclear	• does not contribute to the greenhouse effect except to a minimum extent during manufacture of its fuel • long-lasting uranium supply	• public concern about health and safety • cost-effectiveness questionable • eventual profitability very sensitive to delays in construction • reactor performance • least flexible of energy options, high capital cost with long lead times and great infrastructure requirements • reprocessing, nuclear proliferation • long-lived radioactive wastes
coal	• abundant and secure supply, especially domestically (in the U.K.) • relatively cheap if used at baseload	• most environmentally destructive in mining and combustion • emission control expensive and cause further problems of waste disposal
natural gas	• high thermal efficiency • modular • short payback period (short construction time) • low emissions	• concern about long-term resource availability • transport difficulties • supplies concentrated in the Soviet Republics and other politically unstable areas
orimulsion	• transportable over long distances • high combustion efficiency • 15 to 20 year long-term contracts adjustable to coal prices • not affected by oil prices • can make use of old oil fired stations or new coal plants • carbon dioxide is 20% lower than coal emissions	• high sulphur content • FGD needed • greater particulate emission problem than heavy fuel oil • dependence of few suppliers
energy efficiency (and other demand-side alternatives)	• most flexible of options • most publicly acceptable • most environmentally benign	• require education and promotion • need incentives • efficient devices to be sold
renewables (energy from wind, solar, biomass, tidal, geothermal, waste-incineration)	• independence from finite sources • availability in small sizes and quick installations • relatively low environmental impact • low operating costs • wide geographic dispersion • tremendous diversity	• low power density • periodicity of supply (intermittent output) • high capital cost • intensive manpower requirements • require subsidies or preferential treatment to be commercially viable • many techniques require further development to improve efficiency, reliability, and cost

Technological obsolescence is a crucial concern when planning horizons are long, during which time changes in regulation and environmental standards are expected.

On the other hand, the newest and latest technologies take years before their cost effectiveness and fuel efficiency are fully accepted. New installations usually have lower load factors in the first two years, reducing the electricity output and revenue income. Any new installation will always carry this performance uncertainty. Even technology that has been accepted in other countries has to undergo much investigation and understanding before being adopted domestically. Rigorous technical tests and policy analysis are required for each new technology.

As mentioned earlier, nuclear power has considerable uncertainties surrounding the back-end of the fuel cycle, e.g. decommissioning, waste treatment, and containment. In addition to these scientific uncertainties, nuclear power also faces regulatory uncertainty in the UK, as the government's decisions on various issues concerning Nuclear Electric are still pending at time of writing. A favourable decision to the nuclear industry could result in building of new pressurised water reactors which will come into service in early next century. If not, a large amount of nuclear capacity may need to be retired, unless the industry can bear the enormous costs through other means. If Nuclear Electric is privatised, it could diversify its plant mix, e.g. build non-nuclear plant. The 1998 expiry of the Non Fossil Fuel Obligation (NFFO) and the Fossil Fuel Levy (FFL), which subsidise the nuclear industry as well as renewable energy, also causes financial concern as it is uncertain whether the European Commission will allow the extension of these subsidies. Prospects for future investment in nuclear power stations will be determined by their ability to compete successfully in the market.

Technology choice is not restricted to supply-side only. Demand-side alternatives, such as time-of-use pricing, dynamic and spot pricing, improved energy efficiency, and conservation programmes, are attractive because they could provide a viable solution to the environmental problems in the long run. However, demand-side management (DSM), as the US experience shows, requires considerable marketing effort and consumer education. [For energy efficiency, see McInnes and Unterwurzacher 1991, Greenhalgh 1990; for demand-side management, see Hirst 1990b, Hayes 1989, Sim 1991, Gellings et al 1985; for other references on this topic, see Henderson et al 1988, Hobbs and Maheshwari 1990, Berrie and McGlade 1991.]

2.7.5 Financing Requirements

By the time a new power station is ready to commence operation, it has already incurred substantial costs in the form of construction borrowings and accumulated debt. In a climate of economic and regulatory uncertainty, interest rates and exchange rates have a significant impact on financing costs of capital intensive projects. The uncertainties surrounding the cost and availability of new debt and equity capital are discussed in Merrill and Schweppe (1984).

Free competition eliminates the long-term guarantee of sales. Not surprisingly, in a privatised industry like the UK ESI, uncertainty in demand, fuel prices, competition, and the power pool induce risk averse investment behaviour which translates to higher discount rates for capital investment. These impacts have shifted investment to less capital intensive technologies. Discount rates are used to calculate tomorrow’s costs and benefits into today’s terms, reflecting market perception of risks and returns. The choice is not as apparent as in the public sector where a uniform discount rate was set to value projects but not to reflect business risk.

