Modeling the Dynamic Complexity of the Energy Policymaking Process

by
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Submitted to the Systems Design and Management Program in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering and Business Management

at the
Massachusetts Institute of Technology
December, 2001 [February 2002]

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Abstract

Although nuclear power is an important part of worldwide electric energy production, no new nuclear power plants have been ordered in the United States and in most occidental countries during the last three decades. There are many concerns about nuclear energy that continue to limit its growth and which resolution is more a social/political challenge that a technical one. Among these concerns are its economy, safety, proliferation, and nuclear waste management.

The nuclear industry must learn how to influence the social/political system in order to create a favorable nuclear future. To understand the energy policymaking process and how its influential factors affect it, it is necessary to have a common vision of the system and a simulation a tool with which strategic studies can be conducted. The proposal of this thesis is to use the concept of system dynamics to draw the cause-and-effect loops around the energy policymaking system and to build a simulation tool with which to analyze the results of simulating of hypothetical scenarios.

In this thesis, we present a model of the energy policymaking process. Results of simulations made using this model show that nuclear power plants are likely to become the dominant means of electricity generation in the United States provided that an ultimate repository for nuclear waste is open. This result derives mainly from the increasing concern on the greenhouse effect and from the high cost of wind turbines. At present, the main efforts of the nuclear industry should reside on decreasing its capital costs and letting the greenhouse effect been a major problem.

Thesis Supervisor: Kent F. Hansen

Title: Professor of Nuclear Engineering, MIT.

Table of Contents

Table of Figures

Tables

Acknowledgements

Special thanks to Professor Kent Hansen for his guidance and assistance in the completion of this thesis. Appendix 1 includes a list of all the professionals that have contributed to the completion of this thesis. Financial support through the TEPCO sponsored project on this subject is highly appreciated.

This thesis is dedicated to my parents and brother, Nestor, Nelly and Nestor Jr., for their continual support and unconditional love and to my friend, Carlos Conti, for having encouraged me to apply to MIT and for his long-distance friendship.

Chapter 1: Introduction [1]

1.1 Motivation

Although nuclear power is an important part of worldwide electric energy production, its future is uncertain. Nuclear technology as a mean of electricity generation is relatively new and it is likely that many advances and improvements are possible. There are many concerns about nuclear energy, such as high capital costs, safety, proliferation, and waste, which continue to limit its growth. Although technical and economical factors must be considered, the resolution of many of these concerns is more a social/political challenge that a technical one. The nuclear industry must learn how to influence the social/political system around the energy policymaking process in order to create a favorable nuclear future. This is a complex system and its representation and understanding requires having a great knowledge of its elements and the way they interact.

This is precisely the motive goal of the research project of which this thesis is a result: to achieve a deep understanding and a common view of the energy policymaking process by providing a simulation tool developed through intensive literature research and the opinion of experts. In particular this tool would make it be possible to learn how and where to influence the social/political system to: (a) achieve desirable policies, (b) avoid undesirable policies and (c) change policies in desirable ways.

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[1] This chapter is almost a copy of my previous report: Stella Maris Oggianu, Professor Kent F. Hansen, "Modeling the Dynamic Complexity of the Nuclear Policymaking Process and System: The High Level Nuclear Waste Issue." MIT-NFC-TR-033. July, 2001. Center for Advanced Nuclear Energy Systems, Massachusetts Institute of Technology. Cambridge, MA 02139-4307.

1.2 Goals and Methodology

The goal of the project of which this thesis is a result is to achieve a deep understanding and a common view of the energy policymaking process by providing a system dynamics model of this system. This model would make it possible to simulate a great number of different scenarios and analyze their results. In this way, this model would make it possible to know what is the best way to influence the system to leverage the nuclear power with the other sources of electrical energy.

For simplicity reasons, nuclear, fossil and wind are the means of generating electrical energy that are considered in the model. While fossil energy groups coal and gas plants, wind turbines were chosen to represent the renewable portion of electricity generation in the US. This was done under the assumption that they represent the only viable source of renewable electrical energy in the nearest future.

Three big stages lead to the achievement of the project's goal:

1) The results of the first stage are the causal loops representing the policymaking process. This model basically comprises four modules:

- **The policymaking process:** This part of the model generates the amplitude and rate of policies for nuclear, fossil and wind power plants. The inputs to this part of the model are the public concerns related to the electricity generation, the perceived merits of the technologies under discussion and the political bias. In our model, the *policy amplitude* represents how favorable or unfavorable the new policies are regarding each means of producing energy[2]. The policy amplitude is estimated considering the political support and bias for each considered mean of generating electrical energy. The political support depends on the concerns and characteristics of the form of energy analyzed, while the bias depends on the dominant political parties, the results of elections and lobbying activities. *The policy rate* represents the rate at which policies are generated and is a function of the societal concerns regarding electricity generation and their perceived importance.

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[2] Policy refers to laws, regulations, taxes, etc. that are the output of the political sector. In the United States, the political sector groups the administrative agencies, the White House and the Congress.

- **The decision-making process:** It is assumed that the cumulative policies have an impact on the overnight cost and/or the annual production costs of each means of generating electrical energy. The risk associated with each technology and their lifetimes are also considered when estimating their total levelized cost. Given an electricity demand, we consider that the utilities' decision on which means of electricity generation to select is a function of the levelized cost of each investment.

- **The technical sides of the electricity generation process:** The sub-models calculate the cumulative nuclear waste production, greenhouse gases resulting from fossil plants, land occupation due to wind turbines installation, electricity costs and availability resulting from nuclear power plants, fossil power plants (includes coal and gas) and wind turbines.

- **Societal concerns:** Estimation of concerns regarding greenhouse gas effects, nuclear waste, safety, proliferation, availability, land utilization and cost have been introduced. The severity of land utilization (mainly due to wind turbines), greenhouse effects and nuclear waste depend on the production rates of fossil and nuclear energy, respectively.

The drawing of the cause-and-effects loops representing the model required understanding of related social, political, economical and technical topics. For this reason, this model was developed through intensive literature research and the opinion of many experts in the different areas involved.

2) The second stage of the project required the creation of a computer model to simulate the causal-loops that where originated in the previous stage. At this stage, much of the data corresponding to the policymaking process and public concerns were estimated. The aim of this stage was to analyze the results of our representation and compare these results with reality and intuition.

3) Once consensus on the results of the previous stages is achieved, a third stage of the project is to look for historical data to quantify the curves and data needed to have a first version of the simulation tool.

The first stage and part of the second stage of this project have been done and are presented in this thesis.

1.3 Structure of this Thesis

The remainder of Chapter 1 is devoted to providing a background of 1) the nuclear industry, its history, advantages and disadvantages 2) the greenhouse gas problem and 3) renewable means of energy, with an emphasis on wind turbines. This background will make it evident that there are many actors and factors to consider in the energy policymaking process in order to achieve a promising future for the nuclear industry. We use the word actors to refer to all the societal elements that play a role in the decision making process. Regarding electricity generation, the actors are: the international sector, the media, the political sector, the judicial sector, the industry and the public. Within the public the elite, interest groups (examples are environmentalists, anti- and pro-nuclear groups), general public and local public are included. Factors are all things that influence the decision making process, for example: electric energy availability, costs of energy, security of supply, state of technology, environmental concerns (such as nuclear waste, greenhouse gases and other emissions), public opinion, public actions, international standards, etc. The policymaking process and the multiple actors and factors that form the social/political system will be discussed in Chapter 2. At the end of Chapter 2, the reader will have the knowledge to understand the overall representation of the flow of cause-and-effect in the social political and technical systems regarding energy issues.

In Chapter 3, we give an overall view of our model of our energy policymaking model. Chapter 4 explains the social/political sub-model and Chapter 5 include the technical part of the systems dynamics model developed. In Chapter 6, we have included a presentation of the preliminary results obtained with our model. Finally, conclusions, comments and future steps are left for Chapter 7.

1.4 The History of the Nuclear Industry

Nuclear power was first used in the second war world. The same discoveries that lead to military isotope production for nuclear weapons also lead to the development of reactor technology for electricity generation.

In the 50s and 60s civilian ownership and development of nuclear reactors was encouraged, especially in the United States after "Eisenhower's Atoms for Peace Program" (See Ref. [1]). At that time, there were a great number of reactor designs being developed, but light-water reactors predominated. They resulted into the pressurized water reactors and boiling water reactors.

Development of new reactors went on, but nuclear power faced a decline for many reasons. However, long-term research activities were vigorously pursued in some countries, such as France and Japan.

In the United States, President Carter deferred civilian reprocessing in 1977. The intention was to set a political barrier to fuel reprocessing. This caused a declined in the United States nuclear industry without preventing proliferation. The consequences of no-reprocessing nuclear fuels cause: (1) a decline of the energy available from uranium by a factor of about 50, and (2) increased waste volumes because spent fuel requires vitrification and disposal for more than 10,000 years. Even though President Reagan lifted the ban on commercial reprocessing in 1981, there was no response from the nuclear industry sector.

Furthermore, reactors accidents such as Three Mile Island in 1979 and Chernobyl in 1986 increased public and policymakers concern and the awareness that there were many safety problems to solve. Consequently, many European countries such as Sweden, Germany and Belgium have banned new nuclear power plants. Even the accident at Tokaimura in Japan and the incident of BNFL (British Nuclear Fuels) increased public awareness and are remaining that systems are vulnerable to human error.

However, world reactors have achieved improvements in safety and efficiency. Nowadays the increasing energy demands in Asian countries, such as Japan, Korea and China and the need for an environmentally friendly sources of energy, have made nuclear power an attractive source of energy. As an example, Japan has ordered two new nuclear power plants in 2001. Even in the United States, the surplus of electricity is disappearing and there have been blackouts in the past two years. As a response to this scenario in the United States, President Bush signed the new energy strategy on 17th May 2001. This plan places nuclear energy as an important long-term alternative.

It is clear that with increasing global warning and increasing world need for energy, nuclear power remains a viable alternative. Wind and solar facilities will be constructed, but this will not be sufficient to meet the growth of energy demand in the next decades. Other technologies such as biomass and fuel cells will not supplant the existing system. Power plants with reduced capital costs and improved safety are the only choice which is left. However, to make this choice a reality, proliferation and waste management issues must be effectively addressed.

From the technical side, the lessons in the past have been learned. Figure 1 shows the evolution of reactor technology. It can be seen that a Generation IV of reactors is being developed to address the issues of nuclear power as a means for electricity generation. The Pebble Bed Modular Reactor (PBMR) is an example of Generation IV reactor design a modular. It is inherently safe, small and economical.

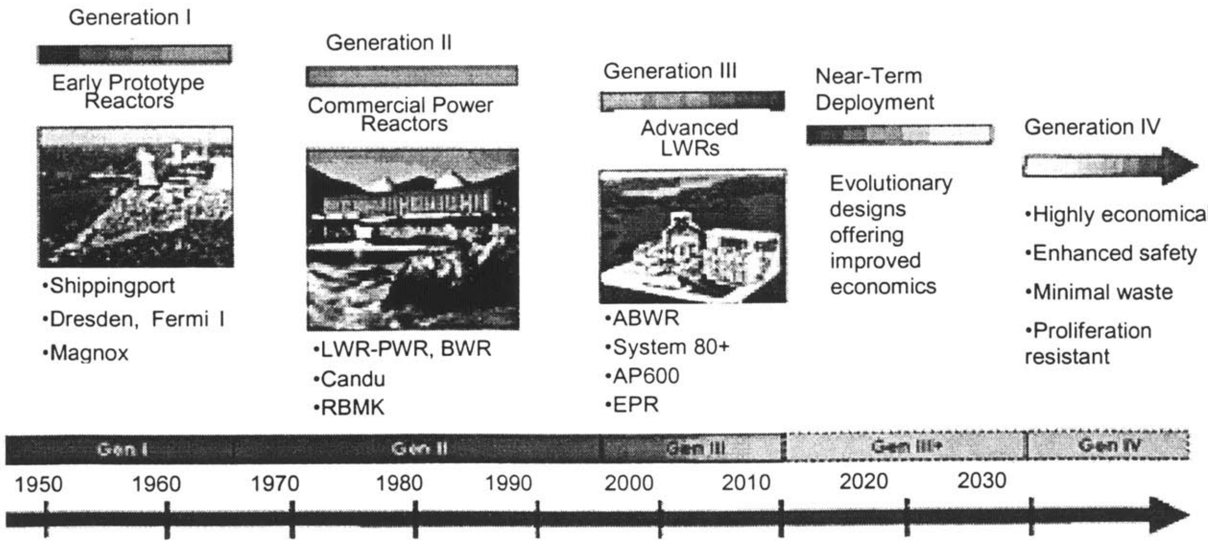

Figure 1: The Evolution of Nuclear Power

1.5 Advantages and Disadvantages of the Nuclear Energy

Nuclear power currently supplies one-sixth of the world's electricity needs as seen in Figure 2.

Nuclear power for energy generation has many long-term advantages over alternative sources, specifically over fossil sources:

a) It is environmentally friendly

b) It provides energy demand sustainability and diversity.

c) The fuel cycle cost is cheaper than alternatives

d) It could be used for other purposes, as for example desalination of seawater.

e) It represents a potential market for technology

Each of these advantages is explored in what follows.

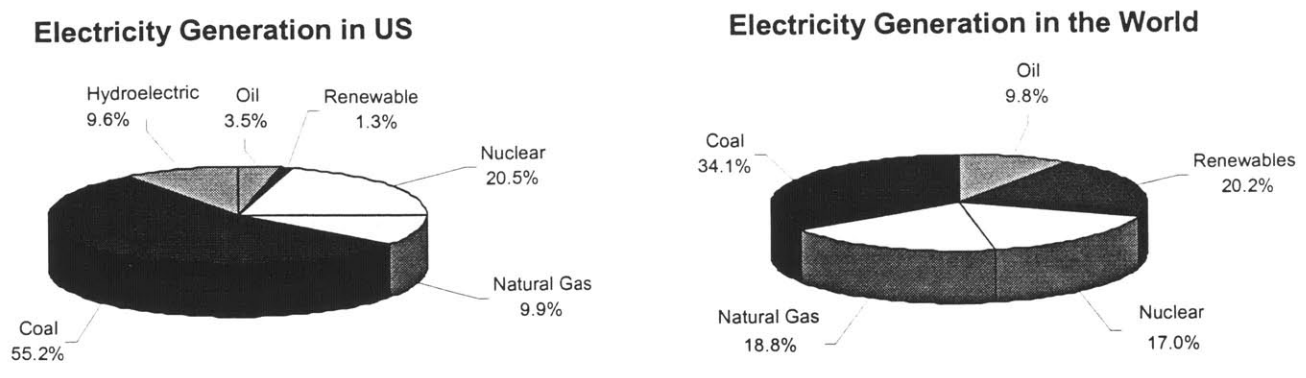

Figure 2: Electricity Generation in the US[3] and in the World[4]

Nuclear Power is environmentally friendly: It reduces air pollution and produces no greenhouse effects. Oil spills are also avoided.

The entire nuclear power industry in the US generates approximately 2000 tons of solid waste annually. In comparison, coal fired plants produces 100,000,000 tons of ash and sludge annually. This ash contains mercury, sulfur dioxide and nitric oxides. According to the Nuclear Energy Institute, between 1973 and 1998, nuclear generation avoided the emission of 87.3 million tons of sulfur dioxide and more than 40 million tons of nitrogen oxides[5].

Also to consider is the greenhouse effect, addressed in Section 1.6. This is a global climate change caused mainly by CO_2 (carbon dioxide) emissions. Fossil-fired power plants are major sources of carbon dioxide emissions, while hydro and nuclear power do not contribute directly to any. The adoption of carbon taxes is a reality in many countries already.

Regarding oil, getting rid of imported oil is desirable from political and environmental viewpoints. From the political perspective, governments should reduce their vulnerability to the OPEC oil cartel. As an example of the environmental viewpoint, the Exxon spill in 1989 was one

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[3] Source of data: Energy Information Administration Annual Outlook, October 2000. (Ref. 2)

[4] Source of data: http://www.eia.doe.gov/oiaf/ieo/tbl_21.html. Department of Energy (Ref. 3)

[5] Source of data: http://pw1.netcom.com/~res95/energy/nuclear.html (Ref. 4)

of the worst environmental disasters in history. However, little oil is used in electricity generation, as seen in Figure 2.

Nuclear power provides energy demand sustainability and diversity.

Each country has a need to have a diversity of means for generating electricity so that if the supply of other sources is cut off, then the country still has an operating energy alternative. Equally important is the protection of natural resources.

Nuclear power could be used for peaceful purposes, other than electricity generation.

Nuclear energy would provide district heating, industrial process heat, chemical fuels, desalination of seawater and marine transportation services[6].

The fuel cycle cost of nuclear power plants is cheaper than alternatives.

In the United States, the process leading to deregulation has resulted in agreements related to recovery the capital cost of nuclear plants. The remaining nuclear operation costs of nuclear plants is as low as 1.83 ¢/kWh, compared to 3.52 ¢/kWh of natural gas plants, 2.07¢/kWh of coal cycles, 3.24 ¢/kWh of oil[7].

Improvements in maintenance and operations practices in existing nuclear power plants also helped to further improve the fuel cycle cost of nuclear power plants. The unit capability factor has reached levels as high as 91% in the United States in 2000 as Figure 3. In addition, safety

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[6] Extracted from Nuclear News, November 2000. P.29. (Ref. 5)

[7] The fuel cycle cost cycles are the last figures up to May 2001.

measures have improved as seen in Figure 4 to Figure 6[8]. Economies of scale plus the application of common best practices helped to achieve this goal.

Nuclear power represents a potential market for technology.

In a relatively short period, most of the world's people will enjoy electricity. Asia and Latin American countries will need to expand their installed electricity generation bases. This represents a major market opportunity for countries with the knowledge and capabilities to provide these technologies and the infrastructure.

In spite of all these advantages, in the short-term nuclear power used for energy generation faces many drawbacks:

a) High capital intensive technology and high liability of NPP (Nuclear Power Plants) in case of accidents.

b) Inability to attract young, talented people into the industry.

c) Public fear for any level of radiation

d) Concerns among the public and policymakers.

    Management of Nuclear Waste

    Proliferation

    Safety

Each of these drawbacks is explored below.

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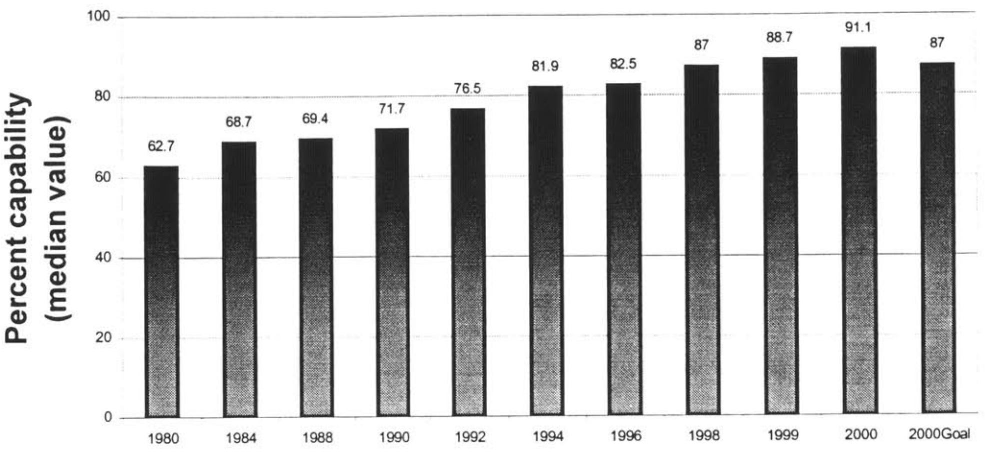
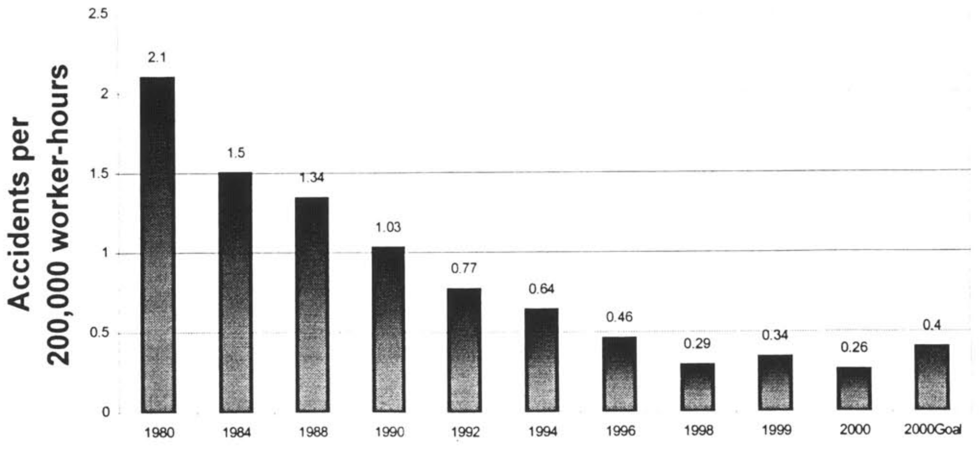
[8] Extracted from Nuclear News, May 2001. P 39. (Ref. 6)



UNIT CAPABILITY FACTOR

Figure 3: Power Plant Capability Factor in US



INDUSTRIAL SAFETY ACCIDENT RATE

Figure 4: Industry Safety Accident Rate in US

SAFETY SYSTEM PERFORMANCE

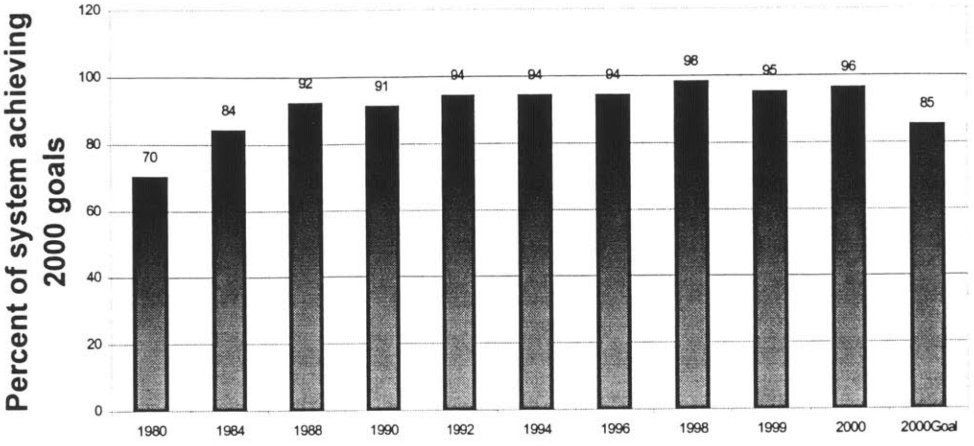


Figure 5: Safety Systems Performance in US

UNPLANNED AUTOMATIC SCRAMS

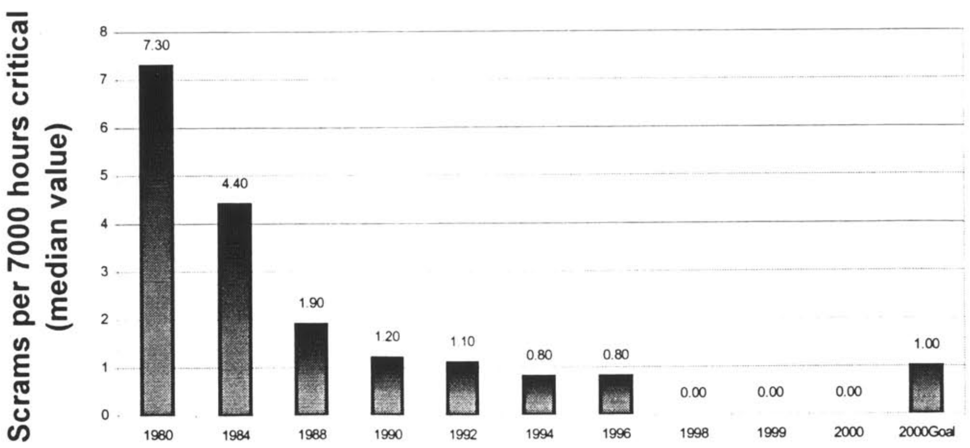


Figure 6: Unplanned Automatic Scrams in US

Nuclear power is a high capital-intensive technology.

In deregulated electricity markets, competitive total power costs are an essential condition for market penetration. Construction times, licensing procedures and regulatory commission requirements are a high percentage of the high total costs of nuclear power plants ($1500-$2000/kW) compared to gas plants ($500/kW) and coal plants ($1200/kW) in the U.S. market.

However, in the US the Nuclear Regulatory Commission (NRC) is granting 20-yrs license extension to some nuclear power plants in the US. If these reactors last so long, the price of electricity averaged over the total life of reactors could be surprisingly inexpensive.

To achieve these longer times, shorter construction times, modular and smaller designs is imperative for new nuclear power plants.

Inability to attract young, talented people.

In the 60s, the nuclear industry attracted the most brilliant and talented people. This is no longer true: there are movements that have painted the nuclear industry as almost antisocial.

Fear for any level of radiation.

It is known that large levels of radiation exposure are harmful. Many people assume that risks of health effects are proportional to the level of exposure, and therefore want to avoid any exposures.

Concerns among the public and policymakers regarding nuclear power for electricity generation.

The various concerns include 1) Management of Nuclear Waste, b) Proliferation c) Safety.

Management of Nuclear Waste: Volumes of waste produced by nuclear power plants are small compared to fossil fuel plants. However, nuclear waste are highly radioactive and must be treated with great care.

This demands one or several of the following measures: a) geological disposal of high-level nuclear waste, b) to reduce the level of nuclear waste by separation or transmutation (S&T).

In the US, the Department of Energy is exploring the Yucca Mountain Site, in Nevada as a repository site. Even if an ultimate site is approved, the fuel has to be transported from every reactor site to the ultimate place. Every state, county and municipality has the potential to delay or stop the shipment. More detailed information about the Nuclear Waste issue in the United States is included in **Appendix 2**.

Proliferation: Diversion of nuclear materials for fabrication of weapons result in increasing demand for safeguard.

Safety: the Chernobyl accident in1986 and the Three Mile Island accident in 1979 helped to understand safety design issues and the human role in nuclear power plant operations. Simplification of designs and operations, development of risk assessment techniques was necessary. However, these two accidents had very negative effects: a) regulations that badly affected the economics of reactors and b) public and political concerns.

1.6 The Greenhouse Effect

Human activities are believed to be causing global warming due to release of greenhouse gases that intensifies the natural radiative process by which the earth keeps its warm temperature.

Carbon dioxide (CO_2) and methane (CH_4) are among the greenhouse gases. The main source of carbon dioxide is the combustion from fossil fuels (oil, coal and natural gas) that provides energy for transportation and electricity. Regarding methane, the human activities related to its atmospheric release are natural gas extraction, incomplete combustion, loss in pipings, coal mining, etc. Considering that 62.7 % of the world electricity and 68.6 % of the electricity generated in the United States (of which 55.2 % corresponds to coal, 9.9 % gas and the remaining 3.5% is oil) is done through the use of fossil fuels, the generation of electricity by fossil means is one of the major sources of greenhouse gases.

In the context of policymaking regarding energy issues, the relevant thing for the purposes of this thesis is to see the way in which the greenhouse effect may affect the future of the electricity supply. The physics of the greenhouse effect, which is schematically shown in

Figure 7, is not studied here (Ref. [7] was used). For our purpose, the parameter to observe is the change in radiative force due to the increase of greenhouse gases in the atmosphere, of which the fossil plants are a major source. It is worth to make a distinction between coal and gas power plants:

- Coal power plants: Their maximum carbon intensity is 24.4 gC/MJ[9]
- Natural gas power plants: Their maximum carbon intensity is 13.7 gC/MJ.

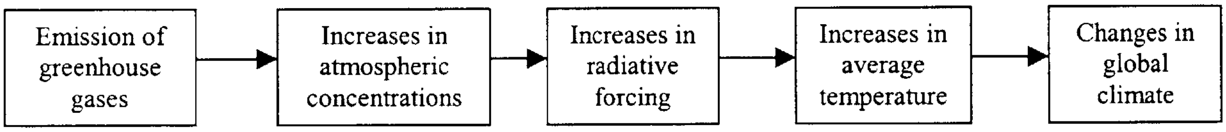


Figure 7: Basic element of the global warming problem. Extracted from ref. [7].

It seems evident that in the case of perfect combustion, changing from coal to natural gas, would reduce to half the realease of CO_2 per unit of energy generated. However, a careful analysis must be performed before drawing a definitive conclusion because the relative radiative strength of CH_4 per ppmv[10] relative to CO_2 is 58 times. Therefore, if the methane release due to incomplete

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- [9] gC/MJ is the mass of carbon existing in the amount of coal necessary o generate 10^6 Joul of energy.

[10] ppmv = parts per million in volume = $\frac{\text{molecules of } CO_2 \text{ (or } CH_4\text{)}}{10^6 \text{ moledules of air}}$

gas combustion, losses in the extraction and pipes is significant, the greenhouse effect could be even worse. This is true even though methane's decay time in the atmosphere of 15 years instead of about 100 to 200 years for CO_2.

We estimated that a 10% methane loss would make the greenhouse effect worst if 20% of the coal electricity plants were replaced by gas plants in the United States. In the realistic case of a 2% methane loss, and in the long run (3 to 4 times the lifetime of methane in the atmosphere), the greenhouse effect would be slightly improved by this switch

1.6.1 The Kyoto Protocol

The Kyoto Protocol is an agreement made by the major industrialized countries in the world to reduce the emission of greenhouse gases at an average of 5.2% below 1990 levels by the period 2008-2012. At that time, the United States had agreed to reduce its emissions by 7%. However, the United States has not yet ratified the protocol.

Our concerns regarding this agreement are 1) the protocol's objective to reduce the carbon release to the atmosphere without considering the chemical composition of the actual gas being released, which can cause the radiative force even worse; 2) the protocol does not include the participation of developing countries (China and India are among them).

1.7 Renewable Sources of Energy: Wind Turbines

Renewable sources of electricity include

- Solar energy. The obtaining of electricity is based on the photoelectric effect.
- Biomass power plants. They convert waste from paper mills, sawmills, wood products manufacturing, orchard pruning and agricultural byproducts into electricity.
- Geothermal plants, which take advantage of the heat from the earth.

- Ocean energy, in the forms of thermal energy, tides and waves.
- Wind turbines. They convert the kinetic energy of the wind into electricity.

At present, renewable energies represent a small fraction of the production of electricity. It is foreseen that their percentage will increase.

Due to their potential performance and economics, wind turbines are the most viable source of renewable energy at present. For this reason and also to keep the model as simple and representative as possible, wind turbines are the only renewable source considered in our model. The information about lifetime, cost, availability and land usage vary from source to source. (See Ref. [8], [9] and [10].). To give a general idea of the potential of wind turbines:

- Reported cost of a wind turbine vary from ¢ 4 to 8 /kWh (depending on the capacity factor),
- At most six turbines can be located per square kilometer and they must be located in places where wind speed exceed 5 m/s,
- Each turbines can deliver a peak power of 1.5 - 2 MWe ,
- The reported design lifetime vary from 13 to 20 years.

Information about the wind turbines structure is included in **Appendix 3**.

1.8 Conclusions: The Energy Policymaking, a Systems Dynamics Problem

The intentions of this chapter were: 1) To introduce the motivation and goals of the project in general and of this thesis in particular. 2) To leverage the knowledge of the nuclear industry through a brief review of its history and advantages and disadvantages compared to alternative sources of energy. It is clear that the way in which nuclear energy was born and the long history of accidents and incidents make public opinion a vulnerable point to deal with. 3) To present the issues to solve regarding nuclear power for electricity generation: safety, waste management, proliferation and economics, 4) To give an insight of the many international and political interests around the nuclear power, for which public perception and actions are important 5) To give brief introductions about the greenhouse effect and wind turbines.

Innovations in technology and risk management are being produced that solve technical and economical issues mentioned above. However, new policies and regulations are needed to boost further development of the nuclear industry. In the case of energy policymaking, these policies depend mainly on "political support" for nuclear energy and the "importance" of the energy issue. We assume that this is true for any means of generating electricity, i.e. there's also a political support for wind and fossil that- together with the importance of the energy issue at any given time, determine the amplitude and rate of policies affecting their production cost. These amplitudes and importance depend mainly on perceptions on the merits of a certain technology regarding safety, proliferation, availability, environment, etc. and also the public concern about this issue. At the same time, these perceptions are molded by history, bias, lobbying and the flow and intensity of information flow. In this regard, for instance, interest groups and the media play important roles.

In a phrase: unlike the technical side of the electricity industry, its social/political sides are far from being understood. To understand this side, it is necessary to have a tool with which strategic studies can be conducted. This will make it possible to know, for example: 1) how and to whom the merits of nuclear energy can be expressed, 2) how concerns about nuclear energy can be reduced, 3) how to neutralize anti-nuclear opinions, 4) how to deal with transportation issues, accidents and sabotage, 5) how best to take advantage of environmental drawbacks of alternative sources, natural resource availability and energy diversity and demands.

The social/political environment determining the nuclear energy future fits all definitions of a dynamic system: it is composed of multiple parts influencing each other. The proposal is then: (a) to use the concept of system dynamics to draw the feedback loops of every issue around the whole system and (b) to change from lineal language, to cause-and-effect cycles. This will help to discover the hidden opportunities within the policymaking system and to understand how an action in one of its element can unexpectedly effect other parts of the system[11].

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[11] For more information about system dynamics refer to Refs. [11], [12] and [13].

Chapter 2: The Policymaking Process and The Social/Political Environment[12]

2.1 Introduction

This chapter is devoted to the introduction of facts related to the political system and the policymaking process in democratic countries. The objective of this chapter is to provide the basic sociopolitical background necessary to understanding of the way we modeled the energy policymaking process.

Public policies are developed by bodies corresponding to the political sector. Although in our first approach to model the policymaking process we neither separate the political sectors in its constituents, nor address the atomized sectors which opinions and actions influence the political decision-making in different ways, they undoubtfully form part of the social/political environment and it is worth to address them at this stage. Regarding electricity generation, the sectors take some role in the decision making process include the international sector, the media, the political sector, the judicial sector, the electricity industry and the public. The actions and concerns of all these sectors on different aspects of electricity production - either as they actually are or as perceived by the politicians- together with the inherent or perceived merits of each technology, and their relative importance for the nation as a whole, influence the amplitude and rate of energy policies in ways that are very difficult to predict without a proper tool.

In this chapter, we describe the policymaking process, the factors that are considered in each step of the decision-making, and the sectors that constitute the social/political environment. The depth and way in which the social/political system and process are described here have been

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[12] This chapter is almost a copy of my previous report: Stella Maris Oggianu, Professor Kent F. Hansen, "Modeling the Dynamic Complexity of the Nuclear Policymaking Process and System: The High Level Nuclear Waste Issue." MIT-NFC-TR-033. July, 2001. Center for Advanced Nuclear Energy Systems, Massachusetts Institute of Technology. Cambridge, MA 02139-4307.

intentionally chosen to understand the cause-and-effect loops that represent the dynamic complexity of this system. They will be presented in Chapters 3, 4 and 5.

2.2 The Public Policymaking Process

2.2.1 Public Policy Definition

Public policy is the sum of government activities in response to a problem or matter of societal concern. The governmental bodies or officials belonging to the political sector make decisions considering several factors. These factors depend on the issue of concern. In the case of energy generation examples of influencing factors are availability of electric energy, costs of energy, security of supply, state of technology, environmental concerns, public opinion and actions, international standards, etc. A policy output may involve a law, services, money, taxes or moral suasion. It has an impact on industries or on the lives of citizens. The graphic representation of this definition of policy making from a systems dynamics prospective is seen in Figure 8. The word stimulus in Figure 8 refers to any matter of concern that can be the initiator of the policymaking process. Political system refers to the governmental bodies that actually create policies (i.e. the policymakers).

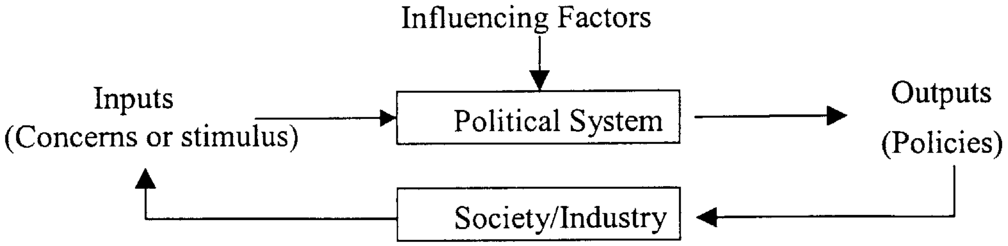

Figure 8: First level system approach for public policy making.

The substantive policy issues of concern at the federal level comprise making economic policy, health-care policies, social security and welfare, educational policy, defense and law enforcement and energy and the environment. The focus and examples in this report refer to energy policies. However, the policymaking process described here is general enough to be applied to any other issue.

Policymakers consider public opinion when setting their agendas and make their decisions. At the same time, the resulting policies have an impact on the society and industry. This feedback concept is represented in Figure 9.

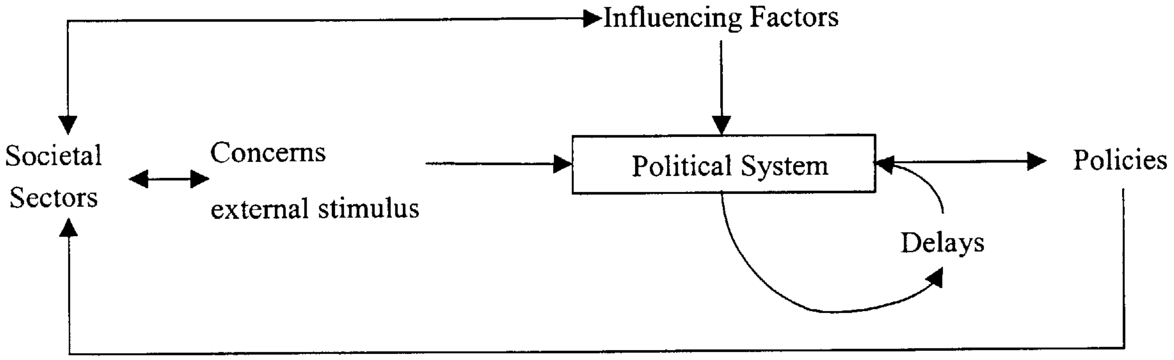

Figure 9: Overview of the policy making process.

Since the concern here is on energy policymaking in particular, it is beneficial to present the policymaking concept already introduced applied specifically to the energy sector.

2.2.2 The Policymaking Process

In general, the following steps can be identified in any policymaking process in democratic countries:

1) Agenda Setting. Public concerns come to the attention of policymakers

2) Formulation. It involves the development of pertinent and acceptable proposed course of action for dealing with public problems.

3) Legitimation. Policy formulation is actually treated and a decision is made. The output of this process is a policy.

4) Application. The policy is actually applied.

5) Evaluation and feedback. The results and impacts of policy application become evident. They actually modify the original inputs (i.e. stimulus or concerns) to the policymaking process.

These processes and their outputs are seen in Figure 10. However, in each of the processes there are a great number of factors influencing the nature of the outputs which have not been depicted in the figure. The next subsections will be devoted to explaining them in a certain detail.

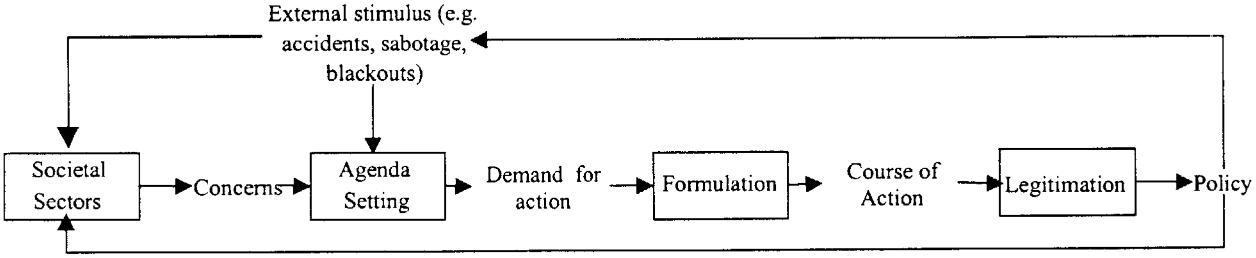

Figure 10: The Policymaking Process

Agenda Setting

Of the many demands made upon government, only a few receive serious attention from public policymakers. Those demands that policymakers choose constitute the political agenda. There may be many ways in which a problem reaches a political agenda. One way is suggested by Truman (Ref. 14, 15):

> When the equilibrium of a group (and the equilibrium of its participant individuals) is seriously disturbed, various kinds of behavior may ensue. If the disturbance is not too great, the group's leader will make an effort to restore the previous balance...*this effort may immediately necessitate recourse* to the government. Other behaviors may occur if the disturbance is serious to the point of disruption.

Some of the important factors in agenda settings are[13]:

- The existence of a **crisis** or a particular event. The recent blackouts in California are the most recent example of a crisis. Three Mile Island accident in 1979 is an example of a particular event.
- Political leadership and the sense of political risk. Political leaders may consider particular problems motivated by political advantage or by public interest.
- National security and leadership. Security of supply of energy, diversity of energetic resources and environmental issues are among these factors.
- Protest activities. As an example, anti-nuclear groups can act against the existence of nuclear power plants or a national repository.
- The attention of communication media and the elite can give more salience to a certain problem.
- Availability of technology. Problems will not be placed in the public agenda unless there is a technology believed to be able to solve it.

The representation of the agenda setting process and the influencing factors is seen in Figure 11.

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[13] For further discussion on some of these factor refer to ref. [15].

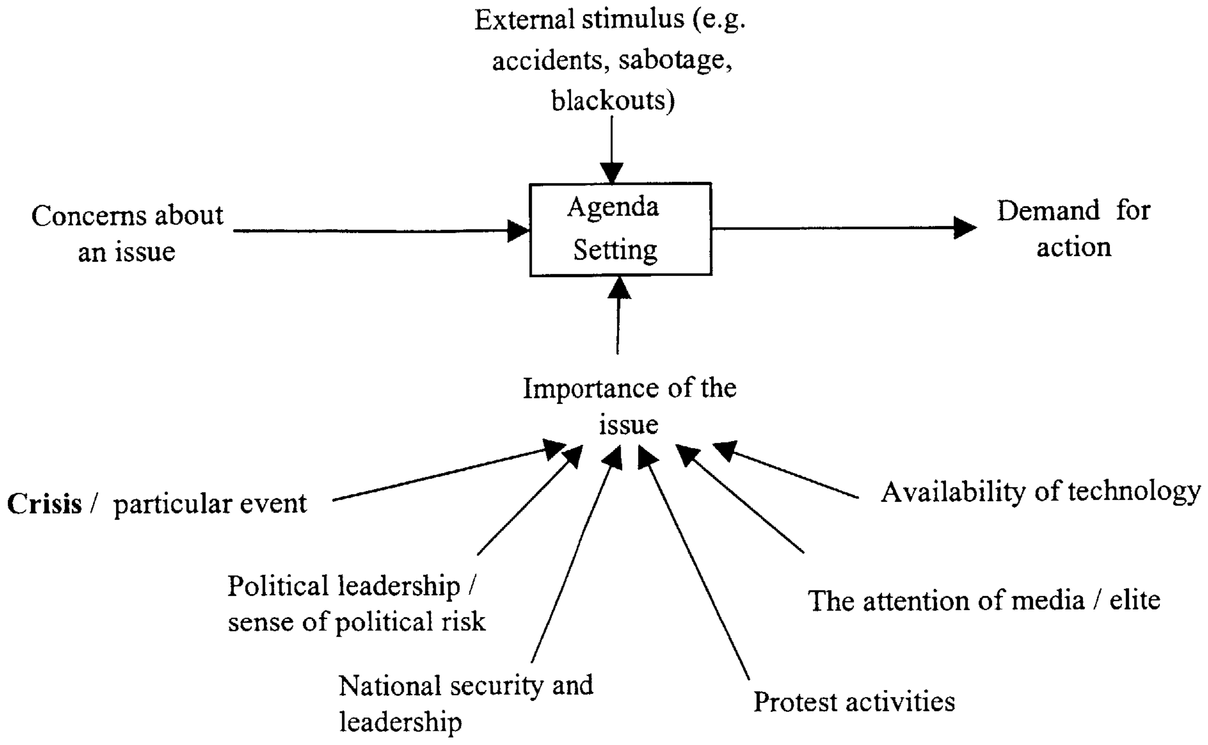

Figure 11: Agenda Setting

<u>Formulation of Policy</u>

After the political system (that will be described in Section 2.3.1) has put a problem inside the agenda for policymaking, the next step is the policy formulation. Not every problem that is on the political agenda is formulated.

Policy formulation involves two kinds of activities:

- The first is deciding what should be done about a particular problem. In the case of high-level nuclear waste management this activity may involve the scientific community, and for example the answer to the question: "What kind of repository is the safest and most strategic for the country?"
- The second activity is the actual writing of the course of actions meant to solve the problem.

Legitimation of Policy

In this process, the policy formulation is actually treated and a decision is made. The output of the legitimation is a policy. This process is actually a decision making one, in which the alternative formulations made in the previous step are approved, modified or declined. Among the several factors influencing the decision-making criteria for every policymaker are:

Political values and political party affiliation. Decisions are made based on which is the best alternative to achieve the goal of the political party. This concept is closely related to the political risk associated with what voters want. In general, Congressmen support their party position unless there are strong objections from their constituents.

Organizational values. This decision factor is of especial importance for administrative agencies, who may defer to the judgement of their directives.

Policy values. Decision-makers may act on the basis of his/her perception of the public opinion or on what he/she believes is morally correct.

Anderson (Ref. [15]) suggests that public opinion does not have much influence in significant policy issues. Regarding high-level nuclear waste, Kevin Crowley, Director of the United States Board on Radioactive Waste Management, suggested that public opinion had little consideration when deciding what to do with the nuclear waste.

Regarding the correctness of a policy in the case of energy-related issues, policymakers evaluate the long-term security of supply, national and international strategy and environmental effects. In evaluating these issues, scientific judgement is of special importance. Cost/benefit analysis is usually done[14].

Personal values. The urge to protect the self-being.

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[14] Cost/benefit analysis is a technique in which all costs and benefits of a proposal are reduced to an economic value and then compare among alternative policies.

Ideological values. In the case of the nuclear industry, a person may be anti- or pro-nuclear, for example.

Figure 12 represents the most important factors considered during the formulation and legitimation process. Initiation is a term used here to group both these processes. In Section 2.3.1 we explain how the actual action chosen from the many options in the United States.

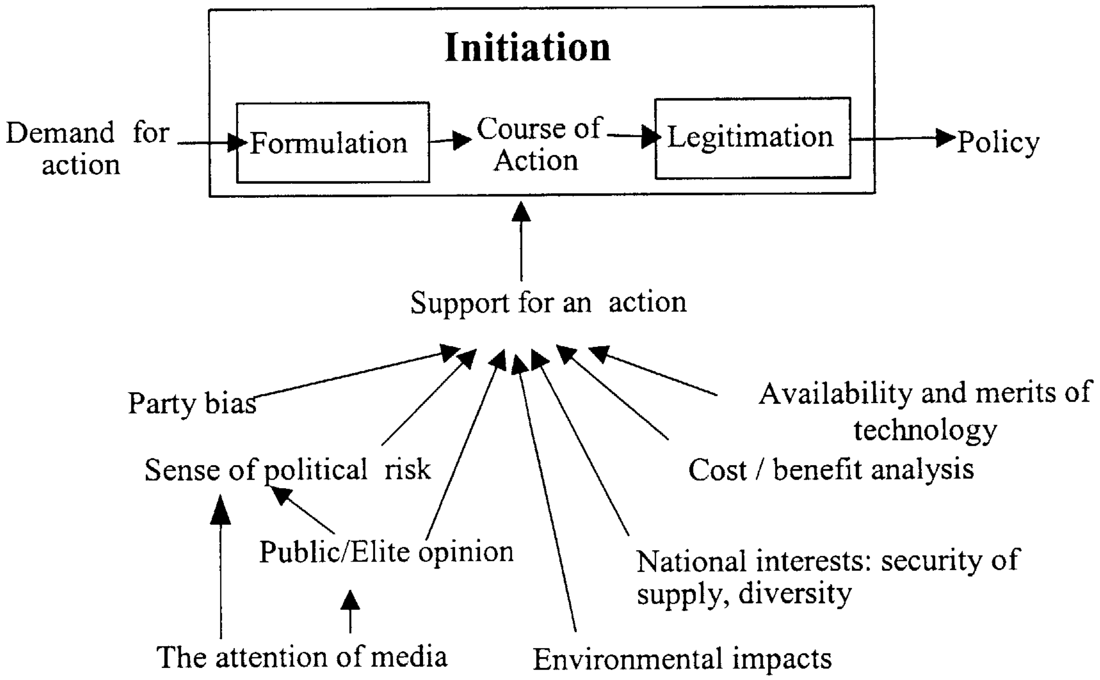

Figure 12: Factors Considered in Policy Formulation and Legitimation

Application, Evaluation and Feedback of Policy

Once one option has been adopted, it is implemented. In United States public policy is generally implemented by the administrative agencies. In the case of policies regarding energy issues, the Department of Energy (DOE) is involved. Courts have the task of enforcing these laws.

The content of a policy can be modified after its implementation. Policies have impacts on interest groups and industry, which may raise other concerns to levels such that the political sector has to modify the policy or re-initiate the process. This feedback loop is represented in Figure 8, Figure 9 and Figure 10.

2.3 The Social/Political Environment

An overview of the policymaking process in democratic countries was presented in the previous section. Many societal sectors are directly or indirectly involved in this process. Policies are made by policymakers and generally implemented by administrative agencies. Both, policymakers and bureaucrats belong to the political sector of society. However, when setting an agenda, formulating and legitimating a policy, the policymakers consider multiple factors, many of them come from other societal sectors. In the case of energy issues the sectors involved are the media, public, courts, industry and international is shown in Figure 13. Table 1 shows the subdivisions further considered. Each of them influences the others and will be addressed in the following sections.

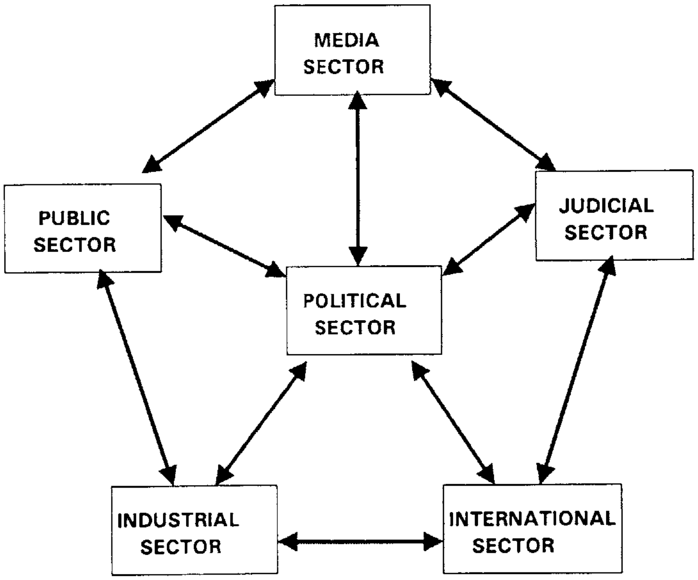

Figure 13: The Sectors

POLITICAL SECTOR Federal Congress White House Administrative agencies States	**JUDICIAL SECTOR** Courts (state and federal)
MEDIA SECTOR Niche Written Media (Books, Journals) Mass Visual Media Mass Written Media Reports (Newspapers)	**PUBLIC SECTOR** General Public Local Public Elite Interest groups and NGOs
INTERNATIONAL SECTOR International agencies Foreign Countries	**INDUSTRY SECTOR** Utilities Exploration, mining and production Enrichment Reprocessing Vendors

Table 1: The Sectors and Subsections

2.3.1 Political Sector

In this section, reference is made to the structure of the political sector in the Unites States. The structure by which policy is formulated, legitimated and implemented in the United States is complex. A complete picture of the structure and functions of the policymaking in the American government can be found in Refs. [16] and [17]. The American government has a great number of structures and has three levels of division: 1) Federalism, 2) Separation of powers, 3) Subgovernments.

Federalism is the constitutional allocation of governmental powers between the states and the federal government. This first level of division of powers is of significant importance in the high-level nuclear waste issue. Decisions on a national repository made at a federal level may conflict with the interest at state levels, as every state has to approve the storage and transportation of nuclear materials in its territory.

Separation of powers refers to the distribution of power in the federal government between three branches: *legislative* that makes law, *judicial* that interprets law and *executive* that enforces law. Figure 14 illustrates this concept and the functions and controls of each branch on the other two. In this discussion, and with the objective of building the model of the policymaking process, it is important to note that the president can veto pieces of legislation. The legislature has two chambers, the House of Representatives and the Senate. In each chamber there is a majority and a minority party: Democrats and Republicans alternatively. Each of the chambers can veto the other one's bill. The senate can also override a presidential veto, needing two-thirds of votes to do so. The majority and minority parties may or may not have the same political party as the president.

As an example, in 2000, President Clinton vetoed the nuclear waste storage bill that provided for storing high-level nuclear waste from commercial nuclear plants in 34 states at Nevada's Yucca Mountain. The senate failed to override President Bill Clinton's veto on a 64 to 35 vote—two votes shorter than needed.

Subgovernments, usually referred to as the "cozy triangles" or "iron triangles" involve 1) Congressional committees or subcommittees, for example the Committee on Energy and Natural Resources, 2) Administration agencies, such as the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA), 3) Interest groups, which may belong to the public or industry sectors. Pro-nuclear, anti-nuclear groups, environmentalists and the nuclear industry are included in the interest groups.

What has been called "the federal sector" consists of federal policymakers (including the legislative branch and the White House) and the administrative agencies. The administrative agencies advises the White House and implements policies. The White House consists of the President, Vice President and the Executive Office of the President. The White House, together with the federal agencies and departments constitute the executive branch. This definition of the federal sector excludes the courts, which are part of the judicial sector. The components of the political sector at the federal level are seen in Figure 15.

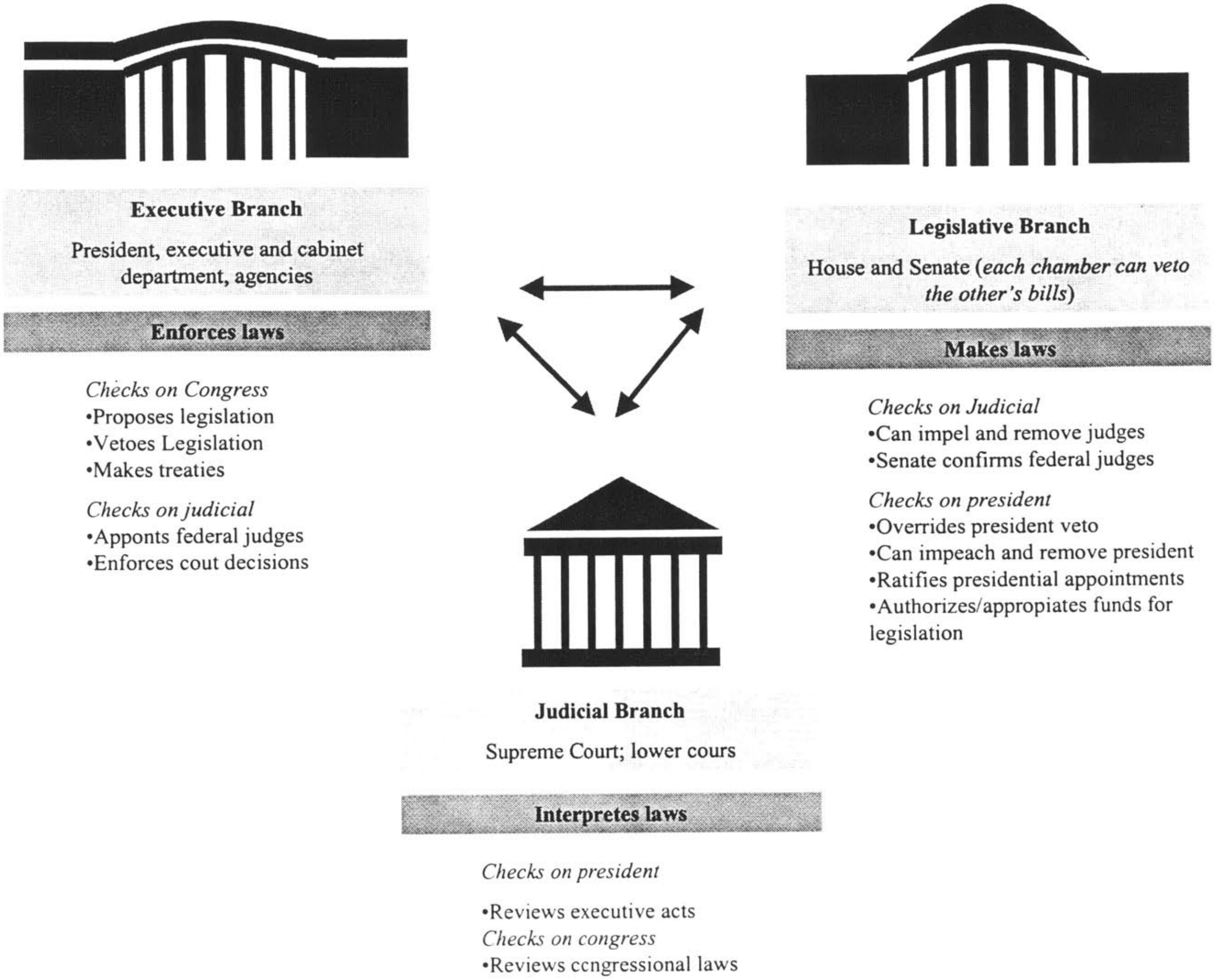

Figure 14: The Separation of Powers in the United States [15]

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[15] Source of figure: Ref. [17], Johnson, Miller, Aldrich, Rhode, Ostrom, *"American Government"*, 3rd Edition, 1994.

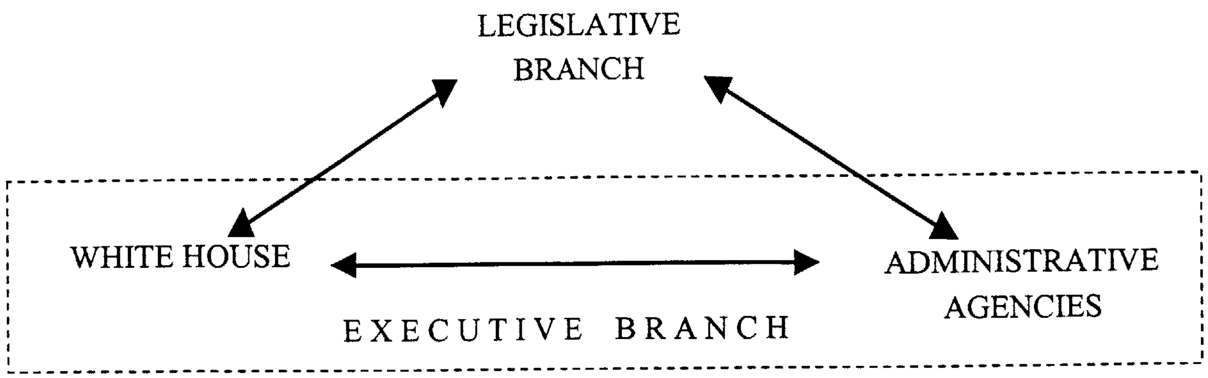

Figure 15: The Political Sector at the Federal Level (The Federal Sector).

2.3.2 The Judicial Sector: The Courts

The role of the courts is to review executive acts and legislative laws according the constitution. They also protect the interests of the citizens according to the laws. As will be seen in Chapter 4, the courts are playing an important role in the high-level nuclear waste issue. As an example, many nuclear power plants sued the DOE as a result of its failure to begin removing used nuclear fuels from plant sites. The courts found that the DEO is liable for damages caused by its breach of contract with the utilities.

2.1.1 The Public Sector

Although not done in the model, it is interesting to note that the behavior of the public sector varies, in general according to their geographical location, interests and beliefs. This division is considered suitable for this project: local public, general public, elite, academia/scientists and non-governmental organizations (NGOs). NGOs include interest groups (such as pro-nuclear, anti-nuclear and neutral groups). These subgroups are briefly explained in what follows:

- General public opinion is generally related to the voice of the "voters". The public is composed of millions of individuals who have different backgrounds and opinions. In democratic countries, the public is a source of political power: the public has votes. In this way, politicians will not go against what they perceived the public wants. Regarding nuclear issues, several surveys suggest that public opinion is in reality not so opposed as it is perceived. However, the issue of public acceptance for an expansion of the nuclear industry remains an important factor. In dealing with nuclear waste policies, the general public opinion is not a relevant factor[16].

- Local public is that part of the public that has physical proximity to a power plant, a nuclear repository or any other area where nuclear or fossil elements are handled. For the specific case of high-level nuclear waste, local public is directly affected by the installation of a nuclear repository in their neighborhood, so they may actively participate in the decisions. People in Nevada oppose the existence of a repository in their territory. However, the nearby people may benefit from employment opportunities and may favor the existence of such a repository.

- The Elite includes people that by virtue of their education or position have a great power over agenda setting and political decisions. The President of MIT or the Publisher of the New York Times are examples of elite.

- Academia and scientists can advise the policymakers on the advantages, disadvantages, consequences and costs of each alternative.

- Non-governmental organizations have an important role in changing the general public opinion and the perception of this opinion. They can also change the priority of a problem in the agenda of policymakers through protest activities, media information and campaigns quickly raising the awareness of an issue. Examples of anti-nuclear groups in the U.S. are Greenpeace USA, Union of concerned Scientists, N-base Nuclear Information Service,The Nuclear Waste Citizens Coalition and Sierra Blanca Legal Defense Page. Pro-Nuclear grounps include the American Nuclear Institute and the Nuclear Energy Institute. The RAND Institute is a neutral organization.

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[16] From personal communication with Kevin Crowley, Director of the U.S. Board on Radioactive Waste Management.

2.1.2 The Communication Media

The media sector in general can be further subdivided into the niche media and mass media. Niche media mainly comprise print magazines or books targeted to academia, industry or interest groups. In the case of mass media, both broadcast and print forms are equally important. Mass media can be seen as a profitable industry that publishes what the general public likes to read. In this way, in the case of nuclear issues, it represents anti-nuclear groups.

At the same time, mass media influences public opinion and creates the agenda for public discussion. Media can play an important role in putting an issue in the public agenda and bringing about political action.

2.1.3 The Industry

The heart of the electricity generation industry in the United States are the Utilities. Many of the utilities owners have interests that lie on both, fossil and nuclear power plants. It is estimated that U.S. utilities will need to construct more than 200 gigawatts (GW) of capacity in addition to the expansions currently planned (Ref. [18]). The decision to build nuclear or fossil power plants depends mainly on economical decisions, where uncertainty plays a major role.

Besides the utilities, there are specific players to the nuclear and to the fossil energy industries. Nuclear and fossil vendors, mining, and enrichment, are examples of such industries that would favor the growing of one or the other source of electricity according to their interests.

2.1.4 The International Sector

The international sectors refers to players external to the country and whose influences are considered in the decision making process. A specific example of international actors considered in the policymaking process is the international agencies that regulate the nuclear power plants standards (the International Atomic Energy Agency, IAEA, for instance).

2.1.5 Influential Factors

What we have called influential factors are all factors that are considered during the policymaking process. Regarding energy issues, many of them have been discussed along this chapters. However, as they are a crucial part of our model, a summarizing list is included here:

- The existence or a *crisis* of a particular event: This includes shortage of electricity supply, sabotage and accidents.

- Public *concerns* (includes general and local public and elite): They are considered by policymakers in order to match their position to the one of their constituents, and also maximize the resources available for the next political campaign. These concerns include environmental concerns, price of energy, safety, etc.

- Attention of the *media*: Media has the role to inform public and policymakers.