Uncertain revenue requirements make financial planning difficult and may prevent utilities from recovering all of their costs. Economic instability and inflation produce higher than expected interest rates and unprecedented cost increases in new facilities. Long lead times and regulatory delays are exacerbated by the inability to recover work in progress. [Other financial concerns are mentioned in

Hobbs and Maheshwari 1990, Jones and Woite 1990, Bunn et al 1991, and Merrill et al 1982.]

2.7.6 Market

Shortly before privatisation, UBS Phillips and Drew (1990) foresaw increased market risk for the newly privatised companies. In a privatised industry, the possibility of business failure is real. Competition should give rise to more efficient electricity markets, implying tighter reliability standards and reducing the spread between cost and price. Deregulation also opens the markets to new entrants, thus increasing the competition and eroding the profit margin. These privatisation effects are discussed in Bunn et al (1991), Berrie and McGlade (1991), and UBS Phillips and Drew (1991).

Pool price volatility concerns all participants in this industry as the trading of electricity effectively replaces the previous dependence on a stable monopolistic system of load scheduling. Competitive elements introduce tremendous uncertainty to pool price expectations. A combination of lower declared availability of plant (OFFER, 1992) has led not only to higher capacity payments and higher pool prices but also increases in uplifts, resulting in very high, short duration price spikes. Immediate demand responses to such high prices coupled by feedback from other elements send rippling effects throughout the system. Supply side disruptions such as plant retirement and reduced plant availability contribute to increases in capacity payments, which in turn raise prices. The time difference between bidding and trading causes discrepancies between provisional prices published one day ahead and final settlement prices.

Unleashing the free market forces in the new UK ESI brings about market uncertainties that are short-term in nature. Reacting to short-term needs runs the risk of jeopardising long-term interests. This is one reason why different types of uncertainties in capacity planning cannot be addressed in isolation.

New entrants and the expiry of fuel-supply contracts threaten the dominant players in the UK ESI. As the independent generators commit their CCGT orders to back to back contracts, they too wonder: how the dominant generators will behave, how the pool prices will change, whether transmission charges will be revised to favour projects in the South and disadvantage those in the North, what new environmental restraints or taxes will be imposed, and what changes to expect in generation capacity (including nuclear capacity). Too much capacity in a short time could deter the orderly investment at the beginning of the next century. There is also a concern about the overall risk of poor business performance, hostile take-overs, and further deregulation of the industry, such as through forced sell-offs.

2.7.7 Political and Regulatory

The power planning life cycle begins from the first stage of feasibility analysis and submission of proposal. Approvals depend on the site selected, the type of plant proposed, and other factors which are subject to many uncertainties. The long planning horizons of the electricity industry, e.g. 30 to 40 years, mean that industry life cycles are much longer than the length of a government in office. Political uncertainty relates to the uncertain implications of changes in the government or policy legislation.

In the UK, UBS Phillips and Drew (1991) along with many other analysts predicted that the 1992 general election could have a major effect on the industry and the value of the firms. UBS Phillips and Drew (1990) warned of a political risk, stemming from the changes that could be made to the industry if political ideology or sentiment were to change or if new legislation were to be introduced by either the UK or EC. Paribas (1990) cited some political considerations of a possible Labour government and how they would affect the status of conservation, British Coal, nuclear policy, payment for renewables, the status of National Grid, and the role of the regulator OFFER.

Regulatory uncertainty refers to the legislative changes that can impact at the firm level. Governments have a wide variety of policy instruments they can use to bring about change. Munasinghe (1990) lists a few: physical controls, technical methods, direct investments or investment-inducing policies, education and promotion, pricing taxes, subsidies and other financial incentives, reforms in market organisation, and regulatory framework and institutional restructuring. The future shape of the regulatory environment (Schroeder et al, 1981) depends on the speed of approval processes, local versus national balance of regulatory control, and emphasis on environmental matters.

Some of the regulatory impacts on the actions of the US electric utilities are discussed in Baughman and Kamat (1980): unanticipated delays in licensing or construction, uncertainty of business environment due to increasing government influence in energy markets, and new policy instruments.