- *Protests and lobbying activities of competing interest groups*: In the case of energy issues, these groups can be environmentalists, anti- or pro-nuclear, for example.

- *National issues, such as security, diversity, leadership, costs.*

- The *bias* of political parties and their *position* in the White House and Congress.

These are the most important factors influencing the policymaking process. Regarding the utility decision making, we assume that the main driver is the net present value and the perceived investment risk, which depends mostly on historical political decisions about the support for a determined way of electricity production.

2.4 Summary and Conclusions

In this chapter, the public policymaking process and environment were discussed. Public policy is the sum of government activities in response to a problem or matter of concern. The governmental bodies or officials belonging to the political sector make decisions considering several factors, many of them come from diverse sectors in society, such as the media, the public, the courts, the industry, etc. The sectors influence each other. The subprocesses of the policymaking process include agenda setting, formulation, legitimation, application, evaluation and feedback. Some of the important factors in agenda settings are: the existence of a **crisis** or a particular event, political leadership and the sense of political risk, national security and leadership, protest activities, the attention of communication media and the elite and availability of technology. During the formulation and legitimation of a policy, the issue is treated and a decision is made. The result is a policy. Some of the most important factors during these processes are: political values and political party affiliation, organizational values, policy values associated with what must be done and with public opinion, ideological value. Once one policy option has been adopted, it is implemented. The content of a policy can be modified after the implementation as a result of feedback process.

The general conclusion is that the policymaking system is extremely complex and comprises multiple subsystems and flows of information that are interdependent. The overall processes, actors and factors have been mentioned and desegregated in a way in which they are considered to be simple and representative at the same time. It is evident that it is impossible to determine the output of a specific policy. However, it is possible to build a model to be able to determine for instance, how to influence the system in order to neutralize anti-nuclear opinions, reinforce pro-nuclear opinions, what's the best figure of merit to use, what are the most influential elements in the system, how to deal with transportation accidents, how would the system react to a certain stimulus, etc.

The theoretical information presented here is used as a background to introduce a first approach to a systems dynamics model of the policymaking system and that is presented in the next chapter. This model is intended to be a representation of the real system and has not yet been quantified.

Chapter 3: Overview of the Policymaking Process Model

3.1 Introduction

Our model of the policymaking process is designed for simplicity while representing the reality of the process. This model includes politcal decision making, utilities choices for different types of power plants, financial estimations, technical calculations and concerns estimations. Some of them are based on well-established physical or financial models. However, the added value of our work is in the modeling of the political decision making process and the way in which the multiple factors affecting the intensity and rate of the outcome policies are combined to produce policies affecting the future of nuclear, fossil and wind power plants.

This chapter is then devoted to give the general overview of the main ideas, simplifications and hypotheses of our work. Details of qualitative and quantitative approaches to estimate the actual value and validity of our models, and the preliminary results are given in the next chapters.

3.2 Model Overview

The model we developed is based on the theoretical framework presented in Chapter 2. The overall idea of this model is seen in Figure 16 and has as the main principles:

1. The federal government has been treated as a 'black box'. It produces policies that are the result of public awareness and own values on certain issues that are of national importance. What we have called policies here are regulations, legislations, speeches, actions or any other means of affecting the evolution of society and industries.

2. Among the issues that generates concern and are of importance are the production of waste: nuclear waste and greenhouse gases, which are the results of nuclear or fossil activities. (More detail about issues of importance is given later in this chapter)

3. The policies that the federal sector produces impact on the costs and perceived risks of each means of producing electrical energy. These parameters, together with the lifetime of the plants are used for calculating the net present value of each investment. In our model, this is the only factor affecting the utility decision on which type of power plants to build.

4. At the same time, the electricity production activities generates increasing concerns about multiple issues, some of them are the release of greenhouse gases, and the production of nuclear wastes, and have been mentioned above. Other factors are the safety, proliferation, cost, availability, and other environmental concerns, such as land utilization in the case of wind plants.

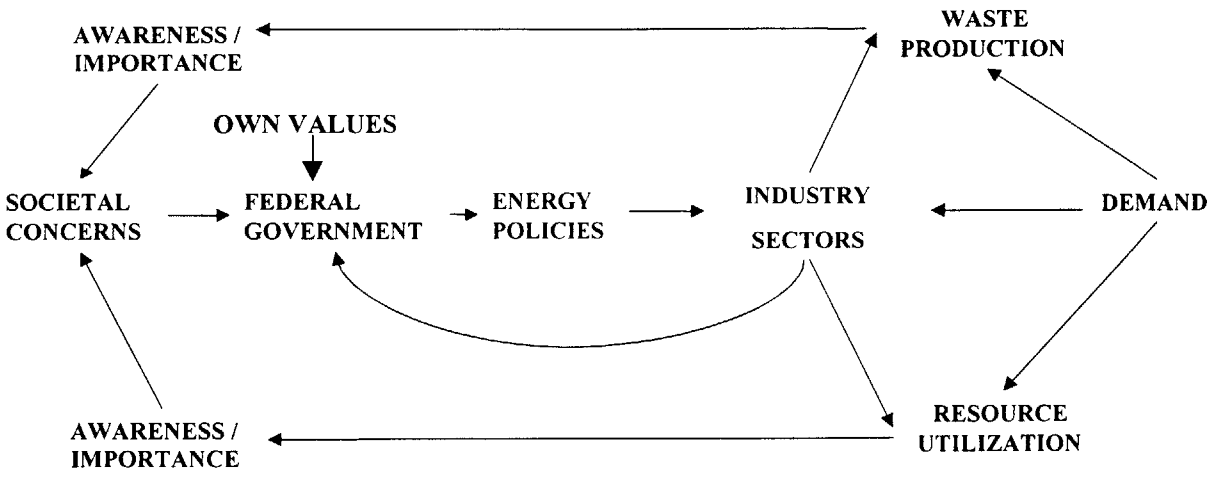

Figure 16: Energy policymaking model overview.

A more detailed schematic representation of our model can be seen in Figure 17. The electricity industry is included and it is composed of[17]:

- The nuclear sector

– The fossil sector, which groups gas, oil and coal.

– The wind turbines sector. As explained in Chapter 1, wind turbines are representative of all renewable sources of energy.

The production of electrical energy impacts on different issues. These issues or subjects of concerns include proliferation, safety, nuclear waste, greenhouse gases and other environmental concerns (land utilization, for instance), costs and availability of energy as seen in Figure 18.

We assume that the generation of energy by the different sectors influences one or many of these problems:

– Nuclear production affects nuclear waste, proliferation, safety, energy costs and availability issues.

– Production of energy using fossil fuels affects greenhouse gas emission, energy costs and availability issues.

– Wind turbines have an impact on environmental concerns, mostly related to the area of land needed for their deployment, the effect on birds, cost and availability of energy.

The functional forms that we used to obtain the estimated levels of concerns will be given in detail in Chapter 5.

Thus far, we have only given the basis of our model. In Chapter 1 we have mentioned that the main goal of this project was to have a model of the social/political process in order to understand where to reinforce the efforts to boost the nuclear industry. For doing that, important factors, other than the concerns introduced so far must be considered. These factors include:

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[17] The hydroelectric type of generating electrical energy has not been included in our model, due to its limited potential to be a growing source of energy in the future.

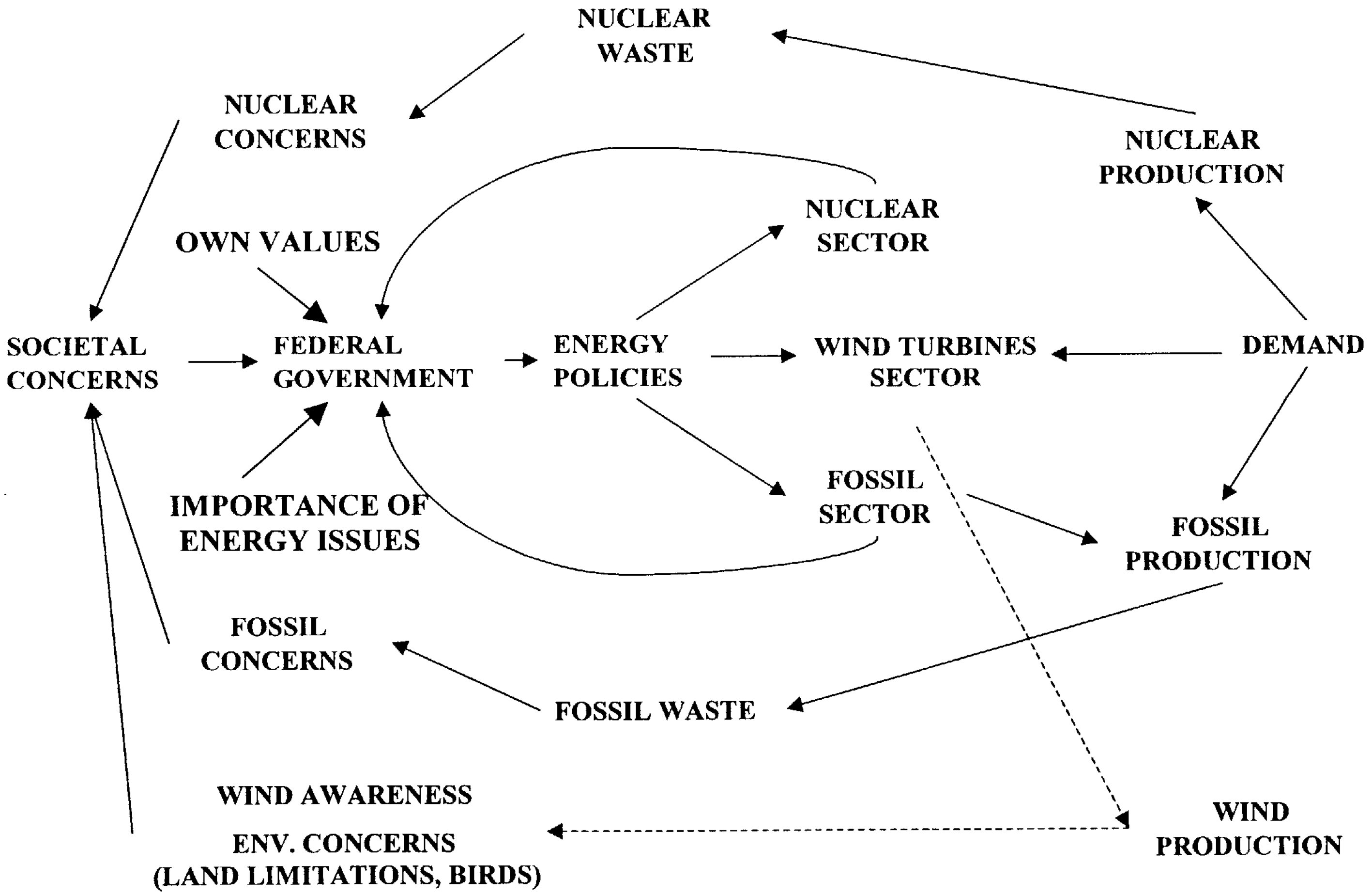
– Lobbying, to inform congressmen of what are the issues that matter, and frequently modify their bias and decisions.

– Public information, which can change preferences of voting by modifying public information. Public media is an important element in this regard.

– Political bias. As an example, in the United States the Democratic Party has not supported nuclear energy development while the Republican Party has shown a tendency to support the nuclear industry. This bias changes with elections that affect the dominant governing parties and with lobbying or information activities.

– Inherent perceived merits of technologies. These take into account how much each technology contribute to solving or worsening and issue of concern. As an example, nuclear power plants do not contribute to greenhouse effects, while fossil plants do so: nuclear power plants have a positive maximum merit regarding this issue, while fossil plants have a negative merit.

Figure 17: Energy policymaking model overview, including fossil, nuclear and wind energy plants.



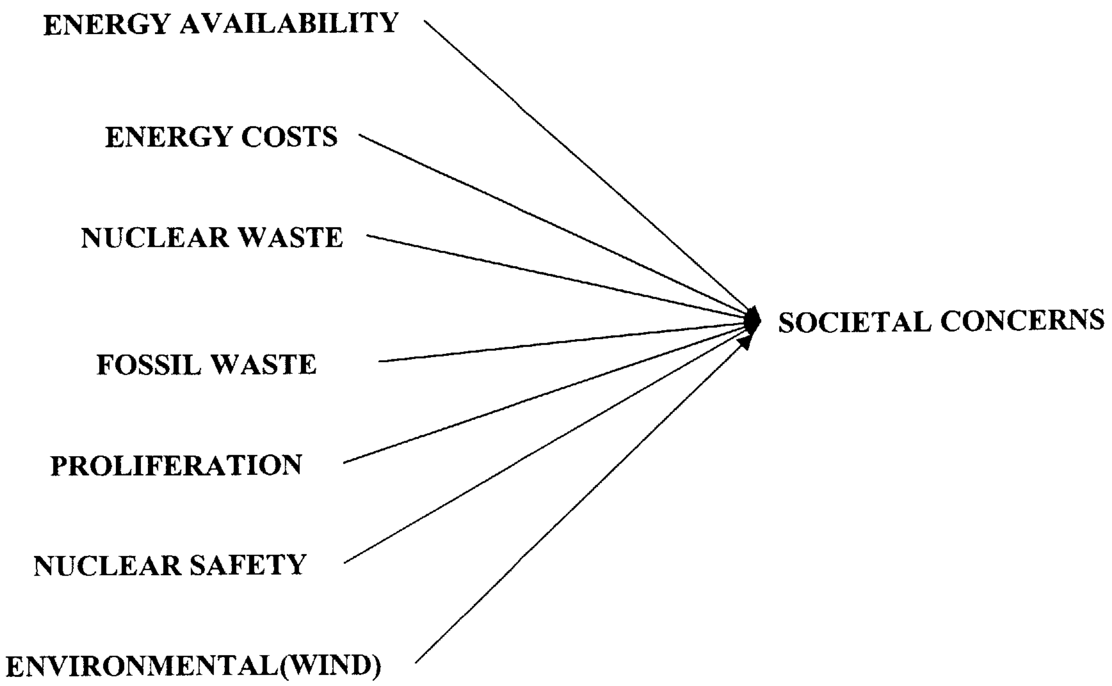


Figure 18: Societal concerns.

3.3 Core Concepts

Our brief introduction of the model has made it clear that there are number of concerns on several issues and factors that are considered in our model. To aggregate all of them in a way which seems to be consistent with what happens in reality, we have developed several concepts which are represented in Figure 19 and explained below.

We consider that policies are represented by an amplitude and a rate. The *policy amplitude* is a variable that represents how favorable or unfavorable a policy is to a certain type of technology. This variable can have positive and negative sign and depends on the *level of political support* for a type of energy. The level of support for a certain type of technology depends on its *figure of merit* and the policymaker's bias. The figure of merit is obtained for each type of technology and is a weighted average of the merits of that technology (i.e. fossil, nuclear or wind technology) regarding the issues of concerns. The weights we have used are related to the societal concerns regarding nuclear waste, proliferation, safety, cost, availability, greenhouse gases and other environmental concerns. In this way, the level of support ultimately depends on the opinion of the constituents, the merits of the technology and the policymaker's own bias. As seen in Figure 19.

Also notice that the perceived merits of technology, the political bias and the public concerns can be modified by information provided by media or by lobbying activities performed by different interest groups.

Regarding the *policy rate*, we consider that it is a function of the existence of an energy crisis or a particular event, both reflected in the concern of societal about energy issues.

Although the concepts of the level of importance, support, amplitude, merits and bias have been given generically, they are modeled for each type of energy. Figure 20 shows these concepts applied to nuclear, fossil and wind power plants. The actual functional relations that we have used for describing the behavior of all the variables that we have presented here are given in Chapters 4 and 5.

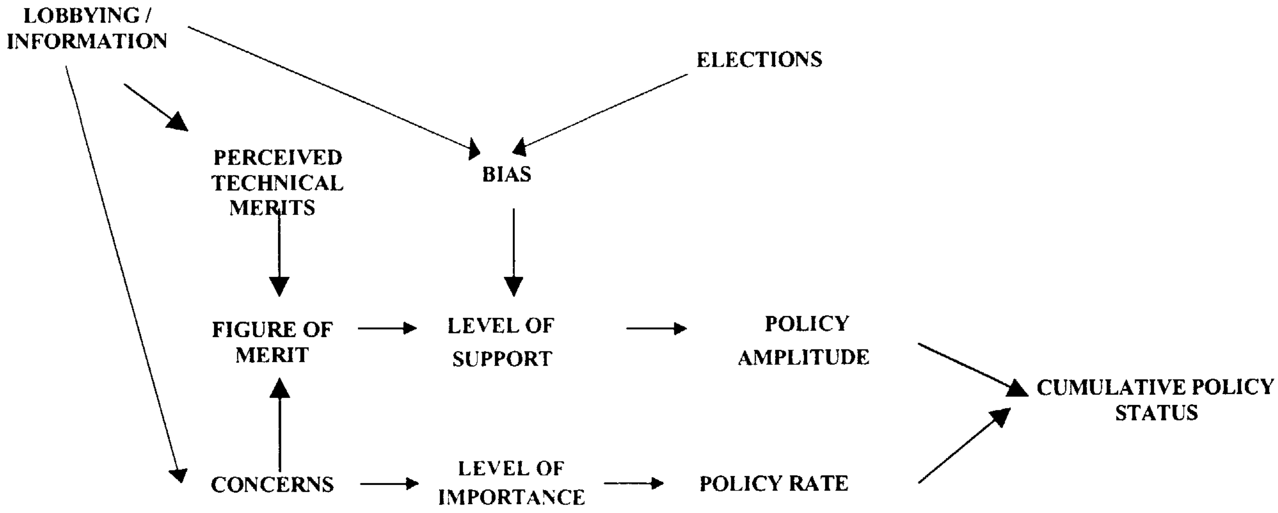


Figure 19: Estimation of Cumulative Policies

3.4 Summary and Conclusions

The model of the policymaking process that is presented in this thesis is based on the following:

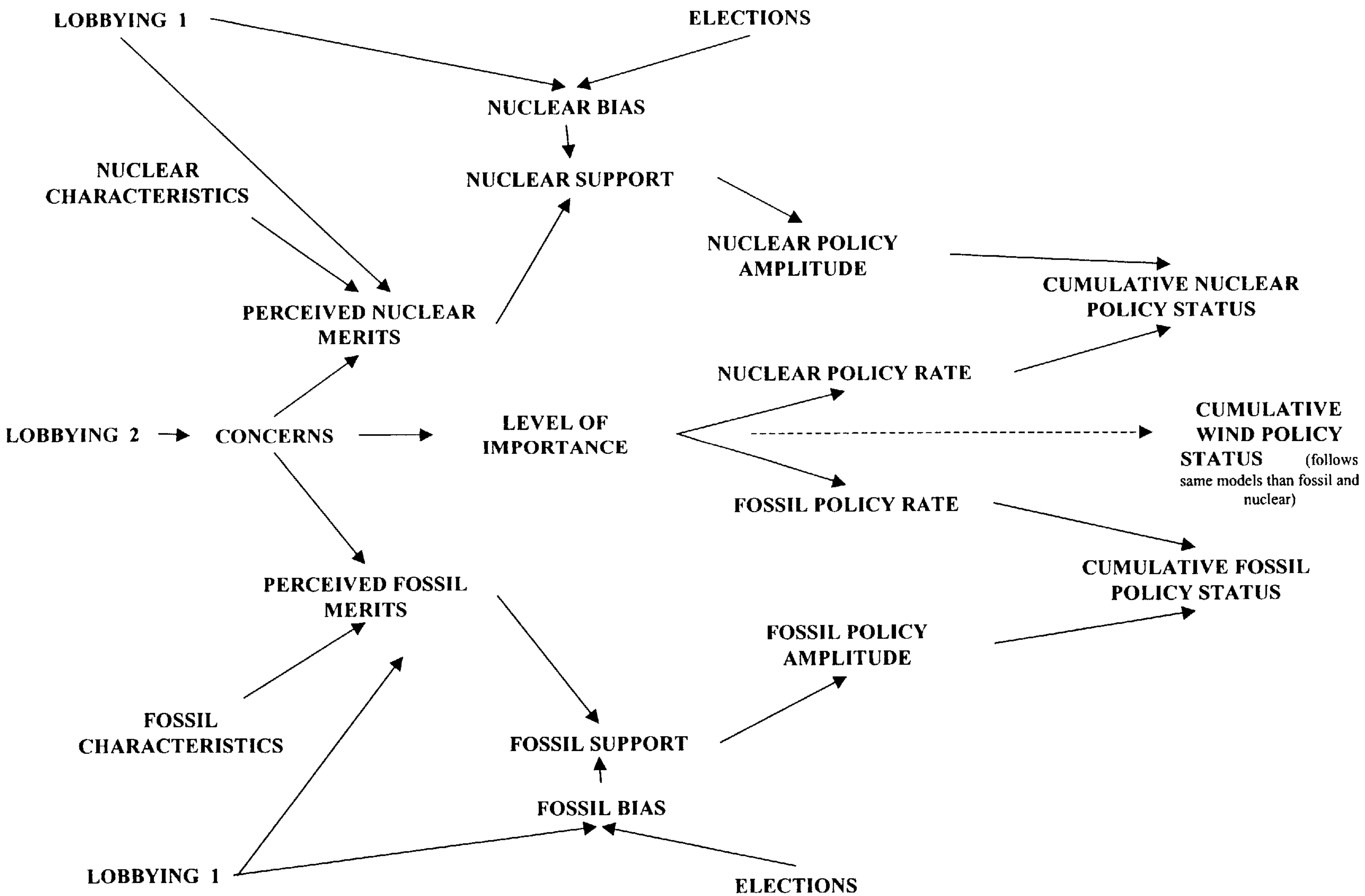
- The federal government has been treated as a 'black box'. It produces policies that are the result of public awareness and own values on certain issues that are of national importance.
- The policies that the federal sector impacts on the factor affecting the net present values of investments in nuclear, fossil, and wind energy. The NPVs are the only element that utilities consider when deciding on which type of power plants to build.
- Activities related to electricity production generate increasing concerns about greenhouse gases, nuclear waste storage, safety, proliferation, cost, availability, and other environmental concerns, such as land utilization in the case of wind plants. These issues are an input for the federal sector and close the main feedback loop.

Other factors considered in our model include lobbying, information, political bias and inherent perceived merits of technologies.

To aggregate all of these concerns and factors in a way which seems to be consistent with what happens in reality, we represent policies for each type of power plants (nuclear, fossil or wind) by an amplitude and a rate. The *policy amplitude* measures how favorable or unfavorable a policy is to a certain type of production power plant. It depends on the *level of political support*, which is estimated using the *figure of merit* and the *political bias*. The figure of merit is a weighted measure of the merits of a technology to the types of concerns that we are dealing with. At the same time, the perceived merits of technology, the political bias and the public concerns can be modified by information provided by media or by lobbying activities performed by different interest groups. Regarding the *policy rate*, we consider that it is a function of the existence of a crisis reflected in the concern of society about energy issues.

With this overview, it will now be easier to understand the details of the model. The calculation of the policy amplitude and rate, together with the level of support, level of importance, and figure of merit will be explained in Chapter 4; while the technical side of the model, including the calculation for availability of nuclear waste storage, greenhouse gas release, concerns, etc. is left for Chapter 5. Results of the model are presented in Chapter 6.

Figure 20: Model Representation



Chapter 4: The Energy Policymaking Model: the Social-Political Side

4.1 Introduction

This chapter presents the first quantitative approach to model the sociopolitical part of our model of the energy policymaking process. The main outputs of this part of our model are the calculation of policy amplitude and rate regarding nuclear, fossil and wind technologies. These six variables are obtained through the level of political support, the level of political importance, the merits of each type of technology and the perceived public concerns regarding electricity availability, costs, proliferation, safety, greenhouse effect, nuclear waste and environmental effects caused by wind turbines.

4.2 Policy Amplitude

In our representation of the energy policymaking process, *Policy Amplitude for the Nuclear Industry*, *Policy Amplitude for the Fossil Industry,* and *Policy Amplitude for Wind Turbines* are variables that represent how favorable or unfavorable policies are to the development of nuclear, fossil and wind power plants, respectively. Historical or potential examples of policies that affect the development of these industries include:

for the fossil industry:

- The 1990 Clean Air Act established taxes on SOx and NOx emissions. This was an unfavorable policy for the fossil industry, and imposed a quota and tax approach on acid rain gas emissions.

- A carbon tax would be an unfavorable policy for the fossil industry. As there is no way to prevent carbon dioxide to be released during fossil fuel combustion, this would be an additional burden to the industry that would be forced to pay the price or evaluate other ways of electricity generation.

for the nuclear industry:

- In the late 70's, after the accident in Three Mile Island, extra safety features were required for licensing nuclear power plants. Many of these safety devices were unnecessary and increased the capital costs required for building nuclear power plants. This is an example of an unfavorable policy for the nuclear industry.

- On 17th May 2001, President Bush signed the new energy strategy which placed nuclear energy as an important long-term alternative. This is a favorable policy for nuclear energy.

for the wind turbines industry:

- A favorable policy for wind turbines could be that the federal government gives parts of federal land for wind turbines farming purposes. This would decrease the required high capital cost for wind turbines.

In all these examples, there are environmental, safety, energy availability, and political reasons for the creation of the policy. Besides, there are energy policies that arise as a result of the need for diversity, electricity costs and proliferation concerns. At a given time, the energy policies are the result of the combination of all these factors weighted by their importance at that time.

In our model, the policy amplitude for all types of energy ranges from –1 to 1, depending on the impact of these policies on the electricity costs. In this way, it partly determines the future growth of the industry. Although it is impossible to establish the exact number on this scale for each policy, the amplitude of a policy for a technology is obtained by observing the impact on the cost of producing energy by that mean of generating electricity: if a policy causes a high increase in the cost of nuclear power plants, then that policy for the nuclear industry has an amplitude equal to –1; if the policy causes the cost of producing electricity to drop considerably, then that policy has amplitude +1.

In our model, the electricity costs are affected by the accumulation of policies in the last 10 years rather than by single policies. The policy impact on the economics of the nuclear, fossil and wind power industry will be one of the main subjects of Chapter 5.

Figure 21 shows the estimated shape of the policy amplitude for each type of power plant as a function of the level of the political support for that particular type of energy. The shape of this curve is based on our intuition. In future steps, we will revise historical data in order to determine the most appropriate shape of the curve.

The concepts behind the level of political support are explained in the next section.

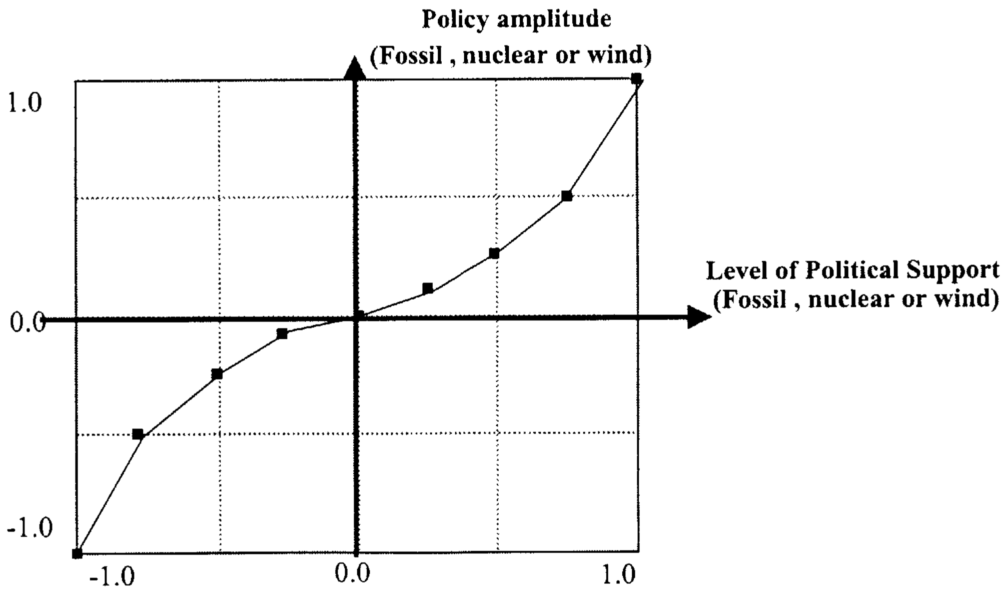


Figure 21: Policy amplitude as a function of the level of support.

4.3 Level of Political Support

The *Level of Political Support for the Nuclear Industry*, *Level of Political Support for the Fossil Industry*, *Level of Political Support for Wind Turbines* are variables that represent the intensity with which the political sector support the growth of the nuclear, fossil or wind industries, respectively.

Historical examples suggest that the level of political support for a technology is a function of the political bias towards that technology and the perceived merits of a technology to help solve the problems around energy issues, as shown in Figure 22.

The levels of political support as a function of these variables for nuclear, fossil and wind turbines as calculated in our model are shown in Figure 23, Figure 24 and Figure 25 respectively. The bias and the figure of merit for each type of technology are explained in the following subsections.

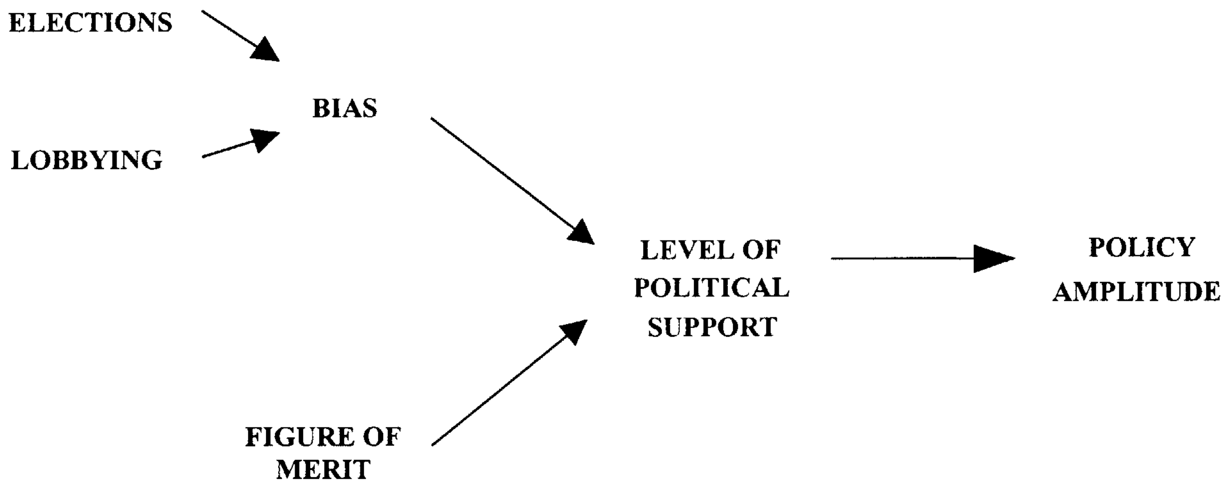


Figure 22: Influence Diagram for the Level of Political Support.

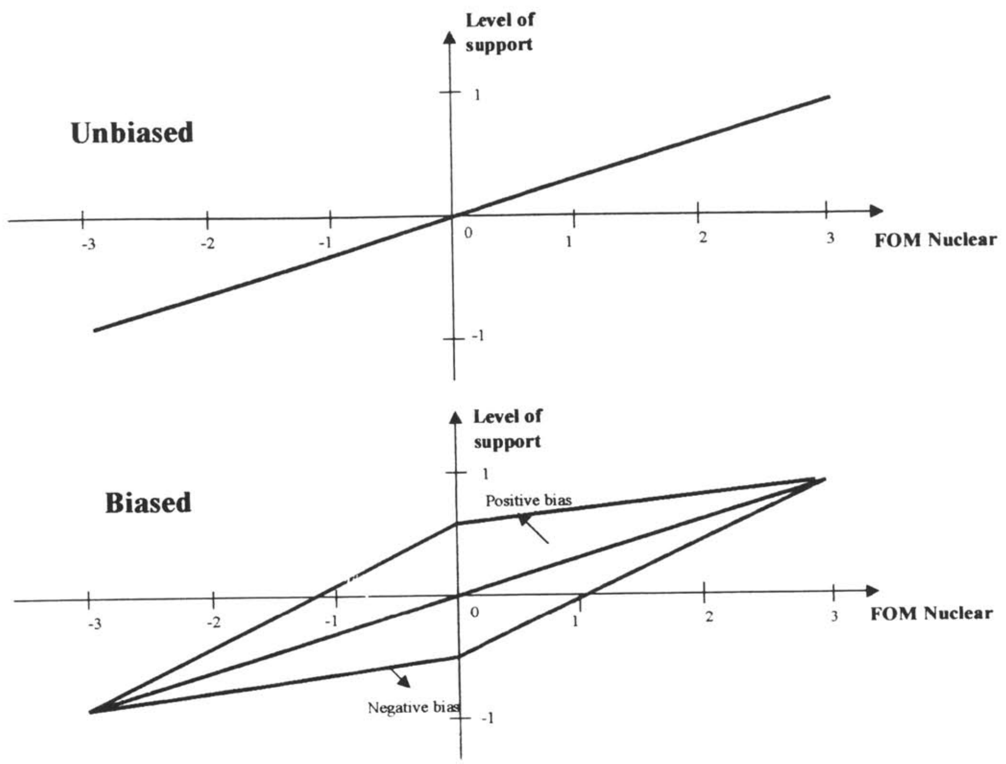


Figure 23: Level of Support for Nuclear Power Plants as a Function of their Figure of Merit.

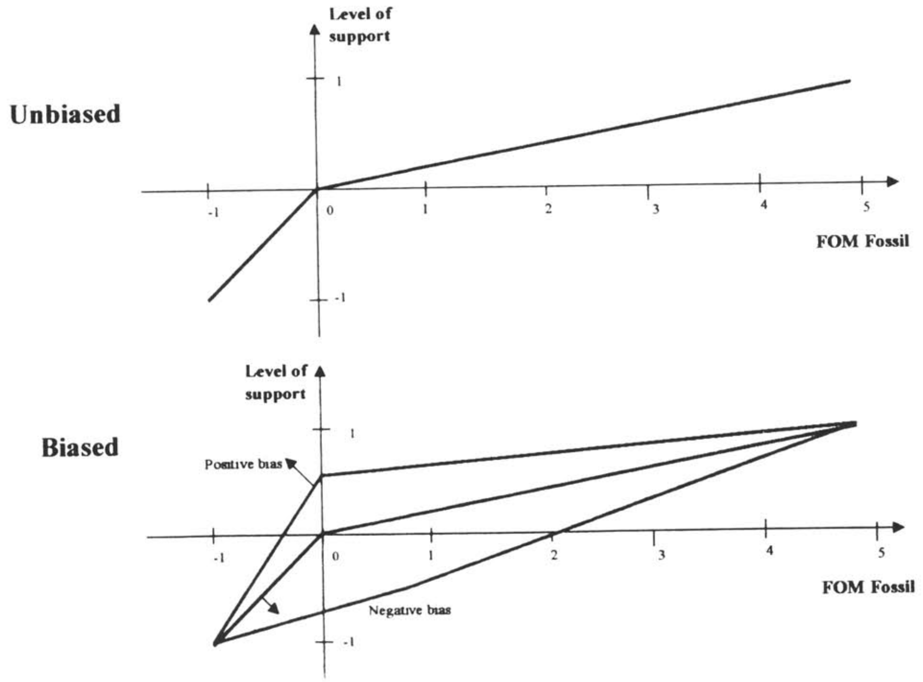


Figure 24: Level of Support for Fossil Power Plants as a Function of their Figure of Merit.

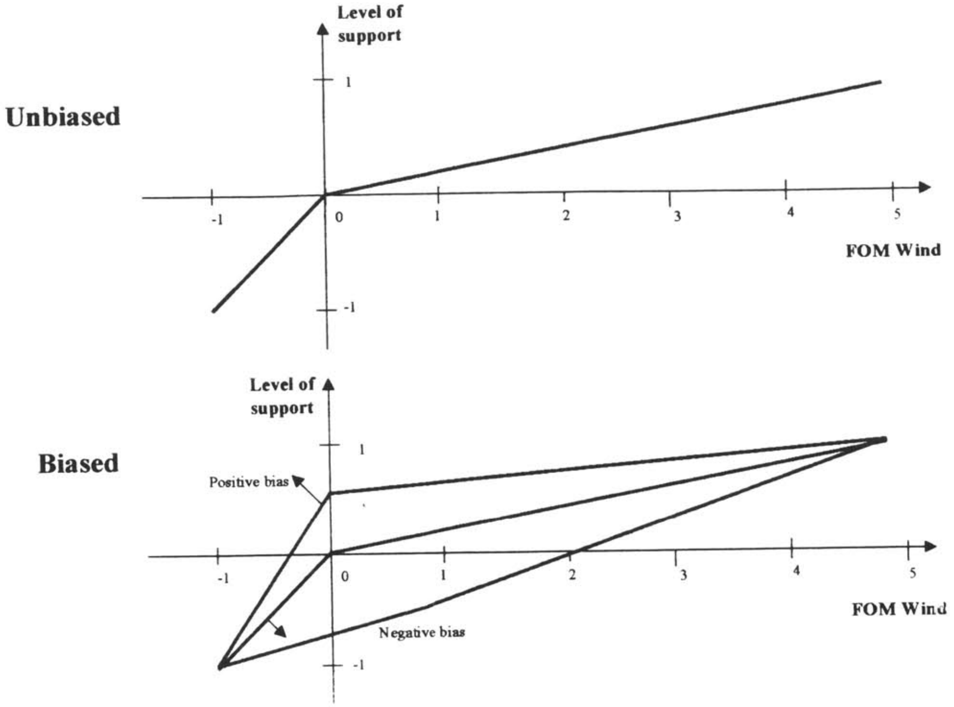


Figure 25: Level of Support for Wind Turbines as a Function of their Figure of Merit.

4.4 Political Bias and Lobbying

Politicians maximize the output of their elections through matching their positions to their constituent's and obtaining money provided for political campaigns by interest groups [18]. The incorporation in the model of variables representing the political bias and the lobbying effects in the level of political support is essential. Historical events show that in general Democrats have not supported the development of nuclear power plants while Republicans are less biased towards the development of the industry. Examples showing that each political party may have a particular bias towards a way of generating electricity are:

---

[18] Personal interview with MIT Professor De Figueredo.

- President Eisenhower's Atoms for Peace Program supported the development of the nuclear industry in the '50s. Eisenhower was a Republican President. (See Ref. [1])

- President Carter (Democrat) deferred civilian reprocessing in 1977. This nearly ends up the era of the nuclear power plants development in the United States.

- In 2000, President Clinton (Democrat) vetoed a bill that would have accelerated the opening of Yucca Mountain as an ultimate repository for nuclear waste.

- In 2001, President Bush (Republican) recommends building new nuclear power plants as a way to generate cheaper electricity.

The examples above suggest that political bias in the United States depends on the dominant political party and on lobbying activities by interest groups. These groups perform lobbying activities by informing Congress, providing money for political campaigns, and also by changing public opinion through information activities. In this way, lobbing activities to influence policy output in many ways, including:

- Change preferences for voting. This causes constituent's opinions to change and so, moves politicians actions to match with the opinion of their constituents.

- Change policymakers bias by informing Congressmen of what really matters and/or provide money for campaigns. These ways of lobbying are directly affecting the policymakers' bias for a way of solving a problem. The Federal Election Commission files data on money given by interest groups for political campaigns.

Other examples of matching Congressmen opinion with their constituents, political party bias and lobbying activities include:

- Yucca Mountain and the people of Nevada.

  Nevada Senator Harry Reid, Democrat, claims to represent Nevada's public when he comments against Yucca Mountain and the transportation methods.

> Congresswoman Shelley Berkeley, a Democrat, said the DOE's scientific evaluation concerning the repository's ability to safely contain the waste was "incredibly optimistic," and conformed only to the "lowest possible standards." She said "Nevadans don't want this project."

– Money for campaigns. Historically, interests groups, including environmentalists, industry, etc. have given money for political campaigns. The Federal Election Commission files this information.

– NEI efforts to educate and provide information. NEI then serves as a unified industry voice before the U.S. Congress, Executive Branch agencies, and federal regulators, as well as international organizations and venues. NEI also provides a forum to resolve technical and business issues for the industry. Finally, NEI provides accurate and timely information on the nuclear industry to members, policymakers, the news media, and the public. (Ref. [19])

Figure 26 is a representation of the lobbying effect on the bias and the concerns of people on different issues, including nuclear safety, proliferation, nuclear waste, greenhouse gases and other environmental effects, availability of energy and costs. The way we have expressed these influences in the model of the policymaking process is:

1. Three variables were introduced to represent the political bias: *Political bias for Nuclear*, *Political bias for Fossil*, *Political bias for Wind*. These variables vary range from –1 to 1.
2. The lobbying effects can positively or negatively modify the bias, continuously or in steps.
3. The lobbying effect on concerns can be represented by shifts of public opinion.

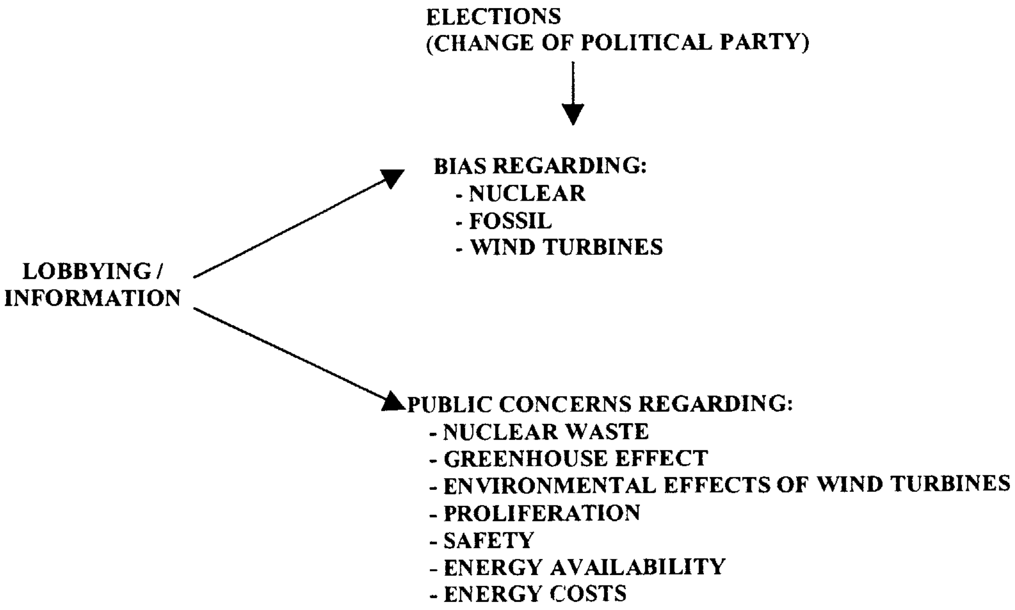


Figure 26: Diagram Representing the Lobbying Effects on the Public Concern and Political Bias.

4.5 Figure of Merit

The level of support for nuclear, fossil or wind technologies is related to the political bias and their merits to help solve the problems around energy issues as perceived by policymakers. Examples are:

- President Carter's decision of prohibiting reprocessing was mainly driven by the fear that some countries could access the materials needed for atomic bombs after the Indian test of nuclear bombs during 1973 and 1974 (proliferation concern).
- Bush's support for nuclear industry is associated to a historical period when greenhouse gases are the potential cause of a global warming and after the energy crisis in California. Therefore, this positive support for the nuclear industry was mainly driven by energy availability and greenhouse effect concerns.

It is evident that at a given point in time, the perceived merits of a technology (i.e. nuclear, fossil or wind turbines) are related to the concerns on relevant issues and to the perceived value of the technology as a solution to the problem. In our representation, the *Figure of Merit for Nuclear*, the *Figure of Merit for Fossil* and the *Figure of Merit for Wind Turbines* are variables ranging from -1 to 1 and are obtained considering the perceived merits of that technology and the perceived public concerns regarding energy availability, nuclear waste, greenhouse gases, safety, proliferation, and other environmental issues mainly related with wind turbine technologies. This is expressed as:

Figure of Merit for Nuclear, $FOM^N = \sum_{i=1}^{6} w_i F_i^N$

where: $w_i = concern_i$ is the weighting factor for the i^{th} issue.

i = availability, nuclear waste, greenhouse effect, safety, proliferation, environmental problems related to wind energy.

F_i^N is the merit of nuclear regarding the i^{th} issue.

FOM^N ranges from -3 to 3 because of the values of the merits of nuclear power plants, which will be explained in the next section.

Figure of Merit for Fossil, $FOM^F = \sum_{i=1}^{6} w_i F_i^F$

where: $w_i = concern_i$ is the weighting factor for the i^{th} issue.

i = availability, nuclear waste, greenhouse effect, safety, proliferation, environmental problems related to wind energy.

F_i^F is the merit of fossil power plants regarding the i^{th} issue.

FOM^F ranges from -1 to 5 because of the values of the merits of fossil technologies.

<u>*Figure of Merit for Wind Turbines*</u>. $FOM^{W} = \sum_{i=1}^{6} w_i F_i^{W}$

where: $w_i = concern_i$ is the weighting factor for the i^{th} issue.

i = availability, nuclear waste, greenhouse effect, safety, proliferation, environmental problems related to wind energy.

F_i^{W} perceived merit of wind turbines regarding the i^{th} issue.

FOM^{W} also ranges from -1 to 5 because of the values of the merits of wind turbines.

Figure 27 shows an influence diagram of the perceived figure of merit for nuclear, fossil and wind turbines. The concerns and the figure of merit of the different technologies regarding the six different issues considered in the next sections.

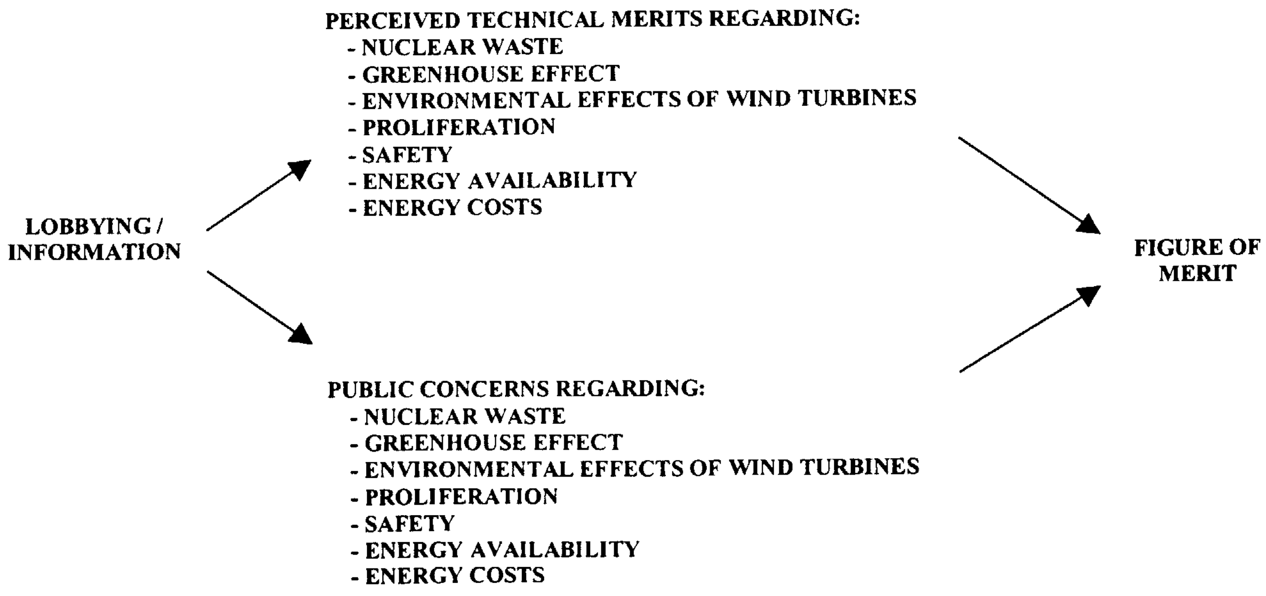


Figure 27: Influence Diagram Representing the Figure of Merit Calculation

(The same pattern is repeated for Nuclear, Fossil and Wind Turbines).

4.5.1 The Perceived Merits of Nuclear, Fossil and Wind Power Plants

The perceived merit of nuclear, fossil and wind turbines regarding availability, nuclear waste, greenhouse effect, safety, proliferation and environmental related issues are 18 variables summarized in Table 2. Their individual values range from –1 to 1 and they represent the perceived value to contribute to worse or improve a problem of each of the three electricity generation technologies considered.

Some of the values that we have used for these variables are included in Table 2. Those which are not fixed and depend on many other parameters are shown in separate figures.

Table 2: Merits of Nuclear, Fossil and Wind Power Technologies.

Availability	F^N_{av}	Depends on construction times	F^F_{av}	Depends on construction times	F^W_{av}	Depends on construction times
GHG	$F^N_{GHG} = 1$	Nuclear does not contribute to GHG emissions	F^F_{GHG}	Depends on technological advances, lobbying	$F^W_{GHG} = 1$	Wind does not contribute to GHG emissions
Nuclear Waste	F^N_{NW}	Depends on technological advances, type of technology and lobbying (perception)	$F^F_{NW} = 1$	Fossil plants do not contribute to nuclear waste production	$F^W_{NW} = 1$	Wind turbines do not contribute to nuclear waste production
Proliferation	$F^N_{Pr.}$	Depends on type of technology and perception	$F^F_{Pr.} = 1$	Fossil plants do not have proliferation problems	$F^W_{Pr.} = 1$	Wind turbines do not have proliferation problems
Safety	$F^N_{Safety} = -1$	Important only during accidents, weighted by the concern (different than 0 after an accident)	$F^F_{Safety} = 1$	Fossil plants do not have safety problems	$F^W_{Safety} = 1$	Wind turbines do not have big safety problems
Environmental (Land occupation)	$F^N_{LO} = 1$	Nuclear plants do not occupy big areas of land nor represent a danger for birds in this sense.	$F^F_{LO} = 1$	Fossil plants do not occupy big areas of land nor represent a danger for birds in this sense.	$F^W_{LO} = -a$	Wind turbines have noise pollution problems and may cause problems with birds if in big areas of land.

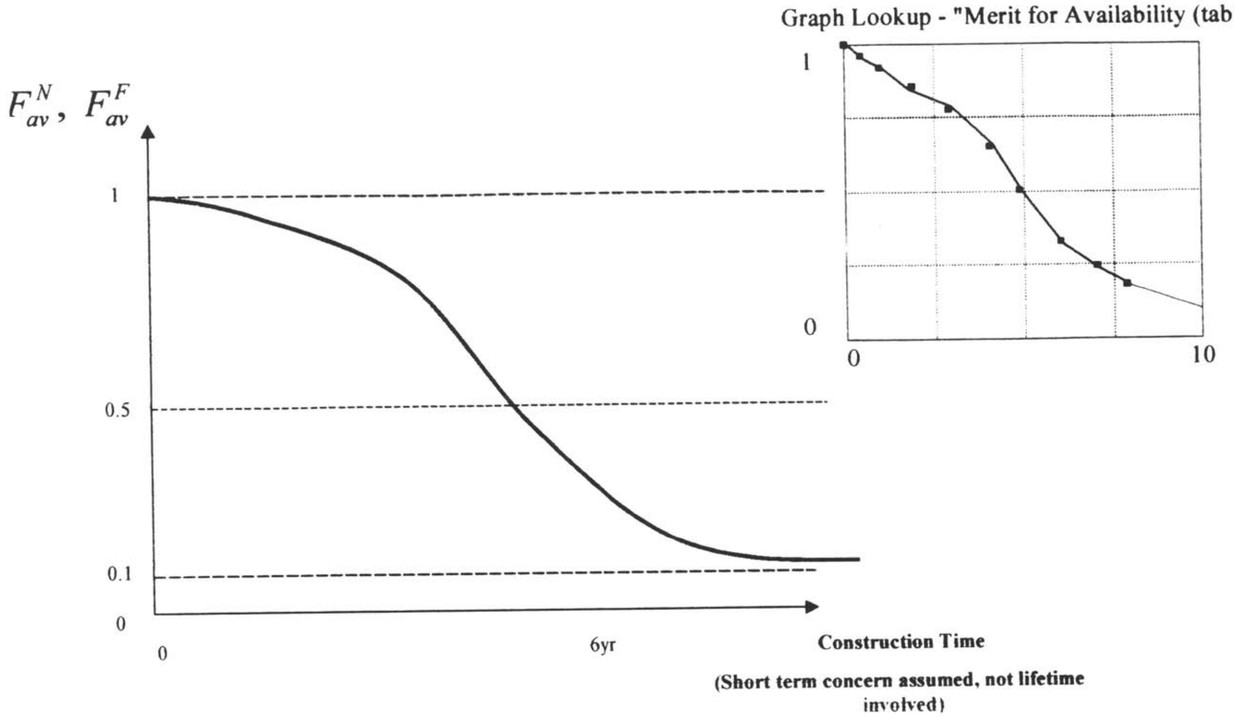


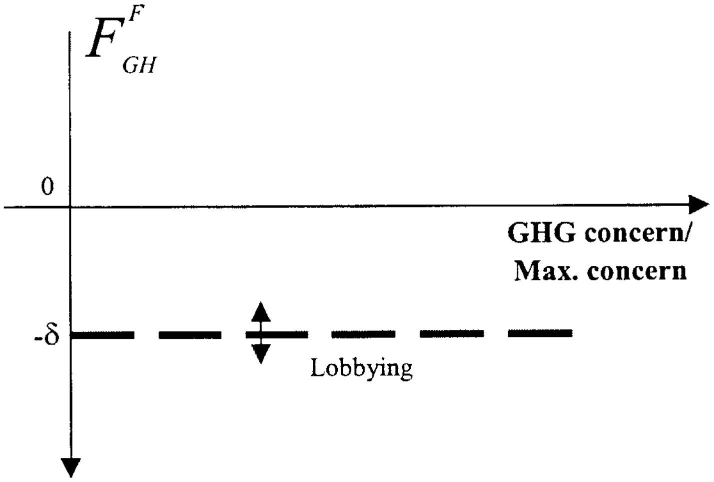
Figure 28: Nuclear and fossil merit for the energy availability issue.

The merit on energy availability of any technology is a function of the time of construction of the nuclear, fossil and wind power plants as shown in Figure 28. In the basic case, we considered 6 years the construction time for a nuclear power plant and 3 years the construction time for a fossil power plant and also for a wind turbine farm.

Figure 29 shows the perceived merit of plants regarding the greenhouse effect issue. Any fossil source of energy inevitably releases greenhouse gases. This is why the merit of fossil sources for the greenhouse effect is negative. In our model, this is represented by a number varying from –1 to 0. The exact negative number is unknown and depends on the type of fossil fuel used and the perception of the problem.

The same is true for the merits of the nuclear industry regarding safety, proliferation and nuclear waste: they are negative number and depend on the nuclear technology used and the perception of the problem. These issues are shown in Figure 30 and Figure 31.

Figure 32 shows the merit of wind turbine for other environmental effects such as land occupation, noise and bird issues. This is also considered a negative variable, which varies on the perception of the intensity of the problem.



Basic Case $F^{F}_{GH} = -1$

Figure 29: Fossil merit for the greenhouse effect issue.

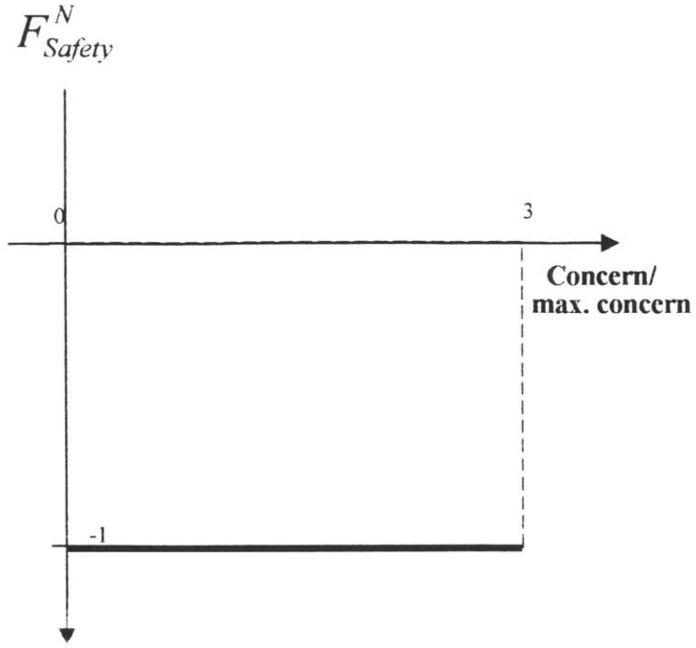
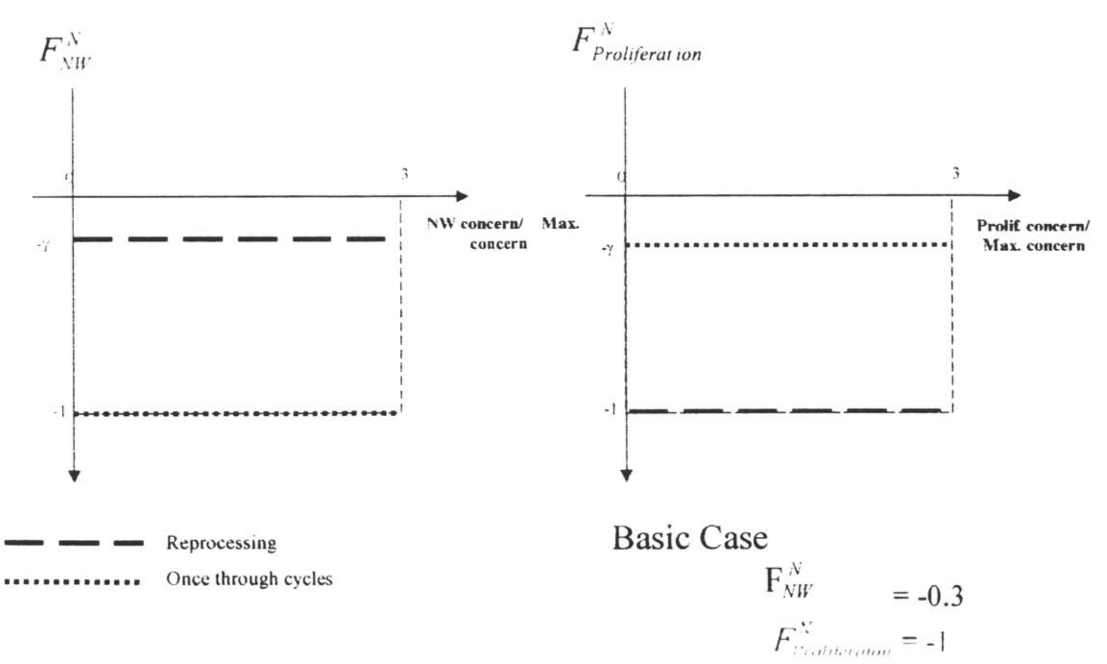


Figure 30: Nuclear a merit for the safety issue.



Basic Case

$F^{N}_{NW} = -0.3$

$F^{N}_{Proliferation} = -1$

Figure 31: Nuclear merit for the proliferation and nuclear waste issues.

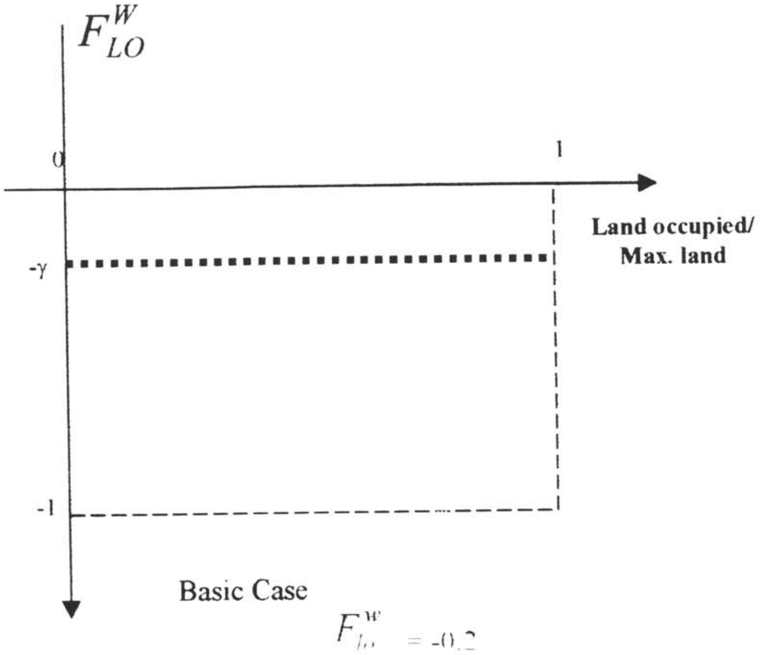


Figure 32: Wind merit for the land occupation issue.

4.5.2 The Perceived Concerns

As seen in Section 4.5, the figure of merit for nuclear, fossil and wind turbines are calculated based on the weighted perceived merits of these technologies regarding energy availability, proliferation, safety, nuclear waste, greenhouse effect and environmental impacts of wind turbines. In our model, these weights are equal to the concerns on these issues. In this section we present the curves used in our model of the energy policymaking process to calculate these concerns. Lobbying, including media reports and education programs, can shift all the curves presented here.

Concern about Energy Availability

The public concern regarding availability of electricity is a function of the ratio of the demand and the supply of electricity in the United States. We assume that this concern increases steadily when this relation is approximately above 0.90 as shown in Figure 63.

The electricity demand function is exogenous to the model and we consider that it will increase steadily at an annual rate of 10 GWe. At any time, the electricity supply is calculated as the sum of the electricity provided by nuclear, fossil and wind power plants.

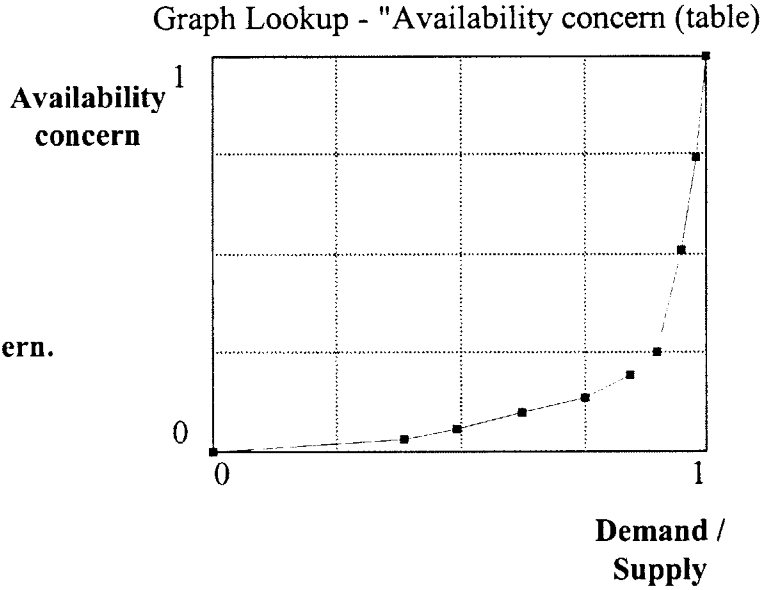


Figure 33: Availability Concern.

Proliferation Concerns

For simplification reasons, we consider that the public concern on proliferation is a constant number and exogenous to the model as shown in Figure 34.

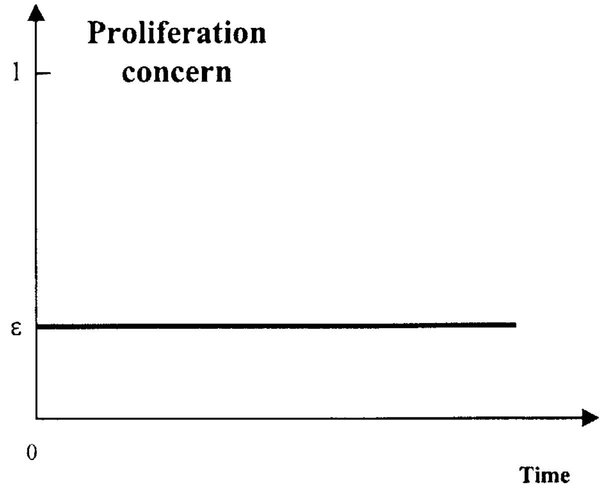


Figure 34: Proliferation Concern.