The impacts of privatisation are far reaching. Bunn et al (1991) distinguish between two types of effects: the transfer of ownership from the public to the private sector and the competitive structure of the market. The former can be analysed according to the rate of return implications, price implications, capital structure or debt implications, and corporate tax implications. The latter (competitive market structure) has been analysed through the power pool incentives to invest, regulatory measures, uncertainty and risk in the new markets, and competitive strategies of the new players.

An independent regulator tries to mitigate anti-competitive behaviour or excess monopolistic returns accruing to any dominant player. However, considerable uncertainty surrounds what the regulator will do. UBS Phillips and Drew (1992) analyse the effects of changing the pool rules, the possible referral of the generators to the Mergers and Monopolies Commission and the valuation of the generating companies.

2.7.8 Environment

Increasingly, energy and the environment are perceived as directly linked. Four key areas to focus future concerns were recommended in a symposium (Helsinki, 1991) on electricity and the environment: 1) energy and electricity supply and demand, implications for the global environment; 2) energy sources and technologies for electricity generation; 3) comparative environmental and health effects of different energy sources for electricity generation; 4) incorporation of environmental and health impacts into policy planning and decision making for the electricity sector. The symposium proposed that the electricity utility companies take a longer planning perspective than just the 7-10 years for construction, in view of the time scale of many health and environmental impacts, such as the irreversible damage to ecosystems and the effects of radiation.

The International Panel on Climate Change (IPCC) warned the world of a global warming of the earth. If not retarded or stopped, the "greenhouse effect" (Leggett, 1990) will cause a rise in sea levels, higher global temperatures, and changes in precipitation and seasonal patterns. Although the exact impact and time frame are not certain, it is known that the largest contribution comes from energy production and use. In the UK, for instance, the burning of fossil fuels in electricity production accounts for 34% of carbon dioxide released, 72% of sulphur dioxide, and 28% of nitrous oxides (Department of Energy, 1992.)

Fossil-fuel burning gives off carbon dioxide, the main greenhouse gas. Reduction will require market incentives or legislative measures, since there are no technical means to reduce CO_2 in fuel combustion other than using fuel with less carbon content or improving thermal efficiencies of plants. A carbon-energy tax has been proposed by the European Commission to encourage energy efficiency and fuel switching. If implemented, this would raise the price of electricity generated by coal and oil, and to a lesser extent, gas. [The effects of a carbon tax are discussed in Grubb (1989), Hoeller and Wallin (1991), Cline (1992), and Kaufmann (1991).]

With the exception of CFCs and carbon dioxide, most emissions are difficult to measure. The projection of future emissions is even more uncertain as atmospheric concentrations of some gases are more sensitive to emission rates than others due to the different lifetimes in the atmosphere. The mechanisms and rate of removal are uncertain. The impact of control measures is uncertain as it depends on time. Much scientific uncertainty surrounds the impacts and timing of climatic changes. The irreversibility of these effects implies that legislation should be passed now to reduce or stop such emissions which will impact on a generator's future plans.

Recent UK legislation, following EC directives, requires power stations to reduce SO_2 emissions to 60% below 1980 levels by the year 2003 and that the NO_x emissions must be 30% lower than in 1980 by the year 1998. A government White Paper on environment has set the target of 1000 MW to be generated from renewables by the year 2000 and to provide 24% of the UK energy by 2025. This target adds to the growing list of objectives that planners must consider. The UK has conditionally complied to the IPCC target to stabilise CO_2 emissions at 1990 levels by 2005. These legislative requirements affect all power producers directly.

To meet the sulphur emission target, utilities use fuels with lower sulphur content or fit desulphurisation equipment. Desulphurisation and denitrification equipment is so expensive that it is only cost effective if installed on the newer and larger plants to allow for economies of scale and longer operating time. Capital cost of flue gas desulphurisation equipment (FGD) on Europe's largest coal-fired power station Drax (National Power, 1992) is around £700 million. On a per kilowatt basis, it is equivalent to £373/kW, a significant proportion of the total capital cost of the plant.

Environmental externalities, such as those side effects of electricity generation described above, have not been traditionally included in electricity prices. As environmental costs may be internalised universally through pollution taxes or other policy instruments, Ottinger et al (1991) urge electricity producers to anticipate for self-interest although accounting for such externalities is still fairly new with significant uncertainties to be reviewed for each externality. In support of this, Markandya (1990) suggests to identify and account for the main sources of electricity (oil, gas, coal, hydropower, nuclear) and their effect on the environment.

In the past, negative environmental aspects of power generation have been overlooked in times of electricity shortage. However, expectations of over-capacity in the UK ESI combined with stricter environmental laws impel power generating companies to re-evaluate the options they have to meet the interests of reliability, profitability, and the environment.