Safety Concern

We assume that safety concern exists only after a nuclear accident. The amplitude and decay time for this concern depends on the severity of the accident. The occurrence of an accident is a variable exogenous to the model. Figure 35 shows an example of a curve used to represent the concerns on nuclear safety after a severe accident.

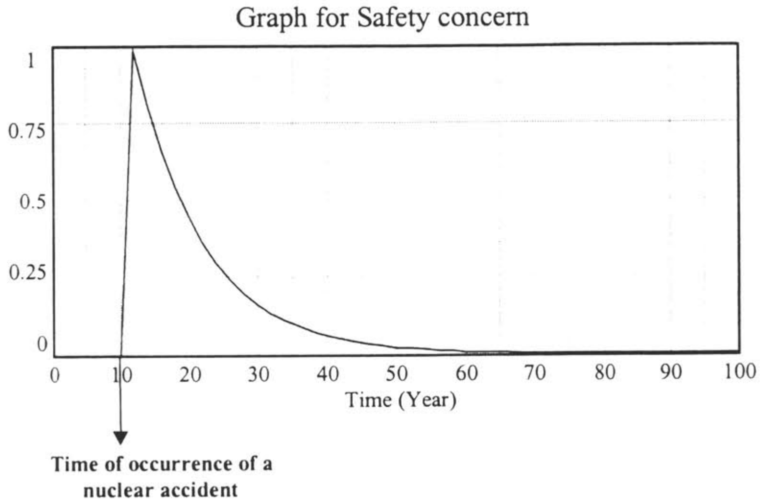


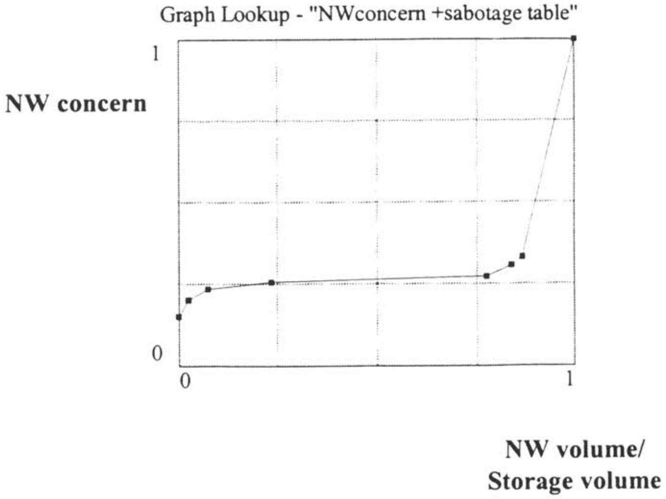
Figure 35: Safety Concern

Public Concern about Nuclear Waste

We consider that the public concern on nuclear waste is a function of the ratio of the volume of high level over available storage space. This concern is high when this ratio is above 0.80. Below this value, this concern is dominated by nuclear materials transportation issues, including sabotage and accidents. Figure 36 shows the actual curve used in the model to represent the public concern on nuclear waste.

The volume of high level nuclear waste is related to the electricity production by nuclear power plants. The available storage volume is a function of the opening of Yucca Mountain and on-site capacity, including storage pools and dry-casks. A complete model of the high level nuclear waste problem is given in Ref. [20] and will also be addressed in the next Chapter.

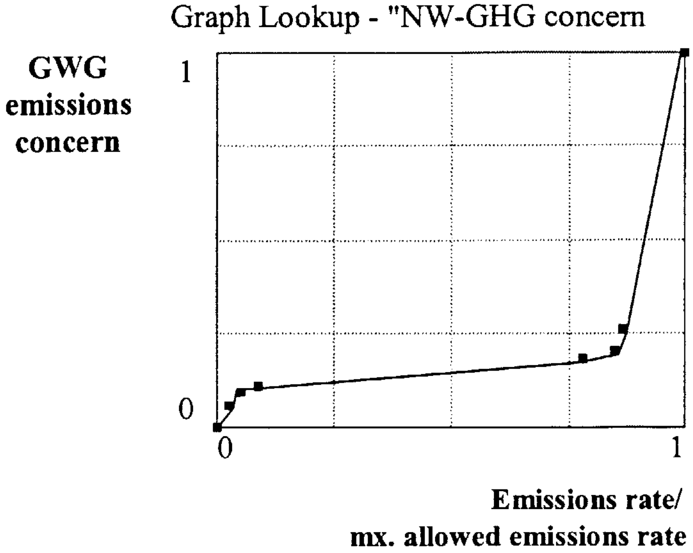
Figure 36: Nuclear Waste Concern



Public Concern related to the Greenhouse Effect

The public concern on greenhouse effect is modeled as a function of the ratio of the rate of greenhouse gases production and the maximum allowable production rate. As no legislation exists at this moment about this issue in the United States, we have considered that the existing release rate is about 90% of the maximum allowable rate at this time. The release rate of greenhouse gases is modeled as a function of the electricity generated in fossil power plants and the relative percentage of coal and gas plants and will be explained in the next chapter. In this way, the energy supplied by fossil powered plants changes the production rate and so, the public concern on the greenhouse effect. The distinction between gas and coal plants is necessary because besides carbon dioxide, methane released during the extraction and transportation of methane have been considered and will be described in the next chapter, which deals with the technical side of the model. Figure 37 shows the actual lookup table used in the model.

Figure 37: Concern about the greenhouse effect.



Concern on Other Environmental Impacts

Environmental concerns about wind turbines include:

1. Noise pollution, which is being solved using new wind turbines technologies.
2. Bird migration interference, which is said to be avoided by placing the turbines away from the migration paths
3. Land occupation. According to Ref [8], with the present wind turbines technology, each wind turbine delivers 1.5 MWe and six turbines can be installed per square kilometer. According to ref [8], the amount of wind turbines necessary to reduce the actual greenhouse emissions in the United States by 7%, (as proposed in the 1997 Kyoto Protocol) would cover an area of 194×194 km^2 (121×121 $miles^2$). We assumed that this is a maximum area to be covered.

Only the land occupation concern has been represented in our model. The actual curve used is seen in Figure 38.

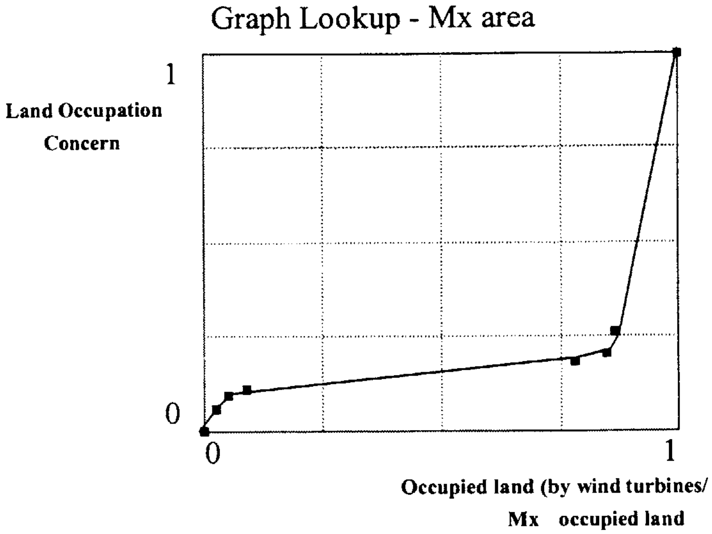


Figure 38: Concern regarding land occupation by wind turbines.

Concern about the cost of Electricity

Although the concern on the cost of electricity is not part of the calculation of the level of political support because we consider that the federal government does not regulate the price of electricity, it is used for calculating the level of importance of energy issues, as will be explained in Section 4.6.

Figure 39 shows the curve that we have used to estimate this concern. We assumed that this concern is a function of the electricity cost regarding a certain maximum allowable by the general public.

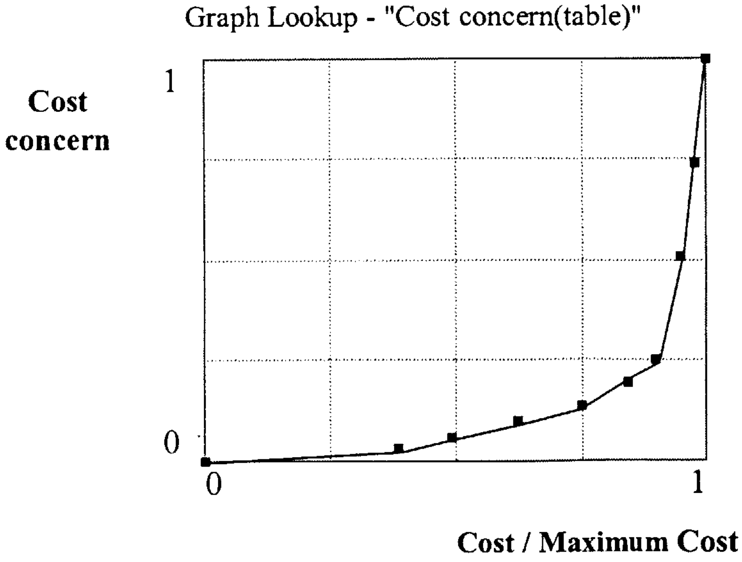


Figure 39: Concern regarding the cost of electricity.

4.6 The Level of Political Importance and the Policy Rate

In our model, we consider that the rate of generation of energy policies depends on the level of importance of energy issues, the maximum and the minimum rate of policy generation, as shown in Figure 40.

Regarding the annual maximum and the minimum rate of policy generation for nuclear, fossil and wind power plants will be determined through historical records.

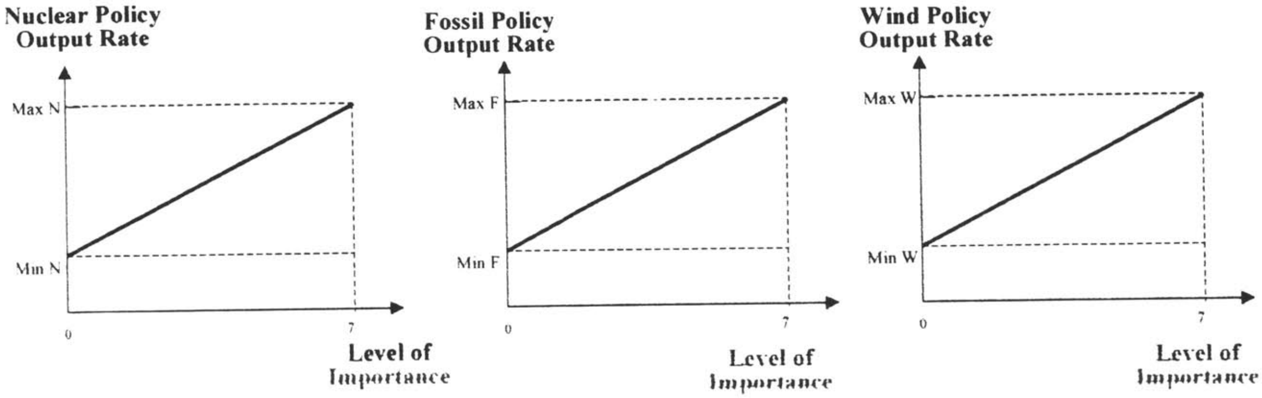


Figure 40: Policy rate curves for nuclear, fossil and wind power plants.

The level of importance of energy issues is calculated as the sum of all concerns regarding electricity generation:

$$Level\ of\ Importance = \sum_{i}^{7} Concern_i$$

with i ranges from 1 to 7 and represents the relevant issues that we are modeling: electricity availability, electricity costs, greenhouse effect, nuclear waste, proliferation, safety and land occupation by wind turbines.

We have chosen this representation because we believe that the importance of an issue as seen by policymakers is related to the existence of a crisis. For example:

- The energy availability crisis in California, in January 2001
- The proliferation concern crisis in 1973, after the Indian made tests of nuclear weapons
- The Three Mile Island nuclear accident in 1979

The public concern, and the political awareness raise during those periods.

4.7 Policy Accumulation

In our model of the policymaking process for energy issues, the variables that we use to estimate the impact of policies on generation cost are the *Policy Accumulated for Nuclear*, *Policy Accumulated for Fossil and Policy Accumulated for Wind Turbines.*

These variables are calculated considering the amplitude of each policies and the generation rate during the last 10 years for each type of energy. Mathematically:

$$\text{Policy Accumulation for Nuclear} = \sum_{year=-10}^{0} \text{Policy Amplitude for Nuclear} \times \text{Policy Rate for Nuclear}$$

$$\text{Policy Accumulation for Fossil} = \sum_{year=-10}^{0} \text{Policy Amplitude for Fossil} \times \text{Policy Rate for Fossil}$$

$$\text{Policy Accumulation for Wind} = \sum_{year=-10}^{0} \text{Policy Amplitude for Wind} \times \text{Policy Rate for Wind}$$

The policy accumulation is the variable used to calculate the impact of policies on the cost of electricity production by the different types of power plants. This will be the focus of discussion in Chapter 5.

4.8 Summary and Conclusions

This chapter presents the quantitative approach of the sociopolitical part of our model of the energy policymaking process, which simplified influence diagram is shown in Figure 41, valid for nuclear, fossil and wind turbines. We summarize the login and variables used and what follows.

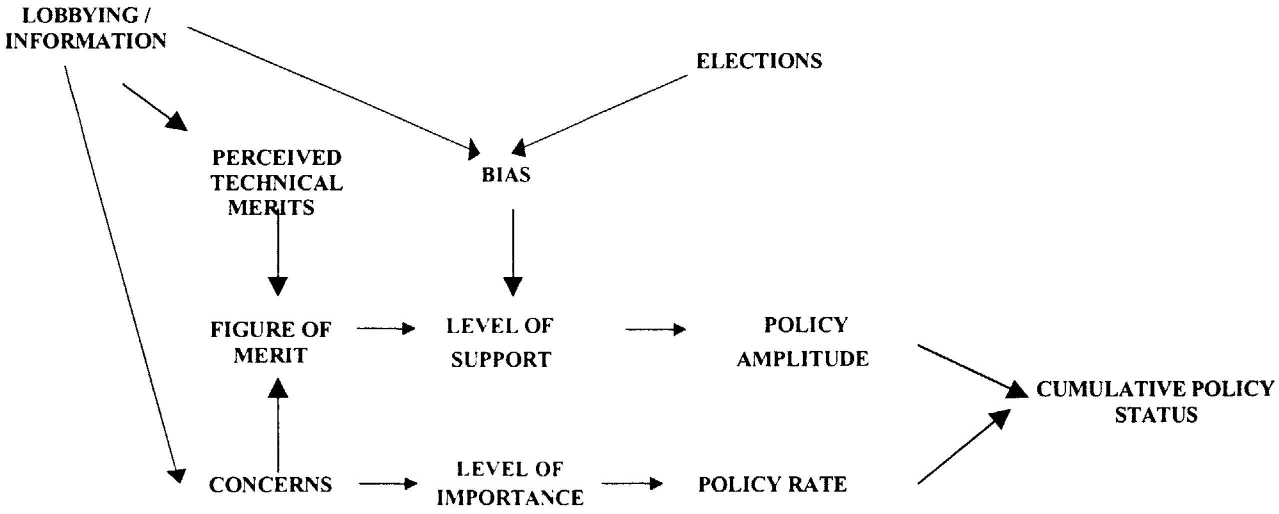


Figure 41: The Sociopolitical Side of the Energy Policymaking Model.

In our representation of the energy policymaking process, *Policy Amplitude for the Nuclear Industry*, *Policy Amplitude for the Fossil Industry*, and *Policy Amplitude for Wind Turbines* are variables that represents how favorable or unfavorable policies are to the development of nuclear, fossil and wind power plants, respectively. These variables depend on the impact of these policies on the electricity costs, and so it determines the future growth of the industry. The policy amplitude for each type of power plant is a function of the level of the political support for that particular type of energy.

The *Level of Political Support for the Nuclear Industry, Level of Political Support for the Fossil Industry, Level of Political Support for Wind Turbines* are variables that represent the intensity with which the political sector support the growth of the nuclear, fossil or wind industries, respectively. These variables take values from –1 to 1, and depend on the figure of merit for nuclear, and the political bias.

The *political bias* is calculated as a function of *lobbying activities* and *elections*, as different political parties think in different way about important issues.

The *Figure of Merit for Nuclear*, the *Figure of Merit for Fossil* and the *Figure of Merit for Wind Turbines* are obtained considering the perceived merits of that technology and weighting factors regarding energy availability, nuclear waste, greenhouse gases, safety, proliferation, and other environmental issues mainly related with wind turbine technologies.

The *perceived merit of nuclear, fossil and wind turbines regarding availability, nuclear waste, greenhouse effect, safety, proliferation and environmental related issues* sum 18 and represent the perceived contribution of a technology to solve or make worse a particular issue.

The *weighted perceived merits of these technologies regarding energy availability, proliferation, safety, nuclear waste, greenhouse effect* and *environmental impacts caused by wind turbines* farms are equal to the public concerns on these issues, which are calculated as:

- The p*ublic concern regarding availability* of electricity is a function of the ratio of the demand and the supply of electricity in the United States.
- The *public concern on proliferation* is introduced as a constant number.

- *Safety concern* is relevant only after a nuclear accident. The amplitude and decay time for this concern depends on the severity of the accident.
- *Public concern on nuclear waste* is a function of the ratio of the volume of high level over available storage space.
- The *public concern on greenhouse effect* is a function of the ratio of the rate of greenhouse gases production and the maximum allowable production rate.
- The *concern on wind turbines environmental impacts* only considers the land occupation related to a maximum allowable occupation.
- The *concern about the cost of electricity* is a function of the electricity cost regarding a certain maximum affordable by the general public.

The rate of generation of energy policies depends on the level of importance of energy issues, the maximum and the minimum rate of policy generation.

The *level of importance of energy issues* is calculated as the sum of all concerns regarding electricity generation.

In our model of the policymaking process for energy issues, the variables that we use to estimate the impact of policies on generation cost are the *Policy Accumulated for Nuclear, Policy Accumulated for Fossil and Policy Accumulated for Wind Turbines.*

These variables are calculated considering the amplitude of each policies and the generation rate during the last 10 years for each type of energy.

A list of all variables introduced in this chapter, their ranges, and their method of calculation is included in Table 3. The curves introduced in the model are estimated, and must be compared to historical data in the future.

Table 3: Variables of the Sociopolitical part of the Energy Policymaking Model

Variable	Range	Exogenous/Endogenous
Policy Amplitude		
Policy Amplitude for the Nuclear Industry	-1 to 1	Endogenous
Policy Amplitude for the Fossil Industry	-1 to 1	Endogenous
Policy Amplitude for Wind Turbines	-1 to 1	Endogenous
Level of Support		
Level of Political Support for the Nuclear Industry,	-1 to 1	Endogenous
Level of Political Support for the Fossil Industry	-1 to 1	Endogenous
Level of Political Support for Wind Turbines	-1 to 1	Endogenous
Bias and lobbying		
Political Bias for Nuclear	-1 to 1	Exogenous
Political Bias for Fossil	-1 to 1	Exogenous
Political Bias for Wind Turbines	-1 to 1	Exogenous
Lobbying for Nuclear	-1 to 1	Exogenous
Lobbying for Fossil	-1 to 1	Exogenous
Lobbying for Wind Turbines	-1 to 1	Exogenous
Figure of Merit for Nuclear	-3 to 3	Endogenous
Figure of Merit for Fossil	-1 to 5	Endogenous
Figure of Merit for Wind Turbines	-1 to 5	Endogenous
Perceived Merits		

Variable	**Range**	**Exogenous/Endogenous**
Perceived merit of nuclear about electricity availability	0 to 1	Endogenous. Estimate curve is used.
Time of construction of a nuclear power plant	Used time: 6 years (can be reduced to 3 by using other technologies)	Exogenous
Perceived merit of nuclear regarding nuclear waste	From –1 to 0	Exogenous
Perceived merit of nuclear regarding greenhouse effect	1	Constant
Perceived merit of nuclear regarding safety	-1 to 0	Endogenous
Perceived merit of nuclear regarding proliferation	-1 to 0	Exogenous
Perceived merit of nuclear regarding other env.impacts	1	Constant
Perceived merit of fossil about electricity availability	0 to 1	Endogenous. Estimate curve is used.
Time of construction of a fossil power plant	Used time: 3 years	Exogenous
Perceived merit of fossil regarding nuclear waste	1	Constant
Perceived merit of fossil regarding greenhouse effect	-1 to 1	Exogenous
Perceived merit of fossil regarding safety	1	Constant
Perceived merit of fossil regarding proliferation	1	Constant
Perceived merit of fossil regarding other env.impacts	1	Constant
Perceived merit of wind turbines about electricity availability	Used time: 3 years	Exogenous

Variable	**Range**	**Exogenous/Endogenous**
Time of construction of a wind turbines farm	Used time: 3 years	Exogenous
Perceived merit of wind turbines regarding nuclear waste	1	Constant
Perceived merit of wind turbines regarding greenhouse effect	1	Constant
The *perceived merit of wind turbines regarding safety*	1	Constant
The *perceived merit of wind turbines regarding proliferation*	1	Constant
The *perceived merit of wind turbines regarding env. impacts*	-1 to 1	Exogenous
Concerns		
Public concern about electricity availability.	0 to 1	Exogenous Curve is used
Public concern about electricity costs.	0 to 1	Exogenous Curve is used
Public concern about greenhouse effect	0 to 1	Exogenous Curve is used
Public concern about nuclear waste.	0 to 1	Exogenous Curve is used
Public concern about safety.	0 to 1	Exogenous Curve is used
Public concern about proliferation	0 to 1	Exogenous Curve is used
Public concern about env. Impacts of wind turbines	0 to 1	Exogenous Curve is used
Availability Calculation		

Variable	**Range**	**Exogenous/Endogenous**
Electricity Demand	Assumed constant increase demand of 10 Gwe/yr	Exogenous
Electricity Supply	Addition of that supplied by fossil, nuclear and wind turbines	Endogenous
Cost Calculation		
Nuclear Electricity Costs	See Chapter 5	Endogenous
Fossil Electricity Costs	See Chapter 5	Endogenous
Wind Electricity Costs	See Chapter 5	Endogenous
Maximum Affordable Electricity Cost		Exogenous
Greenhouse Effect		
Greenhouse gas Release Rate	See Chapter 5	Endogenous
Maximum Allowable greenhouse gas release	15,000,000 ton C/day	Exogenous
Nuclear Waste		
Nuclear Waste Volume	See Chapter 5	Endogenous
Available Storage Space for Nuclear Waste	See Chapter 5	Endogenous
Time to make decision to open Yucca Mountain	From 0 to 100	Exogenous
Proliferation		
Proliferation		
Safety		
Time of occurrence of a nuclear accident	From 0 to n yrs	Exogenous
Amplitude of a nuclear accident	From 0 to 40 yrs decay time	Exogenous
Other Environmental Concerns		
Land Occupied by Wind Turbines	Calculated based on 6 turbines per km^2 and mx. 1.5 Mwe per turbine	Endogenous
Mx allowable area occupied by	194×194 km^2	Exogenous

Variable	**Range**	**Exogenous/Endogenous**
Wind Turbines		
Policy Rate		
Policy Rate for Nuclear	From Min to Max	Endogenous Curve is used
Min. nuclear policy rate	From 0 to *n* / yr	Exogenous
Max. nuclear policy rate	From 0 to *n* / yr	Exogenous
Policy Rate for Fossil	From Min to Max	Endogenous Curve is used
Min. fossil policy rate	From 0 to *n* / yr	Exogenous
Max. fossil policy rate	From 0 to *n* / yr	Exogenous
Policy Rate for Wind Turbines	From Min to Max	Endogenous Curve is used
Min. wind policy rate	From 0 to *n* / yr	Exogenous
Max. wind policy rate	From 0 to *n* / yr	Exogenous
Level of Importance	0 to 1	Endogenous Curve is used
Cumulative Policies		
Cumulative Policies for Nuclear	From $-\text{Min}_n \times \text{T}$ to $\text{Max}_n \times \text{T}$	Endogenous
Cumulative Policies for Fossil	From $-\text{Min}_f \times \text{T}$ to $\text{Max}_f \times \text{T}$	Endogenous
Cumulative Policies for Wind Turbines	From $-\text{Min}_w \times \text{T}$ to $\text{Max}_w \times \text{T}$	Endogenous
T (Validity period of policies)	Used value: 10 years	Exogenous

Chapter 5: The Energy Policymaking Model: the Economics and Technical Sides

5.1 Introduction

In the previous chapters we have presented the theoretical background for building a model of the energy policymaking process. We also gave an overview of the model and the specifics of its sociopolitical part. The explanation of the economic impact of the policies generated for nuclear, fossil and winds turbines power plants is given here. Given the electricity demand curve, we assume that the decision on which type of power plant to build, depends entirely on financial evaluation based on levelized total costs. The power supply for each type of energy is then determined.

At the same time, the electricity generated by each type of power plant, impacts on the greenhouse effect, the nuclear waste issue, proliferation, safety, energy availability, energy costs and land occupation by nuclear power plants.

Due to the simplicity of the other issues, only the green house effect and the nuclear waste technical issues are addressed here.

The general picture of the subjects on which we will focus in this chapter are seen in Figure 42.

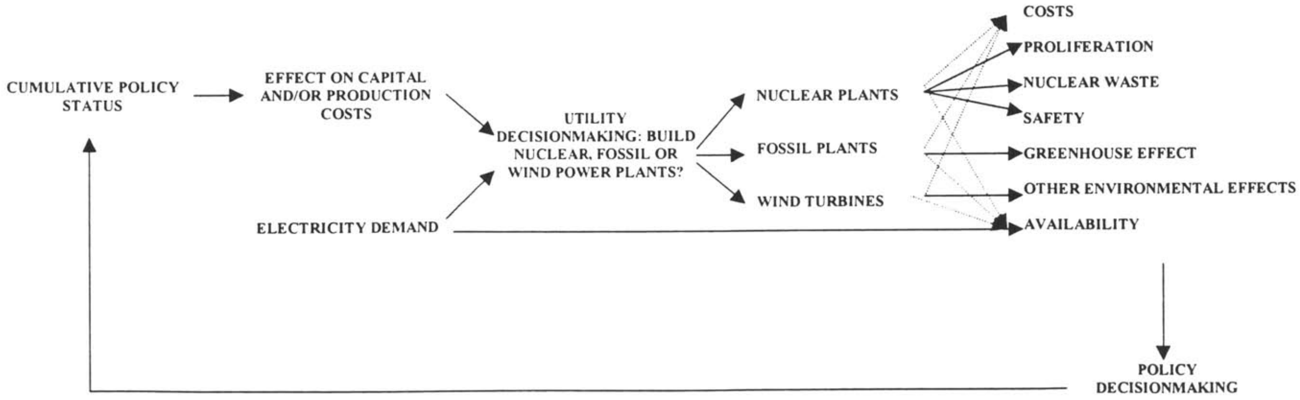


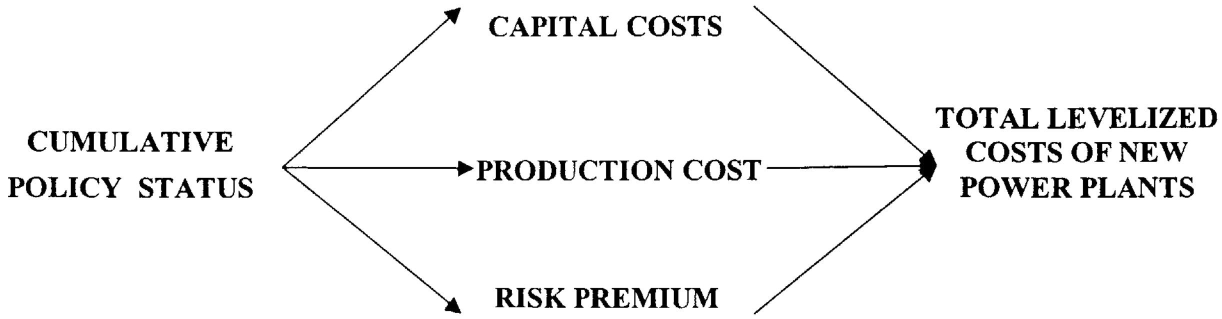
Figure 42: The Economics and Technical Sides of the Energy Policymaking Model.

5.2 The Influence of Policy Accumulation on Capital and Production Costs of Electricity

Basically, for any source of energy, there are four main components of costs:

1. Capital or investment costs, which is amortized over the life of the power plant.
2. Fuel costs
3. Variable operating and maintenance costs, (variable O&M), proportional to the energy produced.
4. Fixed operating and maintenance costs (fixed O&M).

In our model, we have considered capital costs and production costs. The production cost is composed of fuel, variable and fixed O&M costs. In the previous chapters, we have presented the variables: *Policy Accumulated for Nuclear, Policy Accumulated for Fossil and Policy Accumulated for Wind Turbines.* These variables impact directly on the costs of electricity generation by nuclear, fossil or wind means Figure 43 shows the impact of policies on electricity costs for the considered sources of energy.



This representation is the same for nuclear power plants, fossil power plants and wind turbines farms, although the relative impacts on capital and production costs is different.

Figure 43: Impact of Cumulative Policies on the Cost of Power Plants.

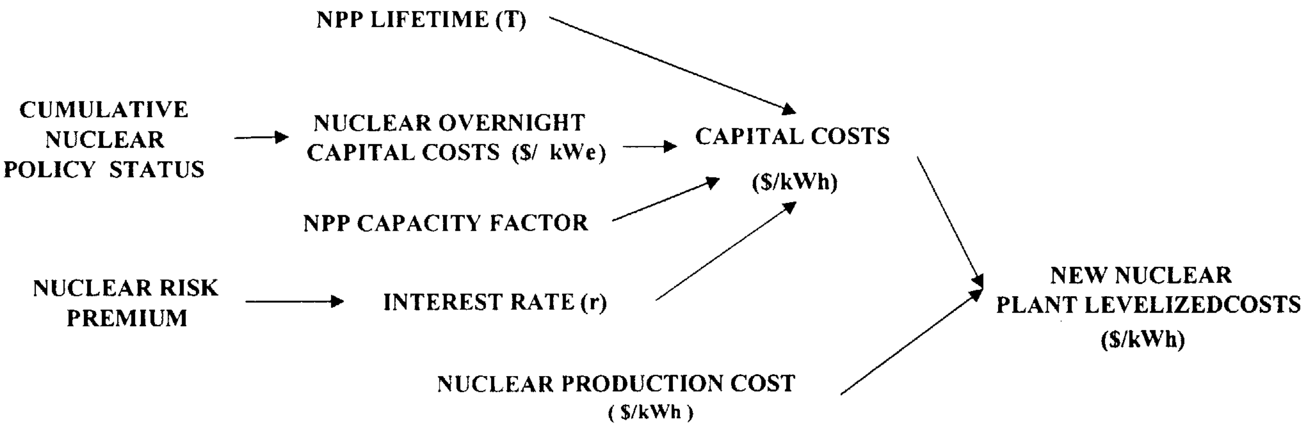
For every means of electrical energy production, the total costs are the result of adding the operational costs and the levelized capital costs. The overnight cost, the lifetime, the internal rate of return and the capacity factors must be considered. Mathematically:

$$Total\ Levelized\ Cost(\$/kWh)_i = Op.cost(\$/kWh)_i + \frac{Overnight\ cost(\$/kWe)_i}{Capacity\ factor_i \times 8760\,h/yr} \times r \times \left(1 - \frac{1}{(1+r_i)^{T_i}}\right)^{-1}$$

$i = nuclear, fossil, wind$

$r = internal\ rate\ of\ return$

Figure 44 shows this the influence diagram for the costs of nuclear power plants; for which we consider that the main impact of policies and regulations are on the capital costs, not on the production costs. This is because policies and regulations modify the safety requirement on nuclear power plants, which mainly impact on the equipment and containment needed.

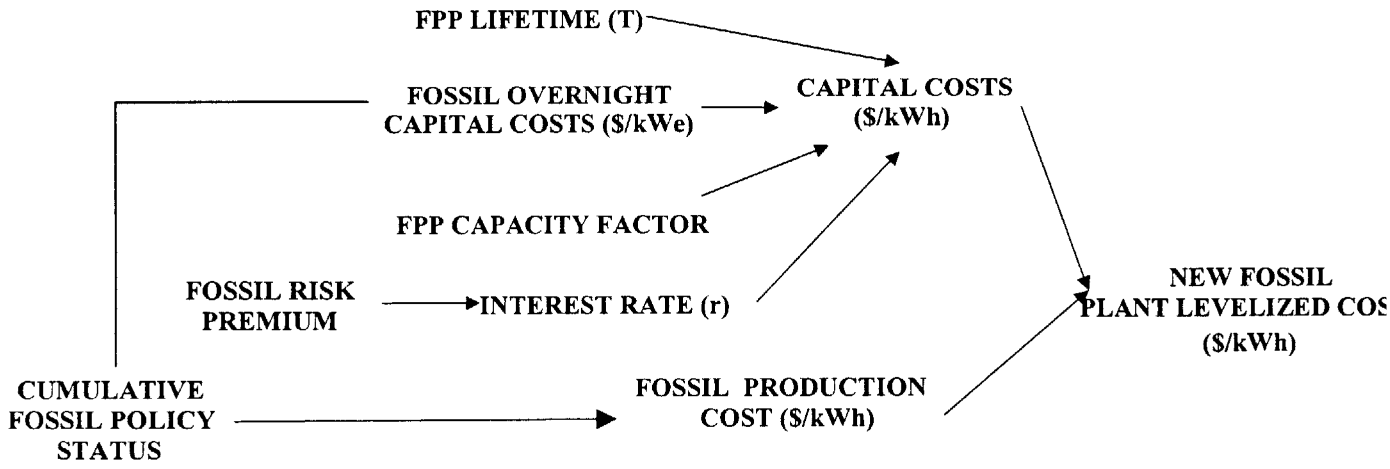


Data used in the base case:

Nuclear overnight capital costs: $ 2000 /kWe (initial value)
Nuclear internal rate of return: 12.8% (initial value)
Nuclear production cost $0.020/kWh (includes O&M and fuel costs)
NPP Lifetime: 40 years
NPP Capacity factor: 90%

Figure 44: Nuclear Power Plants Total Costs.

Figure 45 shows the calculation of the total costs on fossil power plants. In this case, policies may affect both, the capital and production costs. For example, since 1978 all plants have been required to be equipped with flue gas desulfurization to remove SOx, with an impact on capital and O&M costs because of the equipment needed(affects capital costs) and on their operating costs (proportional to the output of the power plant). NOx removal systems are also used, with an impact on the capital cost. In case a tax is implemented on carbon dioxide emissions, this will have a high impact only on O&M costs.



<u>Data used in the base case:</u>

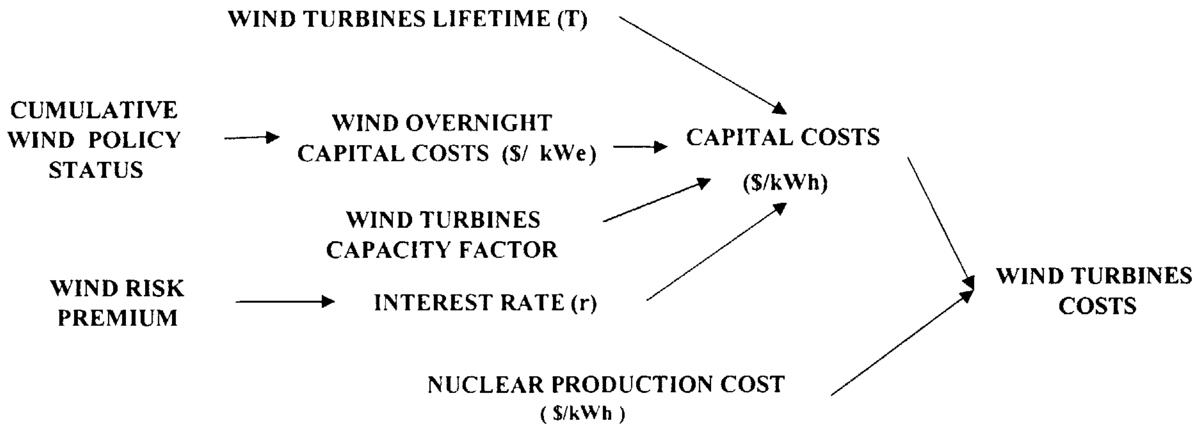
Fossil overnight capital costs:	$ 900 /kWe (initial value)
Fossil internal rate of return:	9.8%
Fossil production cost	$ 0.027/kWh (includes O&M and fuel costs) (initial value)
NPP Lifetime:	40 years
FPP capacity factor:	90%

Figure 45: Fossil Power Plants Total Costs.

Figure 46 is for wind farms. In this case, we consider that policies can only affect the capital costs of wind turbines, because little is spent in operations in this case and regulations are very unlikely to affect them.

In all the cases, we have considered that these technologies are at the end of the learning case, for that reason the very capital cost used for wind turbines in the base case.

Figure 47 presents the curves we used to obtain the effect of nuclear, fossil and wind policies on the cost of electricity generation. We assumed that if the cumulative policies are positive, this would have a reducing effect on the costs, and if the contrary in case they are positive. We assumed that policies mostly affected the generating cost of fossil and wind power plants, and the capital cost of nuclear power plants. In our model, we assumed that the capital cost of fossil power plants will not affected by policies in the future, on the contrary to what it did in the past[19], neither the operating cost of nuclear power plants.



Data used in the base case:

Wind overnight capital costs:	$ 2200 /kWe
Wind internal rate of return:	9.8%
Wind production cost:	$0.00650/kWh (O&M costs)
Wind turbines time life:	20 years;
Wind turbines capacity factor:	60%

Figure 46: Wind Turbine Farms Total Costs.

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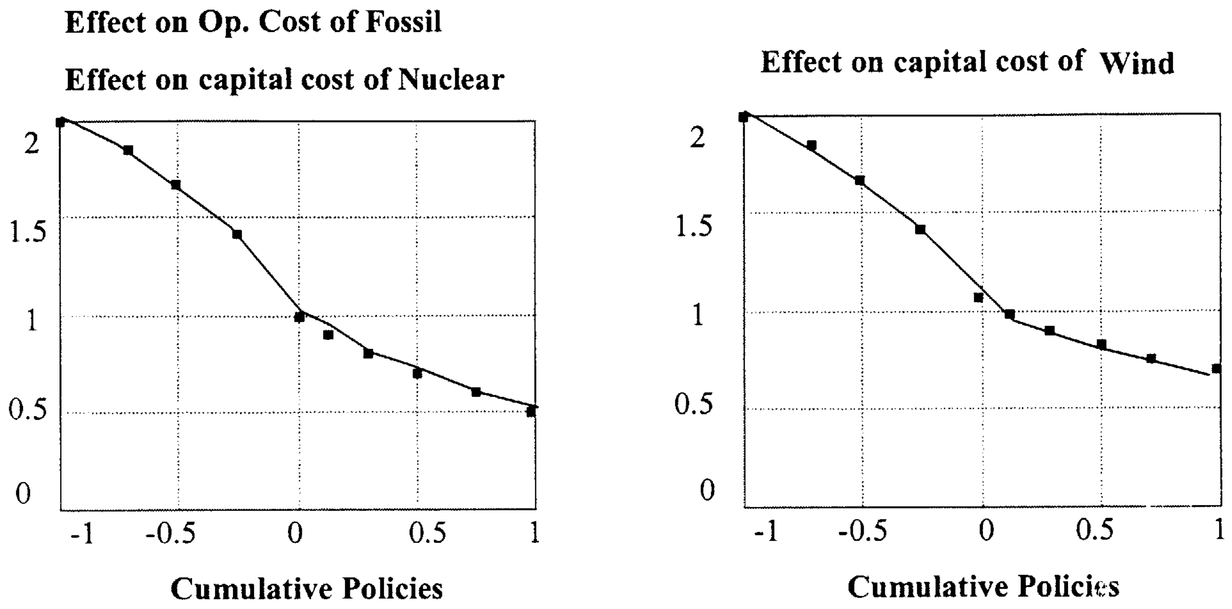
[19] We refer to 1978, when the fossil plants had to install scrubbers to capture SO_2 emissions.



Effect on Op. Cost of Fossil

Effect on capital cost of Nuclear

Effect on capital cost of Wind

Figure 47: Cumulative Policy Effect on Costs.

5.3 Utility Decision-Making and Electricity Supply.

In our model, we assume that if the demand for electrical energy is higher than 90% of the available supply capacity, utility owners decide to build new power plants. We assume that they choose between fossil (includes coal and gas), nuclear and wind power plants (representing the renewable source). We consider that the only variable that utilities look at when deciding how to cover the electricity demand is the net present value of their investment, which includes the risk of investment. Taking the price of electricity as a constant, the decision based on the maximization of the net present value of the investments is equivalent to the decision based on its minimum total levelized costs; which we have calculated in previous sections. Other factors that may influence on the decisions, such as maximum construction rate and diversity of resources, are not considered.

The result of this part of the model is the electricity supplied by each type of power plants. This is the result of adding the new power plants of each type, to the existing ones, also considering their retirement due to lifetime limit and the delays in the construction of new power plants. The construction times used are 3 years for fossil power plants and wind turbines farms, and 6 years for nuclear power plants. The lifetimes of power plants used are 20 years for wind turbines, as a very optimistic number, and 40 years for both nuclear and fossil power plants. This part of the model is schematically shown in Figure 48.

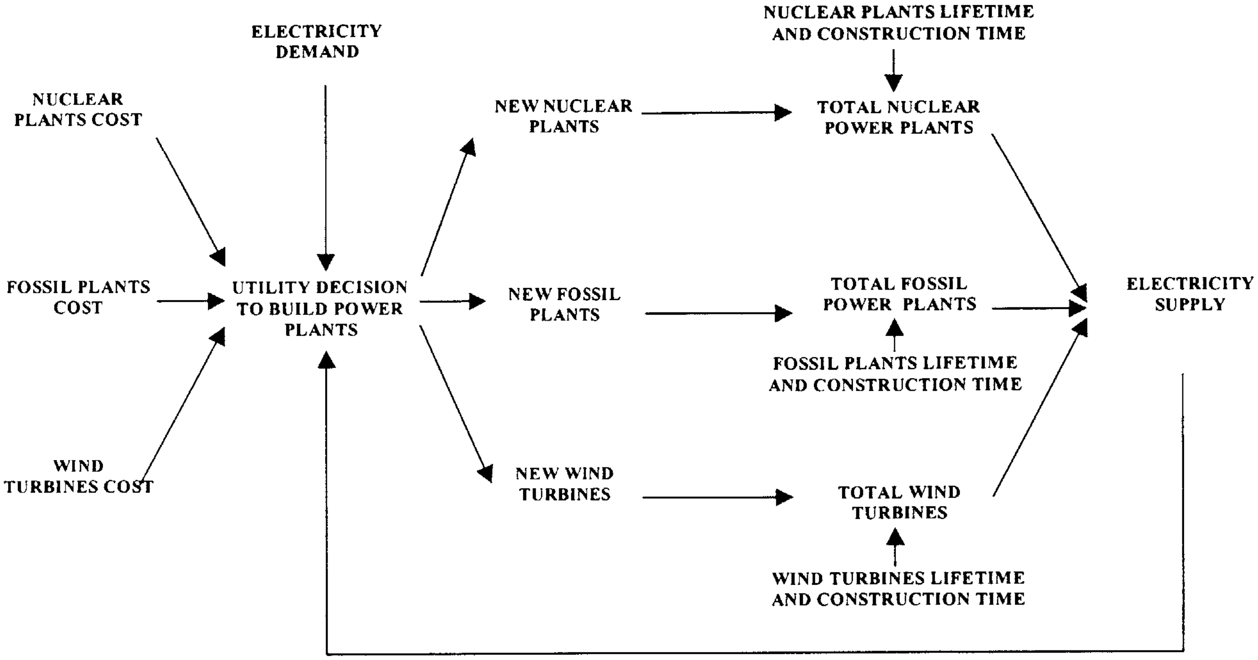


Figure 48: Utility Decision-making and Electricity Supply

5.4 The Nuclear Waste Model

The model of the nuclear waste issue, has as its output the *available on-site spent fuel storage capacity*. This is calculated mainly given the nuclear power plant electricity capacity, which determines the production rate of high-level nuclear waste, the initial on-site capacity and the decision to open Yucca Mountain or any other off-site storage facility. As a reminder, the available nuclear waste storage capacity is a variable that is used to calculate the *perceived* *public concern about high-level nuclear wastes* as explained in Section 4.5.2. Theoretical information about the High-level nuclear waste issue is to be found in Appendix 2.

The description that follows refer to Figure 49 and the words in italics are the actual variables calculated in that model. Calculations are made for both BWR and PWR nuclear power plants because the production of spent fuel in BWRs and PWRs per unit of energy generated is different

The *power capacity of nuclear power plants* is used to calculate the power capacity of BWRs and PWRs. The *percentage of power contribution* for each of these reactors is assumed to remain constant (66% for PWR and 34% for BWR).

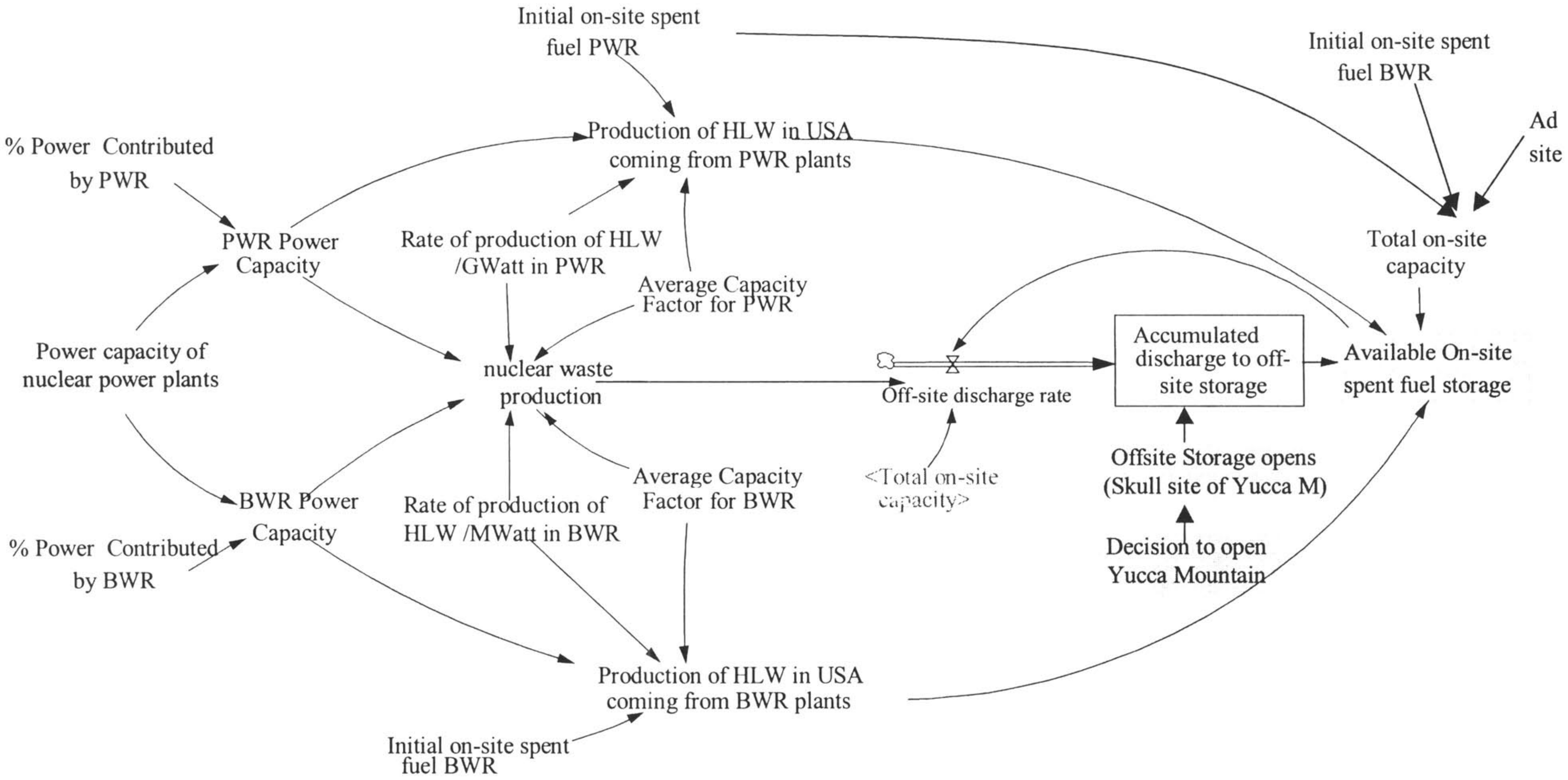
The high-level nuclear waste generated per year in the United States is then calculated as the sum of the BWR and PWR contributions. At the same time, these contributions are calculated considering the *rate of production of high-level nuclear waste per unit power* (13 m^3/GWe/yr for PWRs and 17.5 m^3/GWe/yr for BWRs), and the *capacity factors* (0.8 for PWRs and 0.77 for BWRs).

The value of the *available on-site spent fuel storage capacity* is obtained as the *total on-site capacity*, plus the *accumulated discharge of spent fuel to off-site storages*, minus the *production of high level waste* (i.e. spent fuels) in the United States in *PWRs and BWRs*. The total on-site capacity, is the result of the initial capacity, plus added one due to the decision, for instance, to install on-site dry-casks.

At the same time, the production of HLW in the United States from BWRs and PWRs is obtained integrating the *rate of production of high level waste per GWatt* in each of those plants.

A very important variable of our model is the *decision to open the ultimate site (i.e. Yucca Mountain)*, which is an exogenous variable. However, a delay of ten years is introduced between this decision and the actual opening of Yucca Mountain. After Yucca Mountain opens , the power plants begin to discharge their high level nuclear waste and recover on-site storage space.

Figure 49 : Available On-Site Spent Fuel Storage Capacity



5.5 The Greenhouse Model

Increasing emissions of greenhouse gases is believed to be producing the global warming trend that is being noticed and which consequences can be catastrophic for the living conditions of our planet.

The actual variable associated to the increase of the average temperature of our planet is the change in radiative forcing; which refers to the decrease in outgoing radiation due to the addition of greenhouse gas. The radiative forcing effect depends on the nature of the gas and its concentration in the atmosphere. Carbon dioxide and methane are among the greenhouse gases, i.e they are some of the many gases, which their increase in the atmospheric concentration cause an increase in radiative forcing associated with the increase in average temperature associated with the changes in global climate.

Although the actual radiative strength of a molecule of methane is 58 times higher than a molecule of carbon dioxide, its concentration in the atmosphere is much lower, and its decay time is 12 years compared to the 100-200 years for carbon dioxide. This means that when the limits on greenhouse gas emissions objectively assessed, each gas should be treated as separate. However, in the 1997 Kyoto Protocol (which has not been ratified), the United States agreed a 7% in the greenhouse gas reduction. Only for this reason, we have chosen the use the production rate of greenhouse gases as the variable used as the metrics to obtain the greenhouse gas concern, as explained in Section 4.5.2.

As shown in Figure 50. We calculate the production rate of greenhouse gases (only due to fossil power plants) as the sum of carbon dioxide and methane release. The methane release is entirely due to losses during transportation of gas, or incomplete combustion in gas power plants; assumed to be 2% of the actual gas needed to run the power plants. The percentage of gas power plants relative to the fossil-fuelled power plants used in our model is a constant equal to the actual 17 %, compared to 83% for fossil power plants.

The electricity production by fossil fuelled plants is a variable that is calculated as described in Section 5.3.

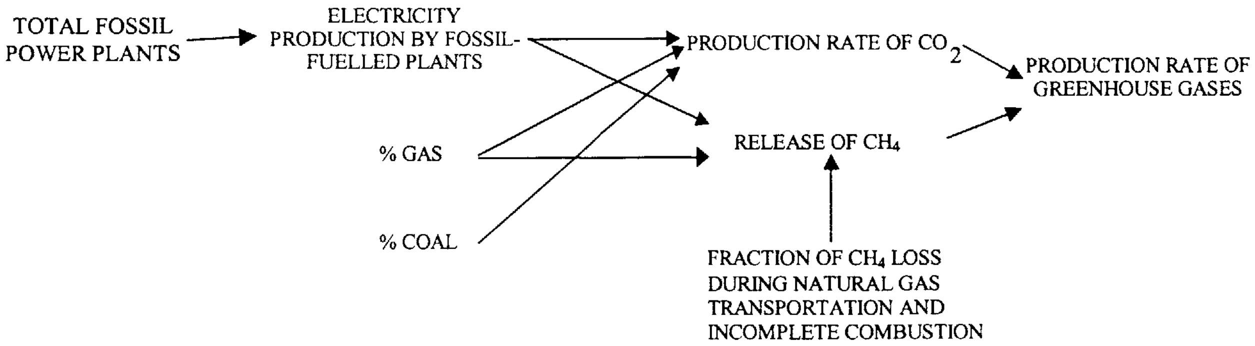


Figure 50: Diagram showing the greenhouse gas production rate calculation.

5.6 Summary and Conclusions

In this chapter, we have presented the details of the calculation if the economics impacts of energy policies, the utility decision-making process and the most outstanding technical aspects of energy production: the greenhouse effect and the nuclear waste issue.

Regarding the financial aspect of power plants, we split the cost of energy generation into levelized capital costs and annual production costs. The production cost is composed of fuel cost and O&M costs. The *Policy Accumulated for Nuclear*, *Policy Accumulated for Fossil and Policy Accumulated for Wind Turbines* impact directly on the costs of electricity generation by nuclear, fossil or wind means respectively.

The utility owners' selection of the type of power plant used to cover the electricity demand is based on the best levelized costs. The electricity supplied is the result of adding the new power plants of each type to the existing ones, considering their retirement due to lifetime limits and the delays in the construction of new power plants.

Regarding the technical part of the model, the model of the nuclear waste issue has as its output the *available on-site spent fuel storage capacity*, which is then used to estimate the public concern on this issue. This variable is calculated given the nuclear power plant electricity capacity, which determines the production rate of high-level nuclear waste, the initial on-site capacity and the decision to open Yucca Mountain or any other off-site storage facility. A very important variable of our model is *the time of the decision to open the ultimate site (i.e. Yucca Mountain)*, which is an exogenous variable. A delay of ten years is introduced between this decision and the actual opening of Yucca Mountain. After Yucca Mountain opens

Regarding the greenhouse effect, we have chosen the use the production rate of greenhouse gases as the variable used to obtain the greenhouse gas concern. This is due to the fact that in the 1997 Kyoto the United States agreed a 7% in the greenhouse gas reduction, without considering the type of gas being released. We calculate the production rate of greenhouse gases due to fossil power plants, as the sum of carbon dioxide and methane release. The methane release is entirely due to losses during transportation of gas, or incomplete combustion in gas power plants.

With all these variables, we are not able to estimate the perceived concerns. In our model, these concerns are the main drivers of policies generation, as explained in previous chapters. This closes the feedback loops of the model

We have now completed the discussion and presentation of the energy policymaking process. Results on basic cases are presented in the next chapter.

Chapter 6: Model Results

6.1 Introduction

As have been explained, the main motivations for building a tool to simulate of the energy policymaking process are: 1) to know how to leverage the benefits of the nuclear industry to the other means of electricity generation; and 2) to be able to gain some insight about the best way to produce the public and political support of new nuclear power plants. The resulting policies include dispositions and regulations that can reduce the perceived risks and costs of nuclear power plants, or increase the costs of competing technologies.

We have also given a comprehensive background of some issues regarding electricity generation. The greenhouse effect and the high-level nuclear waste generation are among the most important ones at this moment. The last three chapters have been devoted to give a detailed explanation regarding the model itself. We now present some preliminary results obtained by this simulation tool, which have been programmed using Vensim (Ref. [21]). Five cases are analyzed:

CASE 1: The basic case. We assume that the decision to open Yucca Mountain is made within 1 year; and it begins to receive nuclear waste 10 year after that. Other assumptions include that the maximum allowable increase in production of greenhouse gases is 3% more than the actual production, and there is no political bias.

CASE 2: Yucca Mountain decision to open is delayed.

CASE 3: The maximum allowable increase in greenhouse gas release rate is changed to 2% and 5% instead of 3%.

CASE 4: There is a negative political bias for nuclear power.

CASE 5: There is a small nuclear accident, the result of transportation spills or sabotage.

The results of all these cases are based on intuitive data and curves. For this reason, the next step of the project is to review historical data to have all the curves calibrated accordingly.

6.2 Case 1: The Basic Case

The assumptions for the basic case are:

- Electric demand grows at a rate of 10 GWe per year.
- Nuclear and fossil plants have a lifetime of 40 years.
- Wind turbines last 20 yrs (overestimated, the time at present is about 10 yrs).
- Fossil plants take 3 years to build.
- Nuclear plants take 6 years to build (although new designs are claimed to be built in 2 to 3 years).
- Wind turbines take 3 years to build
- Each NPP has a maximum capacity of 1.0 GWe
- Each FPP has a maximum capacity of 0.5 GWe
- Each wind turbine has a maximum capacity of 1.5 MWe
- Yucca Mountain favorable decision to open is made in 1 year.
- Yucca Mountain opens 10 year after decision is made.
- The maximum allowable increase of greenhouse gas emissions due to fossil powered plants is 3%.

Based on these assumptions, the resulting electricity supply by each type of power plant is presented in Figure 51. Figure 52 shows the same results, but as percentage of the total power supply for the next 50 years in the Unites States.

Under this scenario, it is seen that the nuclear power plants can reach up to 50% share. Considering that it takes 6 years to build them, the decisions to start building new nuclear power plants is made in year 8, 3 years before Yucca Mountain opens.

The decline in the percentage of fossil-fuelled power plants and the increase in nuclear power plants and wind farms is based on their economics, as seen in Figure 53. Due to the fact that we assume that decisions are made on economics bases, the periods when the number of power plants of a type increases correspond to the periods of minimum costs. This also coincides with the positive accumulation of nuclear policies affecting the base capital and production costs, as observed in Figure 54. As a reminder, the policy accumulation is the result of the integral of the multiplication of the resulting policy amplitude (seen in Figure 55) and the policy rate (Figure 56) with a decay period of 10 years. It is seen that the policy rate does not vary substantially, and that the main determinant of the change of the policies accumulations are the policies amplitude themselves. In this case, where for simplicity reasons the political bias is assumed to be non-existing for all the means of producing energy, the only influencing factor for the determination of the policy amplitude is the level of support, presented in Figure 57.

It is seen that the periods where the cost of fossil-fuelled plants is the highest correspond to the periods when the support for fossil plants is negative; while the support for nuclear and fossil plants is positive and more stable. The explanation for this behavior lies in the fact that the level of support is associated with the weighted merits of the technologies regarding energy availability, energy costs, greenhouse effect, high-level nuclear waste, environmental effects caused by wind turbines, proliferation and safety issues. 7

The weight given to these issues for fossil, nuclear and wind power plants is equal to the perceived concern regarding all these issues. The evolution of these concerns with time is shown in Figure 58.

It is seen that, the periods when the support on fossil fuelled power plants decrease correspond to high concerns on greenhouse gases. This concern decreases when the number of fossil power plants decrease enough to reduce the production rates below the levels of concern.

It is also noticeable that the concern on high-level nuclear waste is high at the beginning and decreases after the first 10 years due to the fact that Yucca Mountain is open then. The reminding concern after that period is due to perceived risk of occurrence of sabotage or accident during transportation or storage.

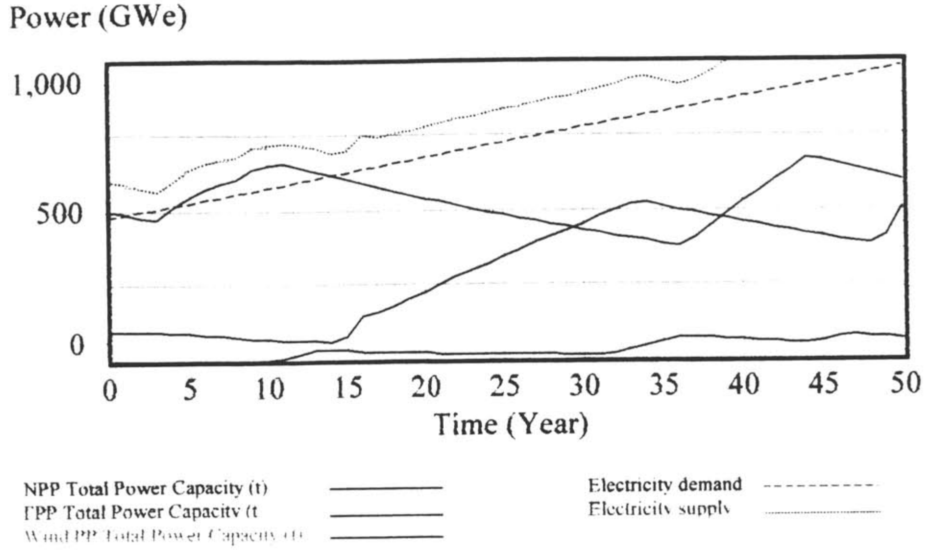


Figure 51: Power capacity, by power plant type for the basic case. Power demand and total supply.

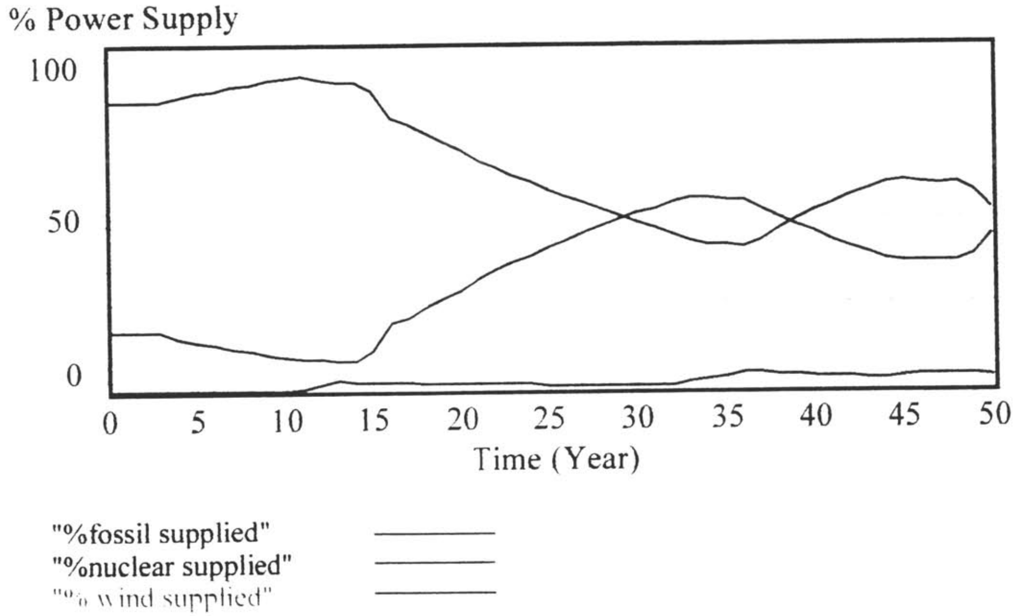


Figure 52: Percentage of power supplied by nuclear, fossil and wind power plants in the basic case.