2.7.9 Public

In some countries, like the US, public opinion has frequently interfered with the business of power generation itself. Foley and Prepdall (1990) cite public sensitivity to new industrial development, e.g. site selection, transmission lines, electromagnetic fields, and public health. People are concerned about health and safety, aesthetics (as a power station is considered visual pollution to the countryside), environmental pollution, etc. Berrie and McGlade (1991) discuss consumer reaction to price and the quality of supply.

Nuclear power is probably the energy source that is most influenced and dictated by public opinion (Evans and Hope, 1984), but it was not until the 1970's that opponents of nuclear power began to delay the development of this industry. The professional response was that nuclear power was cheap and safe and that no other energy source could meet the increasing demands forecasted for world economic growth. In spite of this reassurance, nuclear accidents and adverse public reaction have caused cancellations in construction and curtailed future investment.

British Nuclear Fuels Limited (BNFL) opinion polls regularly show that two out of every three people believe the risks associated with nuclear power outweigh the benefits. Public opinion is powerful enough to put a ten-year moratorium on further nuclear construction in Switzerland and a phasing-out of nuclear power in Sweden. A recent survey (Nuclear Forum, 1992) shows that the more people know about radiation the more likely they are to be in favour of nuclear power.

2.8 Conclusions

This chapter has listed and explained the areas of uncertainties in electricity generation important in capacity planning. These uncertainties have also been viewed from a modelling perspective, i.e. types of uncertainty. Emerging from this discussion are the difficulties of capacity planning in presence of these uncertainties. These uncertainties and complexities are summarised in table 2.6.

Table 2.6 Model Requirements for Capacity Planning

Areas of Uncertainty	Types of Uncertainty	Complexity, Completeness
• plant economics: capital, running costs • fuel: price, supply • demand: shape, growth • technology: performance, side effects, competitors • financing requirements: financing mechanisms, interest rates, revenue requirements • market: volatilities of the pool, competition • political/regulatory: changing legislation, approval and licensing, timing and impact of new policy instruments • environment: scientific uncertainty in energy-environment interface, internalising externalities through new requirements • public: opposition as cause for delay, image of firm	• internal, external (controllable, uncontrollable) • operational, strategic • short-term, long-term • quantifiable, unquantifiable (measurable, intangibles) • risk, non-risk uncertainty • stochastic variability, fuzziness • statistical, interpretational, decisional, external • static, quasi-static, dynamic, unspecified • scientific, forecasting, time lag • data availability, accuracy, detail	• technical characteristics of plants • levels of detail • dependence of factors • business risk • strategic focus • types of decisions: technology choice, capacity size, timing • multiple perspectives: regulator, private sector firm, consumer, shareholder • multiple criteria: reliability, plant availability, efficiency, minimum cost, highest profitability, public acceptance, environment

The uncertainties discussed in this chapter do not exist in isolation. The public's concern for the environment has often led to legislative action. New requirements translate into new technologies, and these in turn fuel the competition. Competitive forces spark off further uncertainties in the market. The enumeration and discussion of uncertainties in power generation pose a big question: ***how do we deal with these uncertainties in electricity planning?*** We propose two approaches to answer this question.

The first is the obvious and classic approach of ***modelling***, ingrained in the engineering culture of electricity industries. In Part One of this thesis, we review modelling approaches to capacity planning as defined by operational research techniques and their application. We criticize their ability to capture the different areas of uncertainties and their treatment of types of uncertainty on the basis of ***completeness*** and ***adequacy***, respectively. Completeness refers to the comprehensive coverage of areas of uncertainties, while adequacy refers to a sufficient or fitting treatment of different types of uncertainties. The enumeration of different areas of uncertainty is aimed at ensuring completeness, i.e. not overlooking any factor. Hence, implicit in the traditional modelling approach to uncertainty is the goal of completeness. We propose that model synthesis is a means to completeness but need to establish its ***feasibility*** and ***practicality***, hence the title "***Model Synthesis for Completeness.***"

The second is a non-traditional approach. Part Two of this thesis addresses the usefulness of ***flexibility*** to uncertainties in electricity planning, hence the title "***Flexibility for Uncertainty***." The literature (Chapter 5) mentions its usefulness as a response to uncertainty, as a practical means of coping with uncertainty, and as a desirable property of a system. However, it is not clear how such a vague and "qualitative" concept could be useful to such a precise and "quantitative" tradition of electricity capacity planning.