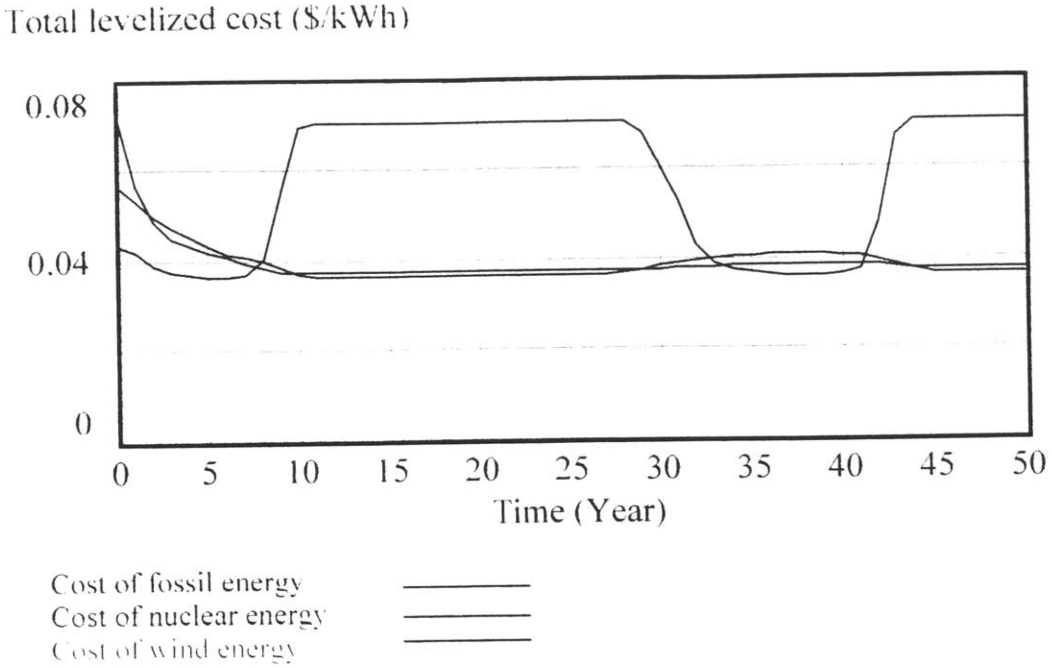


Figure 53: Total levelized cost of electricity production, by power plant type.

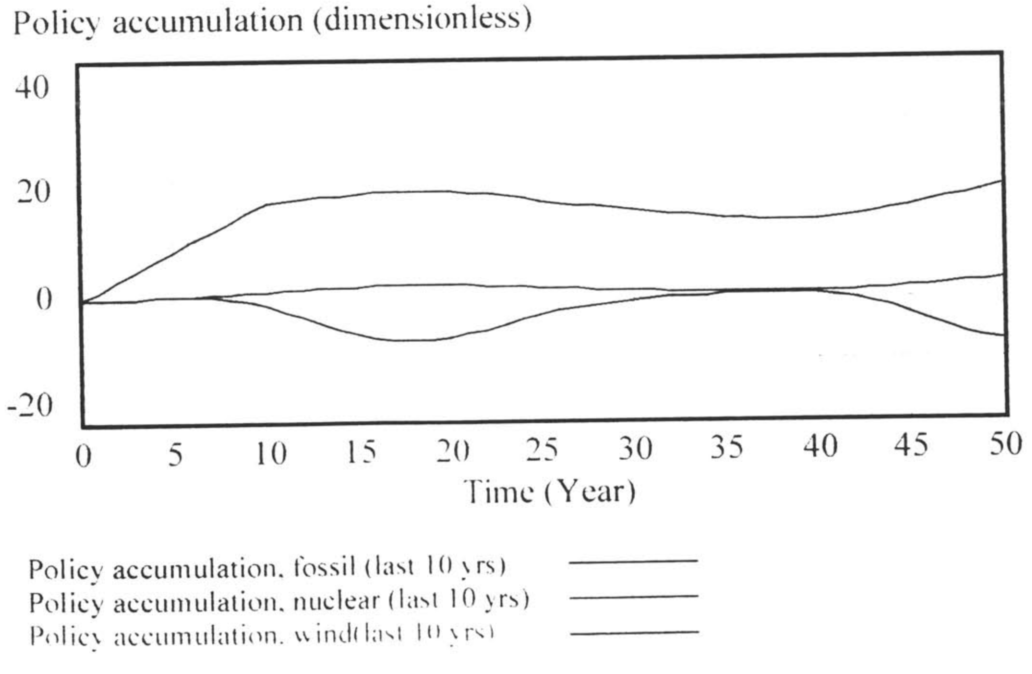


Figure 54: Policy accumulation in the last 10 years, by power plant type.

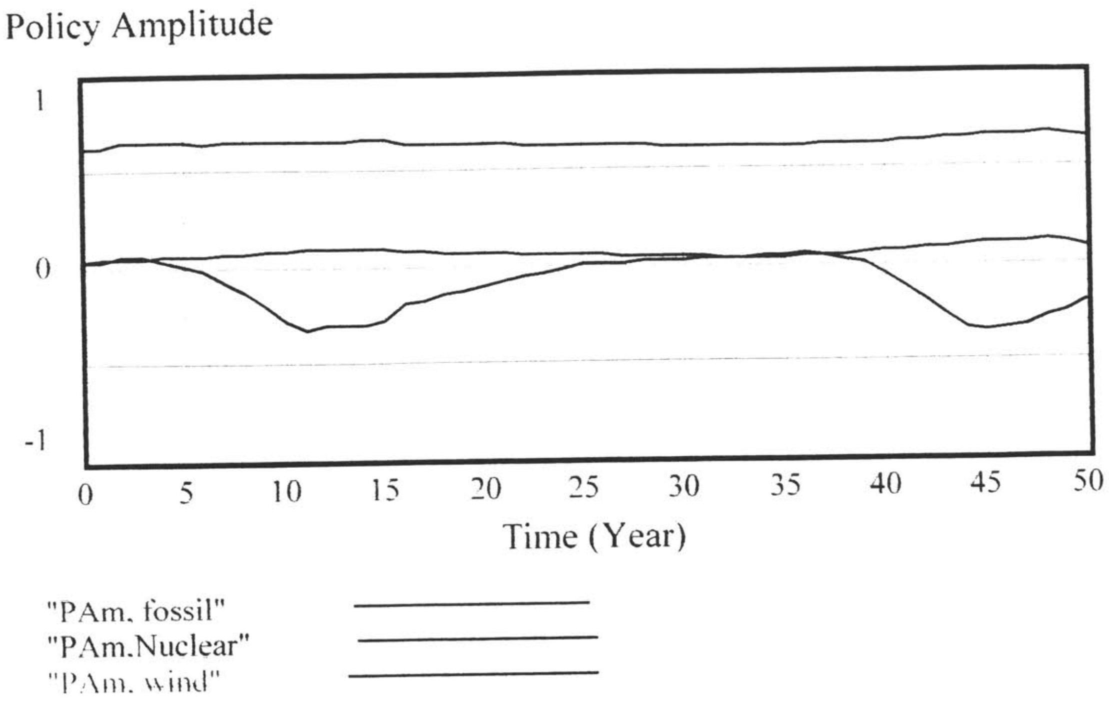


Figure 55: Amplitude of policies generation for nuclear, fossil and wind power plants.

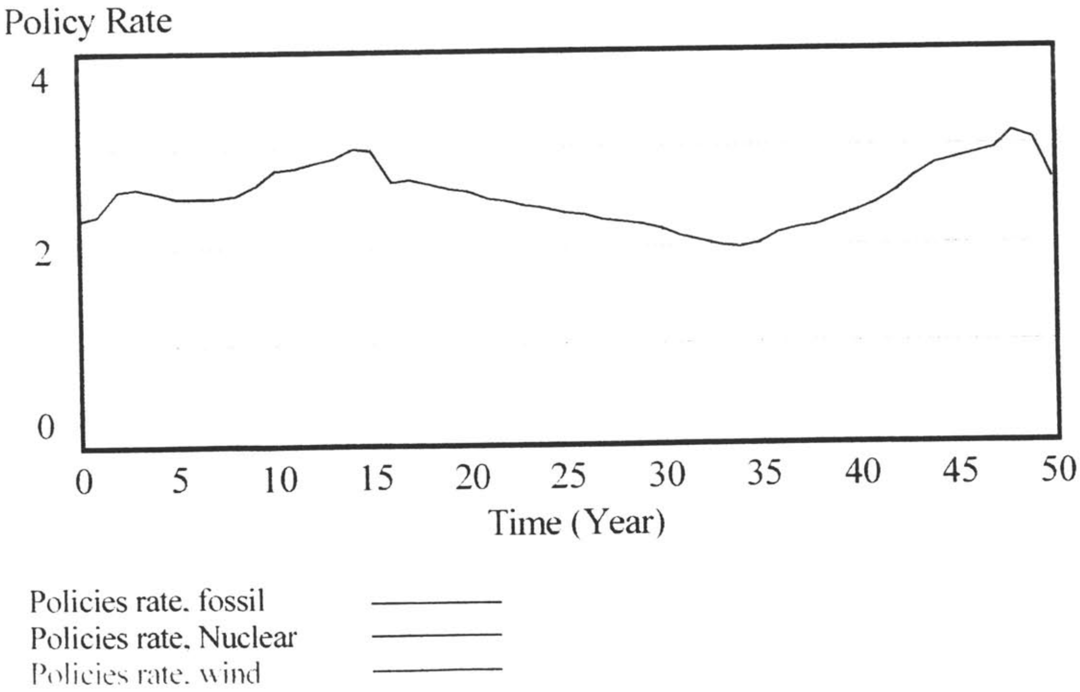


Figure 56: Rate of policies generation for nuclear, fossil and wind power plants.

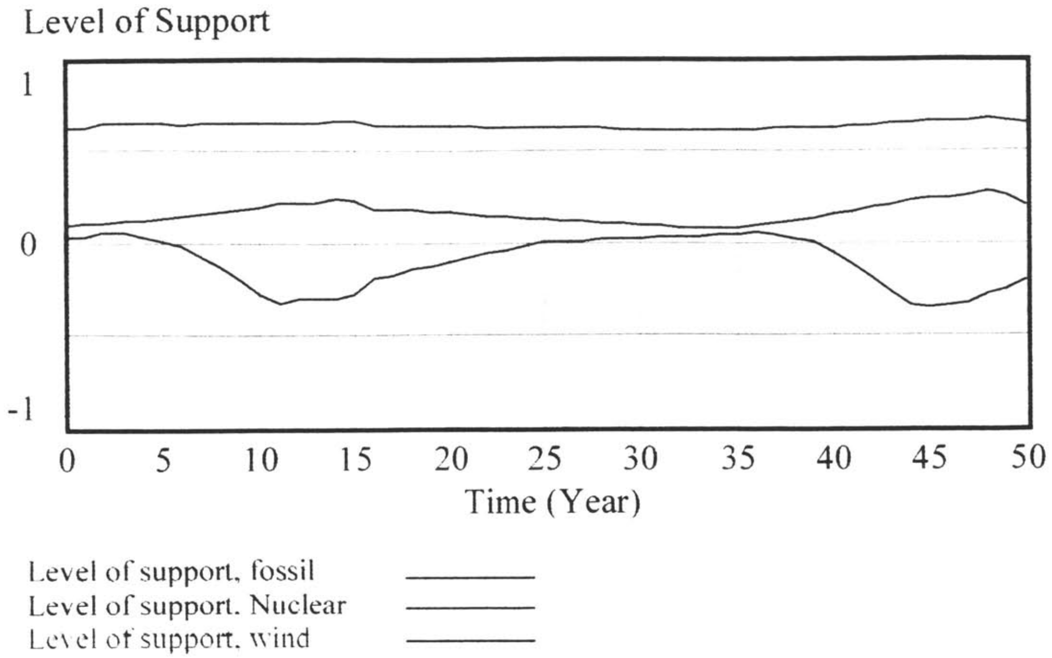


Figure 57: Level of support for nuclear, fossil and wind power plants.

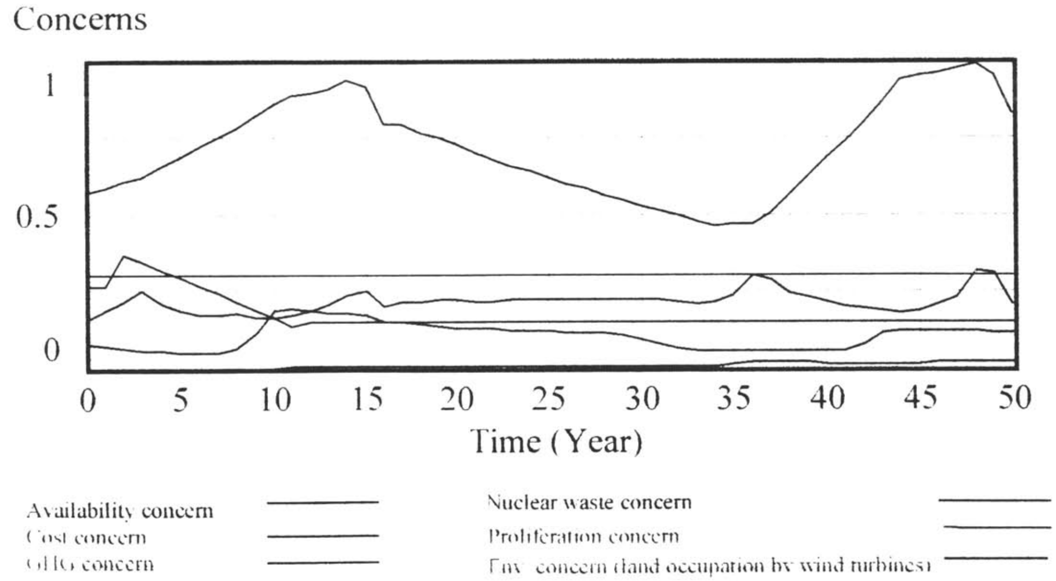


Figure 58: Perceived public concerns.

6.3 Case 2: Yucca Mountain Decision to Open is Delayed.

The first variant to the basic case presented is a delay in the decision to open Yucca Mountain. In the basic case, the decision to open Yucca Mountain is made within the first year. In this case, we have introduced delays of 5 and 10 years. The results of these simulations are presented in Figure 59.

We can see that these delays are translated into delays in the recovery of the nuclear industry, which place is taken by renewable sources. This may happen in case that the greenhouse effect is important enough to constrain the growth of fossil fuelled plants by quotas or economical impacts such as taxes.

We also see that, due to the rate of retirements of nuclear power plants, a delay of 10 years would probably mean the end of the nuclear industry. As it would take another 10 years to finish building Yucca Mountain, this twenty years delay would mean the loose of expertise needed to make a nuclear project viable. Also, during this first stage of our project, we have not considered the constrain imposed by the low capability of the industry to build new power plants, which can make the recovery of the nuclear industry even more difficult, as more delays are introduced.

6.4 Case 3: Sensitivity to Concern regarding the Greenhouse Effect

In the basic case, we have introduced a curve for the concern about greenhouse gases with the change in the release rate of greenhouse gases as an input parameter. The results in the basic case seem to be driven mainly by the the greenhouse effect. That's the reason why we have studied the sensitivity of our results to this effect.

The results of these simulations are shown in Figure 60. The resulting share of energy between fossil and nucler (wind is not shown for simplicity) is presented together with the curves showing the perceived concern vs % of change in the rate of greenhouse gas emissions that have been used. It is seen that a reduced concern regarding greenhouse effects, delays the recovery of the nuclear industry. An real case would be that the US governemnt does not react to the

Figure 59: Power capacity, by power plant type for the case when Yucca Mountain repository is delayed.

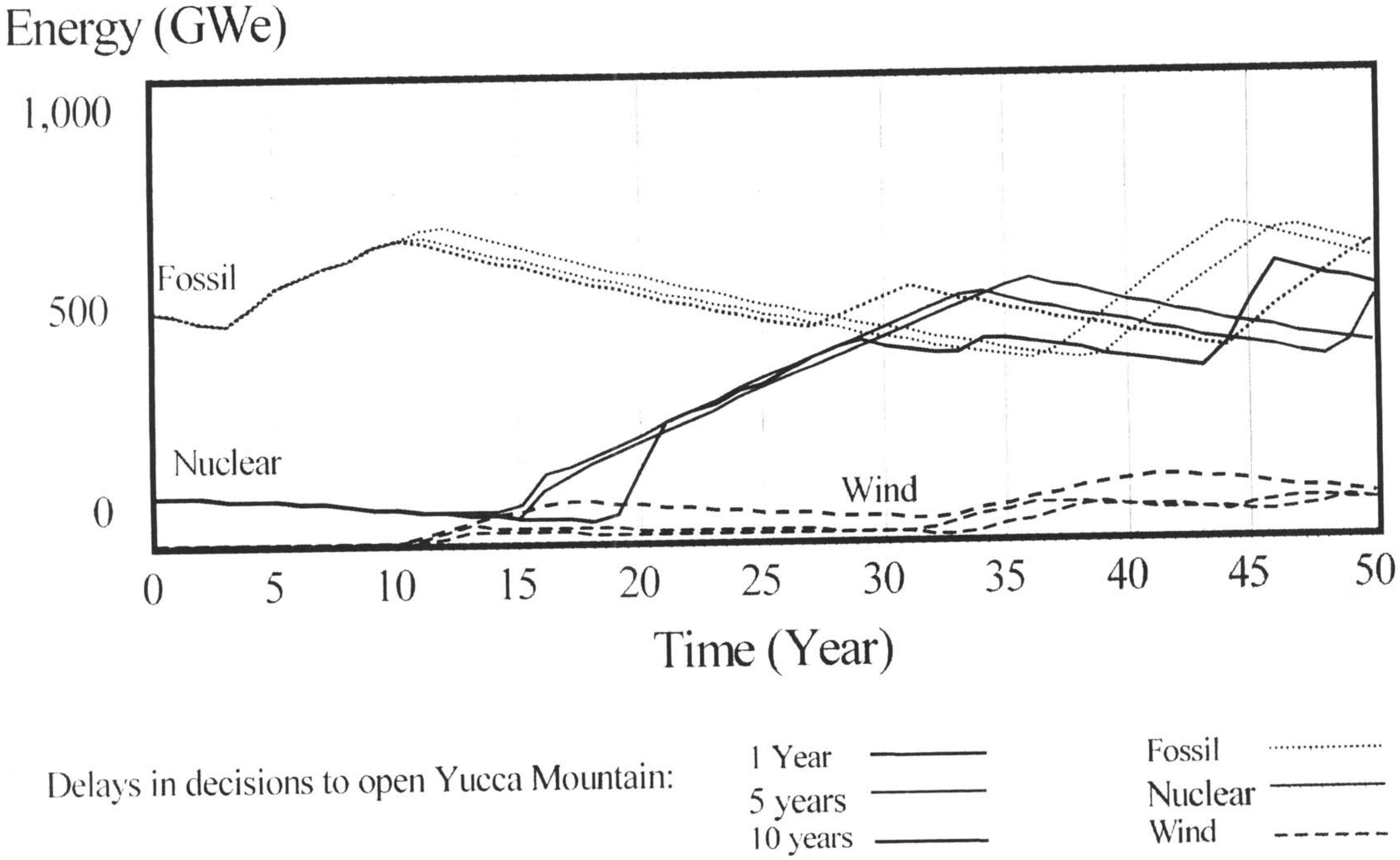
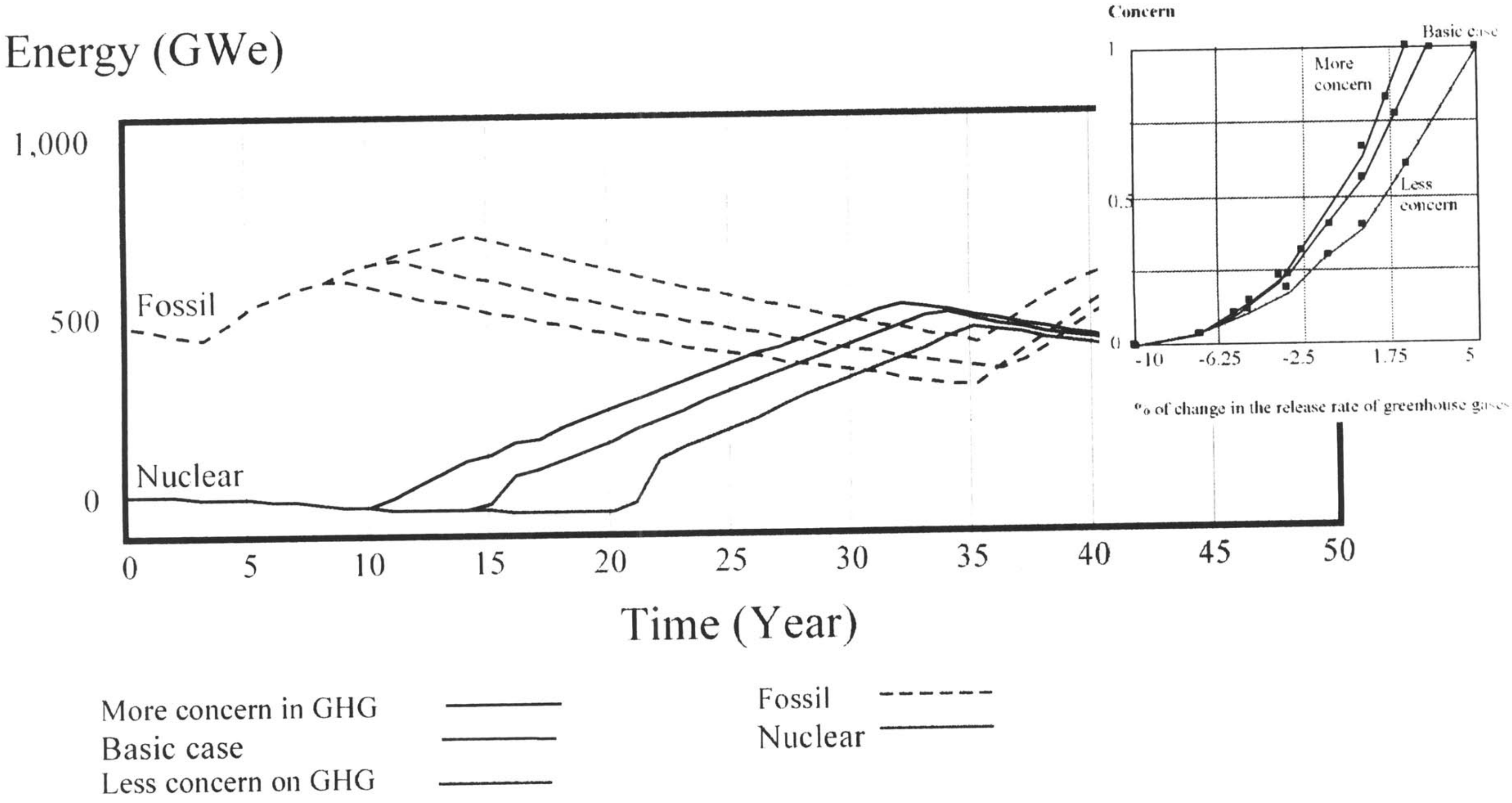


Figure 60: Power capacity, by power plant type for the case when greenhouse gas maximum allowed rate is changed.



international pressures to reduce the greenhouse gas emissions, in which case no tax would be imposed on carbon emissions. The total cost of fossil would continue to be lower than the nuclear, unless the nuclear industry comes with a new technology where capital costs can be reduced by half, as the promoters of the Peeble Bed Modular Reactor claim (Ref. [22]).

6.5 Case 4: Negative bias for Nuclear Power Plants Introduced

Figure 61 shows the basic case compared to the case where a constant negative bias por the nuclear industry is introduced in the model.

The results of this simulation is very intuitive: if policymakers and regulators are constantly against the resurgence of the nuclear industry, the place eventually left by the fossil industry is going to be taken by other sources of energy, even if they have a high cost.

6.6 Case 5: Small Accidents

An interesting case to analyze is when accidents of small magnitude occur that raise the cencerns about the nuclear energy for a short period of time.

To analyze the results of such situations, we have introduced curves representing small accidents or sabotage acts. These are shown in Figure 62.

The interesting result about this is that for an accident of the same magnitude, the biggest damage to the nuclear industry would be if it happens at the beginning of the recovery (blue line in the graphic). Again, this would cause a delay of some years in the decisions to open power plants which would make it doubful for a industry without has lost its expertise to recover. Needless to say, the bigger the magnitude of the accident, the worst its consequences.

Figure 61: Power capacity, for fossil and nuclear power plants. Case: Negative bias for nuclear power plants.

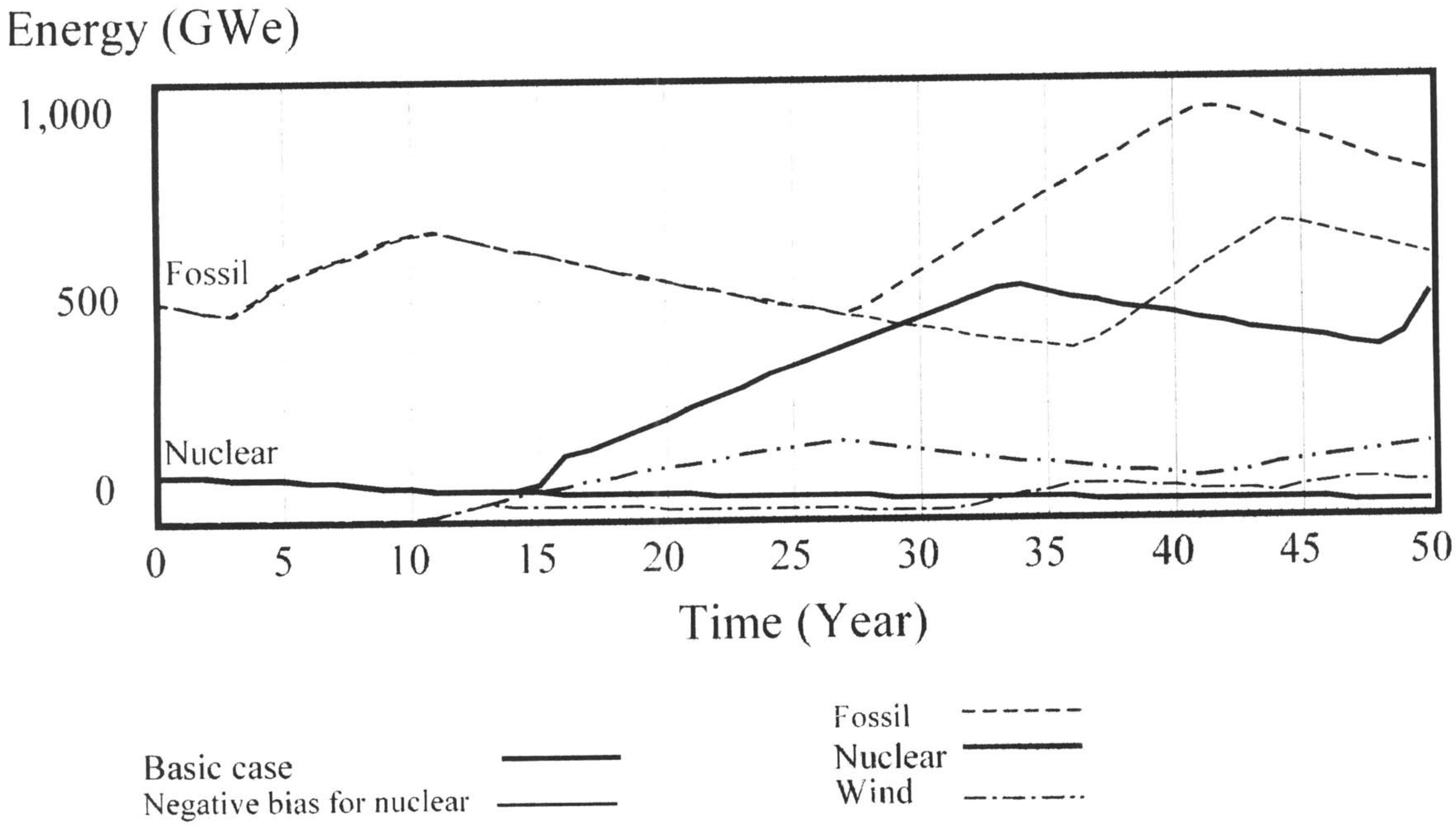
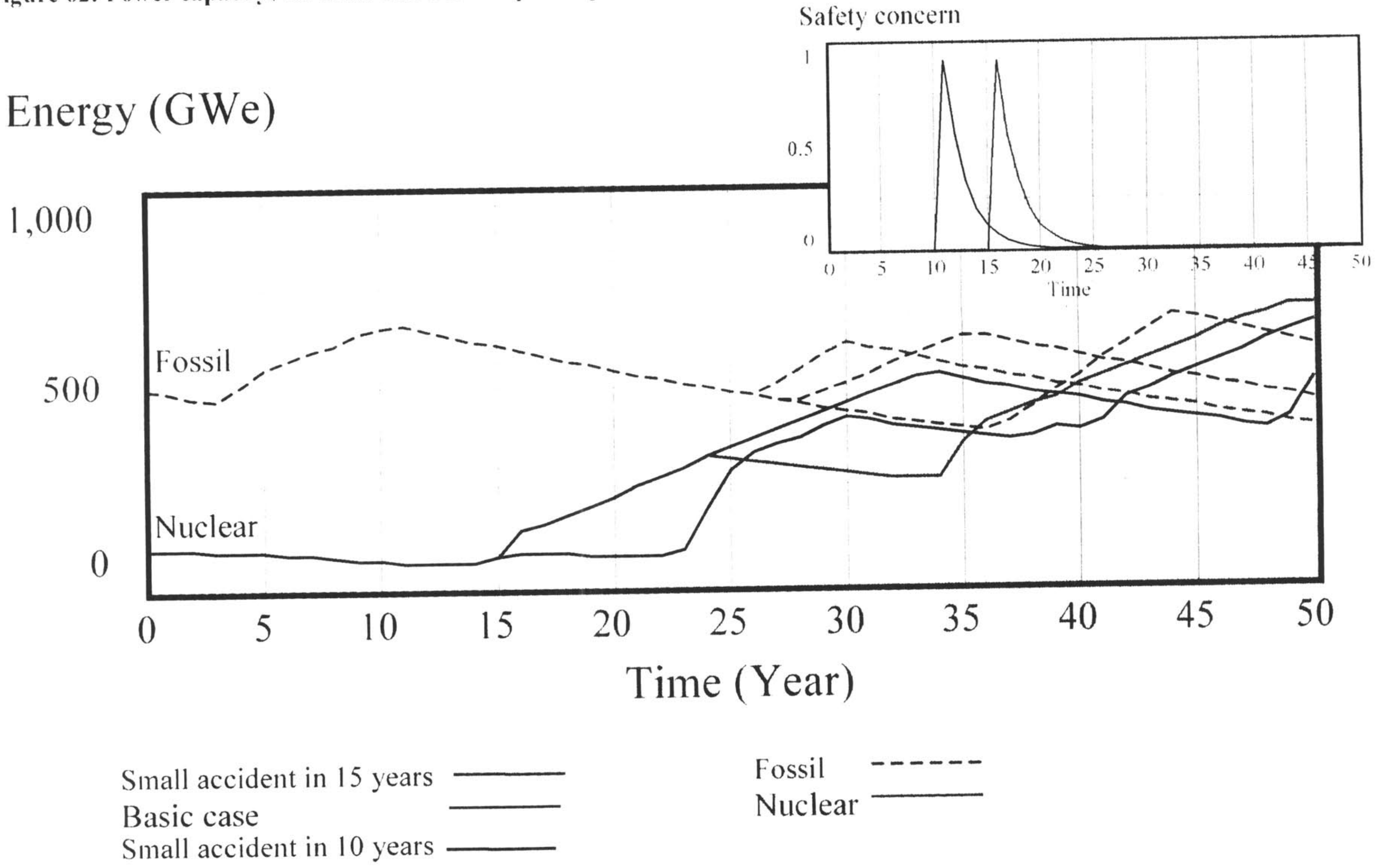


Figure 62: Power capacity, for fossil and nuclear power plants when a small accident or a sabotage act occurs.



6.7 Summary and Conclusions

In this chapter, we presented the results obtained through the use of the simulation tool of the energy policymaking process for five cases. The results are summarized as follows:

CASE 1: The basic case.

The nuclear power plants can reach 50% of the share for supply of electricity in the United States. The decline in the percentage of fossil-fuelled power plants and the increase in nuclear power plants and wind farms is based only on their economics. This low cost for nuclear power plants results from policies affecting positively on their capital and production costs, and negatively on fossil fuelled plants (representing a carbon tax for instance). These policies are mainly driven by the dynamic behavior of concerns regarding energy availability, energy costs, greenhouse effect, high-level nuclear waste, environmental effects caused by wind turbines, proliferation and safety issues.

In our simulations, the resurgence of the nuclear industry is determined mainly by two factors: 1) nuclear waste management concern decreases due to the opening of Yucca Mountain within the next 10 years, and 2) concern on greenhouse gases becomes very relevant.

CASE 2: Yucca Mountain decision to open is delayed.

The first variant to the basic case presented is a delay in the decision to open Yucca Mountain. A 5 year and a 10 year delays have been introduced. These delays are equivalent to delays in the recovery of the nuclear industry.

Due to the rate of retirements of nuclear power plants, a delay of 10 years in the decision to open Yucca Mountain would probably mean the end of the nuclear industry.

CASE 3: The maximum allowable increase in greenhouse gas release rate is changed to 2% and 5% instead of 3%.

A reduced concern regarding greenhouse effects, delays the recovery of the nuclear industry. The total cost of fossil would continue to be lower than the nuclear, unless the nuclear industry comes with a new technology where capital costs can be demonstrated to be reduced by about half of its actual cost (the Pebble Bed Modular Reactor could be a solution).

CASE 4: There is a negative political bias for nuclear power.

The place eventually left by the fossil industry is going to be taken by other sources of energy or fossil power plant's owners would decide to pay the taxes, making the greenhouse effect even worst.

CASE 5: There is a small nuclear accident, the result of transportation spills or sabotage.

For accidents of a given magnitude, the biggest damage to the nuclear industry would be if it happens at the beginning of the recovery (blue line in the graphic). Again, this would cause a delay of some years in the decisions to open power plants which would make it doubtful for a industry witch has lost its expertise to recover.

The main conclusion of the result of this simulations are that the recovery of the nuclear industry is based on a number of factors which main can make it possible to reduce its capital cost relative to that of fossil plants. This can be possible by:

1. Opening Yucca Mountain, so the perceived risk of the investment can be reduced.
2. Giving objective information to public and policymakers about the real benefits and drawbacks of nuclear power plants and their associated processes, as well as informing them regarding the political and environmental consequences of greenhouse gases.
3. Either high penalties on greenhouse gas emissions or flexibilize legislation about unnecessary safety requirements to reduce the burden on the capital costs of nuclear power plants.
4. Reduce the possibility of sabotage or small accidents that can raise the concerns about the benefits of the nuclear industry.

It is evident that the conditions are given for a resurgence of the nuclear industry. A detailed strategy is needed to take advantage of this historical moment where the various elements needed to see the renaissance of the nuclear industry are given.

Chapter 7: Conclusions and Future Steps

7.1 Summary of the Thesis

The increasing demand of electrical energy has to be met by some means. At present, the sources of electrical energy are fossil -including oil, gas and coal-, nuclear and renewable sources of energy – including solar energy, biomass power plants, geothermal plants, ocean energy, and wind turbines.

The use of fossil fuels has a bad environmental impact due to the amount of pollutants released to the air. Among these pollutants are acid rain gases, such as SOx and NOx and greenhouse gases, such as CO_2 and CH_4. The acid rain gases have been controlled in the United States thanks to a tax and quota approach. Greenhouse gas emissions have not been regulated yet and are believed to be responsible for the global warming effect.

Regarding renewable sources, biomass, solar and wind turbines are among the most interesting. Wind turbines are suspected to be the only ones that will have a significant share of the electricity supply. However, they are prohibitively expensive, have a short lifetime and their efficiency is based on the speed of the wind. They cannot provide over 20% of the energy demand. Besides, they have other impacts, such as the area of land or sea occupied, the bird migration paths, the noise produced and the change in wind patterns.

Nuclear power is an important source of the electricity supplied in the United States and worldwide. However, no nuclear power plants have been built in the last three decades. This is partly because there are many concerns remaining about proliferation, safety and nuclear waste storage, but also because of their high capital costs due to the great number of redundant systems necessary to license them. The nuclear industry needs to learn how to influence the social/political environment to create favorable policies and to develop an appropriate strategy to be able to revive. This is the main cause why we developed a system dynamics model of the energy policymaking process. This tool would allow for a common view of the energy policymaking process and for simulation of a great number of different scenarios and analysis of their results.

This model comprises:

- Policy amplitude calculation: This represents how favorable or unfavorable the new policies are regarding each means of producing energy[20]. The policy amplitude is estimated considering the political support and bias for each means of generating electrical energy. The political support depends on the concerns and characteristics of the form of energy analyzed, while the bias depends on the dominant political parties, the results of elections and lobbying.

- Policy generation rate calculation: This represents the rate at which policies are generated and is a function depending on the many energy concerns and their perceived importance.

- Concerns: Estimation of concerns regarding greenhouse gas effects, nuclear waste, safety, proliferation, availability and cost have been introduced. The severity of greenhouse effects and nuclear waste depend on the production rates of fossil and nuclear energy, respectively.

- Policy Influence on energy cost: An estimate of the effect of the cumulative policies on overnight cost, opportunity cost and operative cost for nuclear, wind and fossil energy was introduced.

- Decision-making: The generation cost is the main factor for deciding on the means used to cover the increasing demand of electricity.

The results based on intuitive curves and data were presented in Chapter 6. In case a ultimate repository with infinite capacity is open, we could observe a periodic behavior of the system, which is dominated by the greenhouse effect. The explanation to that is when the number of fossil power plants is high enough to cause excessive concern about greenhouse effect, there are

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[20] Policy refers to laws, regulations, taxes, etc. that are the output of the political sector. In the United States, the political sector groups the administrative agencies, the White House and the Congress.

no new construction orders for them and they decline in number to the end of their lifetime. During those periods, the electricity is mostly supplied by nuclear means, although some renewable is used, until the levels of greenhouse gas release rate are low enough to loosen the burden on fossil fueled plants and they become competitive again.

This basic behavior suffers delays whenever the greenhouse maximum tolerable release rate is changed, or when there are delays in the opening of Yucca Mountain, for instance. If these delays are long-enough, the nuclear industry, and with that, the capacity to manage nuclear technology, could disappear in the United States. The same would happen with the occurrence of an accident, even small, in the next few years in which the nuclear industry is not still strong enough.

From the several scenarios simulated, the main conclusion is that nuclear power plants are likely to become the dominant means of electricity generation in the United States provided that an ultimate repository for nuclear waste is open. This result derives mainly from the increasing concern on the greenhouse effect and from the high cost and low availability of wind turbines. At present, the main efforts of the nuclear industry should reside on decreasing its capital costs and making the greenhouse effect been a major problem.

7.2 Suggested Future Steps

More work is needed to verify the validity of the model and the level of desegregation of the political and public sector specially. Also, the concepts of the level of political support, and the level of political importance, and the way they are actually calculated need to be verified. Concern about the different issues need to be quantified and verified by historical data.

The natural next steps of the project would be to gather sufficient information to obtain the historical policy amplitude and rate for fossil, nuclear and renewable sources of energy. Also it is important to gather historical information on concerns regarding proliferation, safety, cost, availability, greenhouse effect, nuclear waste management and environmental effects of wind turbine; and political bias and lobbying at the same periods of time.

After that, calibration of the variables of the model and verification will be possible.

Appendix 1: Acknowledgements

Financial support provided by TEPCO, is highly appreciated. The authors thank to the contributors of this work:

MIT

Prof. E.B. Skolnikoff:	Professor of Political Science
Prof. R. Lester:	Professor of Nuclear Engineering
Prof. John de Figueiredo	Assistant Professor, Sloan School of Management

US Department of Energy

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Mr. John C. Brons:	Director Policy and Planning

National Research Council:

Mr. Kevin D. Crowley:	Director, Board on Radioactive Waste Management

US Senate

Ms. Colleen A. Deegan:	Counsel, Committee on Energy and Natural Resources
Mr. Pete B. Lyons:	Science and Technology Advisor, Senate Pete Domenici's office

Appendix 2: Introduction to the Nuclear Waste Management Issue

I Introduction

Although nuclear power supplies one-fifth of the world's electricity, creates little pollution and no greenhouse effects, its future remains a question. This uncertainty is due to a combination of economic, technical and social issues.

The most relevant concerns among the public and policymakers regarding nuclear power for electricity generation include management of nuclear waste, proliferation and safety.

a) The Nuclear Waste produced by commercial nuclear power plants can be divided into low and high-level nuclear waste. High-level nuclear waste requires hundreds of years for its activity to decrease to safe levels.

b) Proliferation is the diversion of nuclear materials for fabrication of weapons. This results in increasing demand for safeguards.

c) Safety. The accidents at Chernobyl and Three Mile Island led to great concerns about nuclear safety in both the public and the political sectors. These concerns have affected nuclear regulations, nuclear economics and nuclear plant operations.

The nuclear waste management issue is the one that is analyzed here. A quantitative introduction to this problem is given, while in the next chapter a model of utilities concern regarding this issue and its result is presented.

II Nuclear Waste

Countries worldwide have accumulated radioactive waste as the result of their nuclear power plants, nuclear weapons, medical treatments, food treatments, etc. Some parts of this waste are hazardous for a few years, while others are dangerous for several thousands of years. This waste must be stored until it no longer presents a danger for the environment or life.

II.1 Classification of Nuclear Waste

There are five general types of radioactive waste, according to the U.S. Nuclear Waste Policy Act (NWPA) definition:

High level waste (HLW). (1) They are highly radioactive materials resulting from the reprocessing of spent fuel, including liquid waste produced directly in reprocessing, and any solid material derived in such liquid waste, that contains fission products in sufficient concentrations; and (2) Other highly radioactive material that the NRC determines requires permanent isolation. In once-through cycles, spent fuel is considered HLW.

Transuranic waste (TRU). These are defined as wastes containing alpha-emitting isotopes Z>92, with half-lives longer than 5 years and concentrations greater than 100 nCi per gram of waste.

Low level waste (LLW). They include (1) Not HLW, TRU, or by-product materials; and (2) what the Commission (NRC) classifies as LLW. At the same time, they are further subdivided into A, B, C. About 95% of the LLW falls into the A category and decays to background levels within 100 years and the rest within 500 years. LLW is generated in all activities involving radioactive materials, including clothes, tools, syringes, paper, water purification filters and resins, etc.

Uranium mill tailings. They result from mining activities and are not transported from their generation point.

Natural occurring and accelerator-produced radioactive materials (NARM). In terms of disposal, they qualify as LLW and in the U.S., they are the responsibility of the states.

Disposal of Low-Level Waste

Due to present disposal methods, low-level waste is not a hazard to the people who live near a disposal facility or to the workers. They account for 85% at the volume and less than 1% of the radioactivity of all radioactive wastes.

In the United States, low level waste disposal was done in three sites since the 60s: Richland, Wash; Barnwell, S.C. and Beatty, Nevada. The Beatty site is now closed, but another facility, the Envirocare Site in Utah, opened in 1995.

However, due to the low-level waste disposal cost, generators have reduced the level of low-level waste sent to those sites. Generators - industry, academy, utilities, government and medical- have reduced the amount of it separating radioactive from non-radioactive materials and including techniques such as compaction, incineration, decontamination, and storage while it decays.

Disposal of High-Level Waste

High-level nuclear waste requires hundreds of years for its activity to decrease to safe levels. It can be reprocessed and recycled in which case the volume of high-level nuclear material is dramatically reduced. This is done in France and Japan, for example. However, in the United States it was prohibited by President Carter's administration in 1977. The intention was to set a technological barrier to fuel reprocessing. Although President Reagan lifted the ban on commercial reprocessing in 1981, there was no response from the nuclear industry sector.

Without reprocessing, the management of high-level nuclear waste demands one or both of the following two measures: a) geological disposal of high-level nuclear waste, b) to reduce the level of nuclear waste by separation or transmutation (S&T). However, this last option may be an economically non-viable solution.

In the United States, much of the high-level waste currently been stored was generated by the reprocessing of the fuel from governmental owned nuclear reactors (until 1972), and the vast majority of reprocessing was done by the military for the production of Plutonium (until 1992). This material is under the jurisdiction of DOE and stored in DOE's sites including Hanford, Savannah River, West Valley and INEEL. The rest of the high-level waste is spent-fuel from commercial nuclear power plants. According to Ref. [19], the annual rate of production of spent fuel is 520 m^3 from all PWRs and 700 m^3 from all BWRs per GW(e) produced.

The Nuclear Waste Policy act of 1982 and its 1987 amendments require the Department of Energy (DOE) to locate, build or operate a deep, mined geological repository for high-level waste (including spent fuel from commercial reactors, from nuclear weapons programs, from research reactors and from the Navy's nuclear-powered ships and submarines). In this act, it was also established that NPPs should pay 1 mill/kWh sold to the Nuclear Waste Fund, to finance DOE's activities.

Nine locations in six states met the criteria for potential repository sites. Technical and environmental assessments narrowed down the possibility to three sites. However, the Congress selected the Yucca Mountain Site, in Nevada, as the only site for characterization.

The repository was scheduled to be completed by 1998, however the actual date is uncertain. The projected cost of Yucca Mountain is seen in Figure 64. The current schedule anticipates that the Secretary of Energy will recommend the site to the President during this year (2001). In turn the President will have to recommend the site to the Congress. If the Congress agrees with the President recommendation, the DOE will submit the proposal to the NRC for licensing. The schedule for past and future decision is seen in Figure 63.

Even if Yucca Mountain is approved as an ultimate site, the fuel has to be transported from every reactor site to the ultimate place. Every state, county and municipality has the right to delay or try to stop the shipment.

The Lawsuits

Ten lawsuits have been filed in the U.S. Courts of Federal Claims seeking more than $4 billion in monetary damages as a result of the DOE's failure to begin removing used nuclear spent fuel from plant sites. In the first three, the courts found that the DOE is responsible for damages caused by its breach of contract with the utilities. In a conflicting rule by a different judge of the same court in April 1999, a similar claim for damages was denied. In February 1999, Energy Secretary Bill Richardson made an offer to DOE to "take title" to the used nuclear fuel at plant site in exchange for utilities giving up the litigation. This was a good intent, but it felt short in meeting the utilities needs.

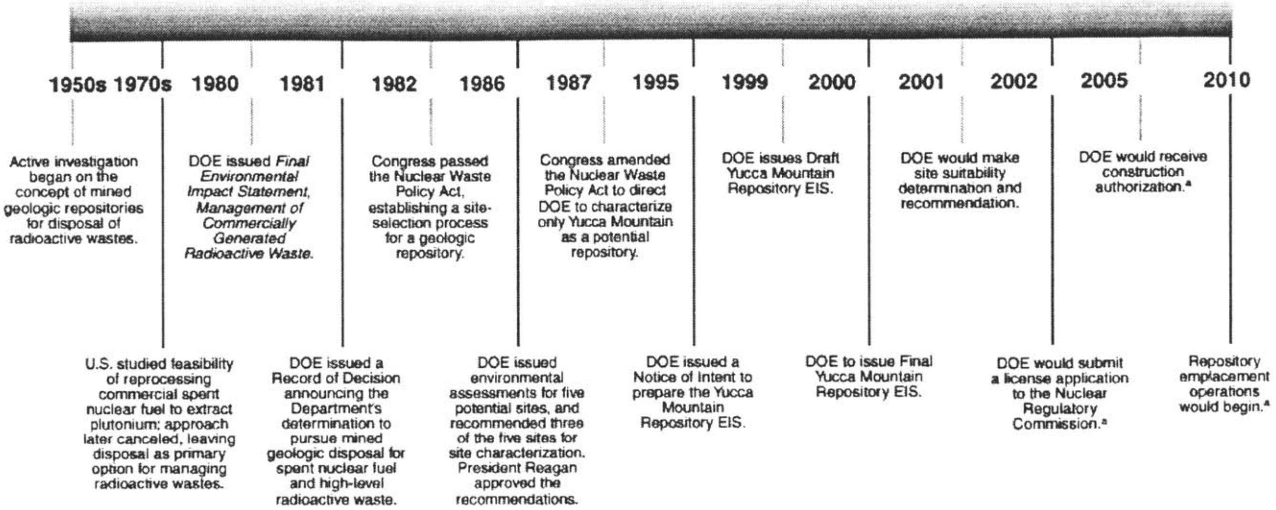
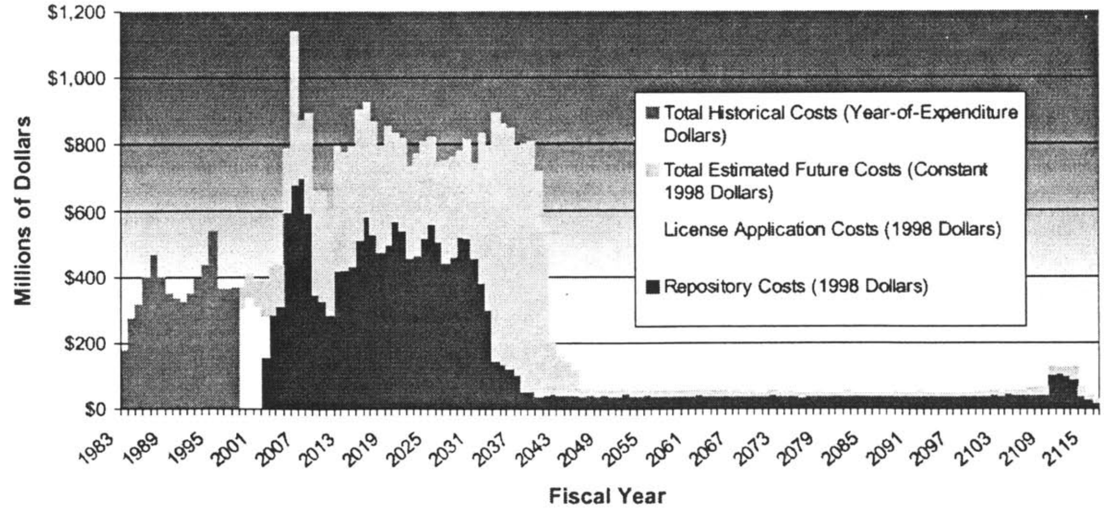


Figure 63: Sequence of past disposal and possible future repositroy activities[21]



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[21] Source: Ref. [25] , NEI, "Nuclear Energy: 2000 and Beyond. 1999 Update to a Strategic Direction for Nuclear energy in the 21st Century".

Figure 64: Profile of the total system life cycle cost[22].

More recently, in August 2000 DOE compensated PECO Energy Company for their delay in accepting spent fuel from commercial nuclear power plants. After that, eight utilities filed suits in the U.S. Courts of Appeal, asking the courts to declare illegal this agreement because it means a financial burden for them regarding the Nuclear Waste Funds.

As seen, the problems regarding the high-level nuclear waste management in U.S. are very complex.

The total volume of commercial and DOE/Defense wastes and spent fuel through 1997 is shown in Figure 65.

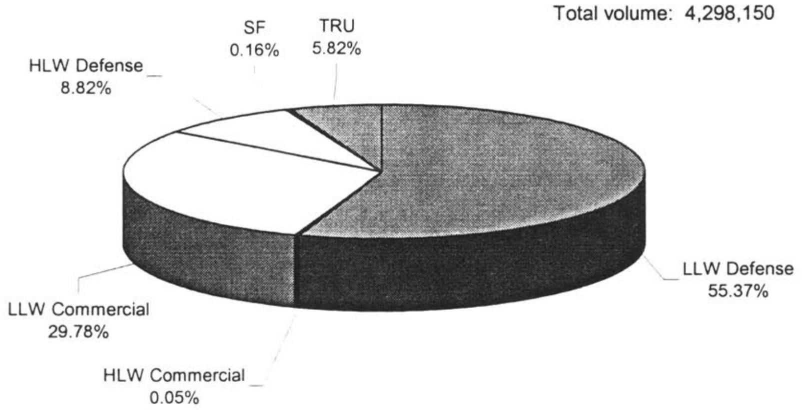

Figure 65: Percentage of commercial and DOE / Defense wastes and spent fuel through 1987[23].

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[22] These cost estimates were made by DOE. Ref. [25] , NEI, "Nuclear Energy: 2000 and Beyond. 1999 Update to a Strategic Direction for Nuclear energy in the 21st Century".

II.2 Interim Storage

The lack of a repository has placed nuclear power plants in the position of storing more used fuel than expected for longer than originally intended. By the end of 2006, about 60 nuclear power plants will have to close due to the lack of space in their storage capacity. By the end of 2010, 78 NPPs will have exhausted their storage capacity. The number of nuclear units with sufficient space available for storing spent fuel is seen in Figure 66 (there are 104 nuclear power plants in operation nowadays).

In this case, a plant has two options to enlarge the on-site capacity:

1) Re-racking: This means moving closer the spent fuel stored in the spent fuel pools. This option has its limitations, as a minimum distance between spent fuels must exist to prevent criticality and overheating. The option of building new pools is too costly and the needed layout is difficult to fit in the existing plants.

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1. [23] Source: Ref. [19]. Nuclear Energy Institute, Online. http://www.nei.org/doc.asp?catnum=2&catid=136. Access date: June, 2001. Access date: 25 October,2001.
2. Stella Maris Oggianu and Professor Kent F. Hansen. "Modeling the Dynamic Complexity of the Nuclear Policymaking Process and System: The High Level Nuclear Waste Issue." MIT-NFC-TR-033. Center for Advanced Nuclear Energy Systems Massachusetts Institute of Technology July, 2001.

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3. Nuclear News. A publication of the American Nuclear Society, USA. September 2001. Page 35.

Cochran, R.G., Tsoulfanidis, N., 1999. The Nuclear Fuel Cycle: Analysis and Management. 2nd edition, American Nuclear Society, USA.

2) The dry storage option: These are large containers made of steel or steel-reinforced concrete. Concrete, steel and lead are used as the radiation shield. The NRC has approved some of the designs for 20 years. After that, they have to be reapproved.

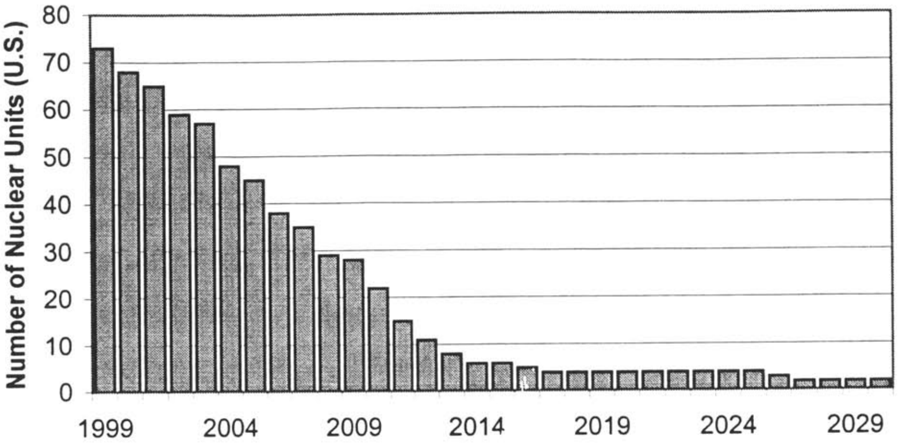

Figure 66: Used fuel pools with sufficient space available[24]

Some states are concerned that the interim disposal would last for more than the envisioned 20-40 years. For this reason, some state governments have opposed the licensing of additional dry storage. Another concern regarding dry-storage is economics: designing, building and licensing a dry storage facility at a plant site requires \$10-20 million. Although each dry-cask cost approximately \$55 to \$115/kgHM it will cost \$5-7 million to grow and maintain the facility (Ref. [19]). These costs are above the contributions that utilities have made to the Nuclear Waste Fund. Each dry-cask can contain from 21-33 PWR assemblies (9-12 tons or 4,500,000-6,000,000 kg of heavy metal), or 45 to 75 BWR assemblies (8-12 tons or 4,000,000-6,000,000 kg of heavy metal).

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[24] Number of U.S. nuclear units with sufficient space in their used fuel pools to off-load all fuel from the reactor core at one time if no interim or ultimate storage is build. Source: Energy Resources International, Inc. Ref. [24]. Department of Energy, Online. Available: http://www.em.doe.gov/tab11.html. Access date: June, 2001..

There is another option to provide for a temporary storage facility: a centralized site. As the United States did not foresee for this option, a group of utilities signed an agreement with the Skull Valley Band of Goshutes in Utah for a private financed used fuel storage facility on the tribe's land. If approved, the site could begin operating in 2002.

II.3 Transportation concerns: Accidents and Sabotages

Spent fuel has to be transported from every reactor site to the storage place or ultimate repository, either by train, by truck or, part of the way, by ship. Every state, county and municipality has the right to try to delay or stop the shipment.

Even though in the past 30 years, there have been more than 3,000 shipments of spent fuel in the Unites States and 30,000 shipments worldwide, there has never been a serious accident. Even in January 2001, Germany authorized France to send their high-level spent fuel to the Gorleben storage facility, after they had been stopped in 1998 due to the discovery of contaminated containers, but not serious accidents. (see Ref. [27]).

However, the fear of accidents can cause an extra delay in the process of moving the spent fuels to the storage sites.

III Summary and Conclusions

Nuclear waste results from innumerable activities with nuclear materials: defense, medicine, electricity generation, research, industrial applications, etc.

High level nuclear waste disposal deserves special consideration because it takes millions of years to reach a radioactivity comparable to the ground level. However, the volumes produced are manageable. Solutions to handle them include 1) reprocess and recycle, which would minimize their volume, 2) separation and transmutation of the isotopes with the higher half-lives and 3) geological disposal. Some countries adopted the first option. However, for historical reasons of proliferation concerns, reprocessing is not done in the United States.

The Nuclear Waste Policy Act 1982 and its amendments of 1987 require the DOE be responsible for all high-level nuclear waste, and its ultimate geological disposal by 1998. These include DOE high-level waste (generated from the military weapons, vessels and research activitoes) and commercial waste produced by NPP. The NWPA also requires the NPPs to pay 1 mill/kWh of electricity sold to the Nuclear Waste Fund (NWF). This fund has been since used by the DOE to explore different geological sites. Yucca Mountain is the only site under exploration now, however the DOE has already a delay of 12 years.

Even if the site is approved, the fuel has to be transported from every reactor site to the ultimate repository. Every state, county and municipality has the right to try to delay or stop the shipment. Accidents and sabotage during transportation are the main concerns.

The DOE is facing many lawsuits and if no alternative measures are taken by 2006, the U.S. will loose half of its nuclear power capacity (this means 10% of its electricity capacity) as NPP will have to close due to the lack of space in their spent fuel pools.

Alternative measures include interim on-site and off-site solutions. Re-racking and dry storage belong to the former category and a centralized off-site temporary repository in the Skull Valley belongs to the latter.

Given the background presented here, a qualitative system dynamics model of the high-level nuclear waste management issue will be presented in Chapter 5. The goal of that model is to provide the value of the *concerns* due to the waste management problem needed as an input to the model presented in Chapter 3. The qualitative influential diagram representing what has been discussed in this Chapter and what will be quantified in the next Chapter is given in Figure 67 and is briefly explained in what follows: The utilities concern regarding the nuclear waste management issue depends on the cost of electricity generation and on the capacity to store spent fuel. Both of these variables depends on the on-site and off-site interim and ultimate storage capacity. The NPP storage capacity and the production of electricity are interrelated: (a) if energy is produced, then waste is also generated; (b) if energy is not generated (which is a very severe problem for the political sector), no waste is produced, but no profits are obtained, affecting the utilities sector. As the concern of NPP owners grows they will bring the government into the Courts, which puts more pressure on the political sector.

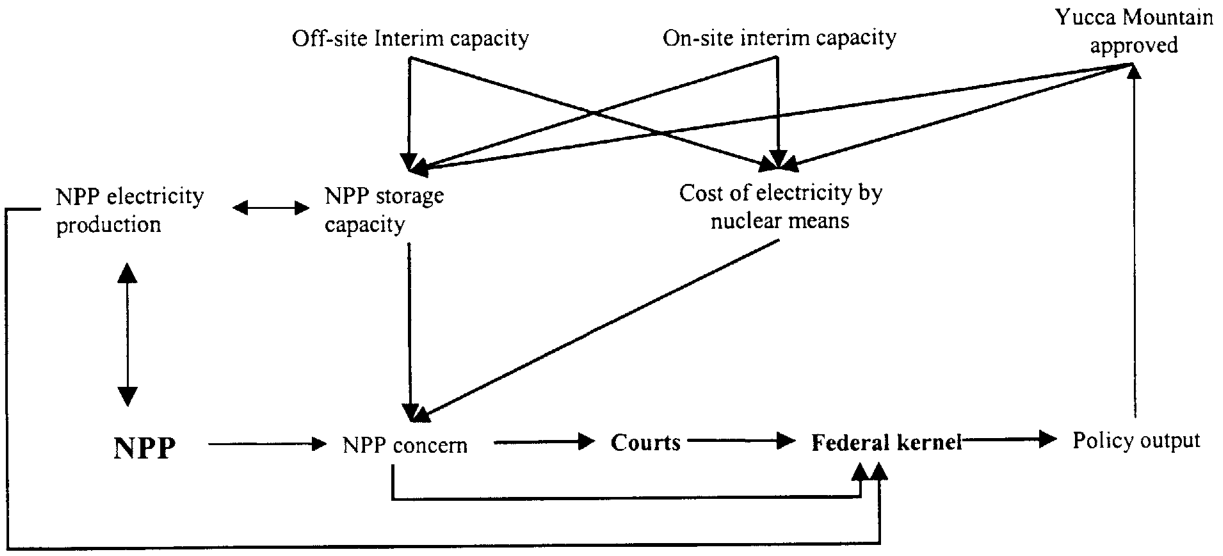
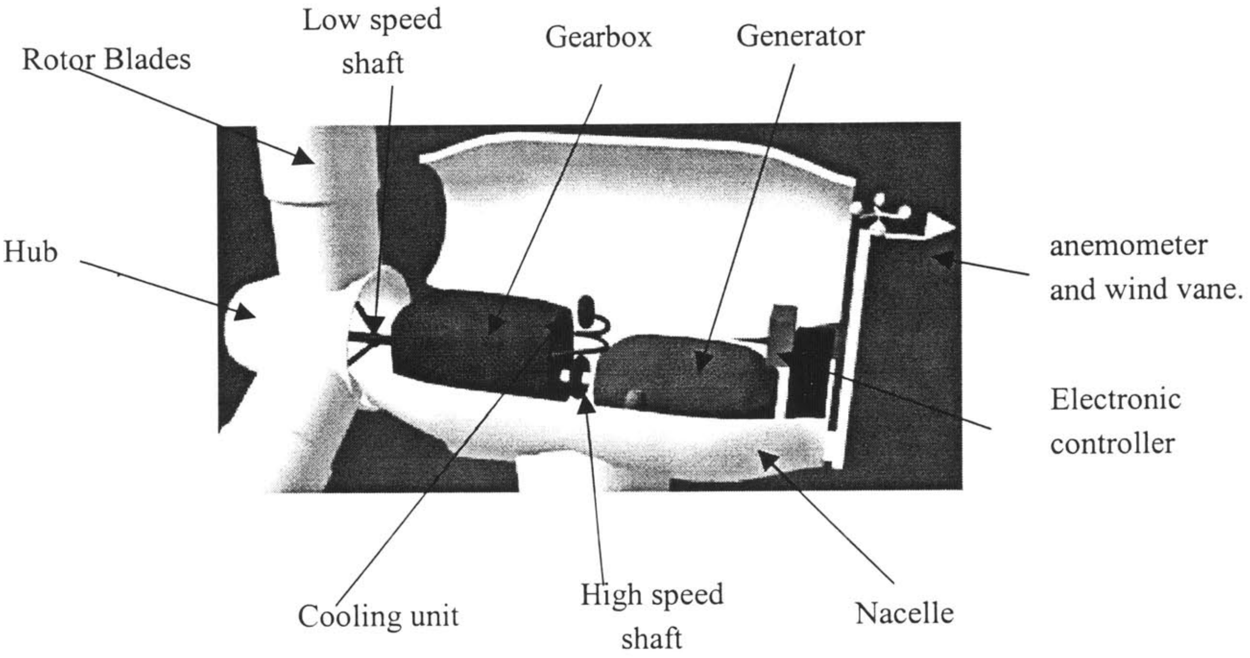


Figure 67: Influence diagram of the spent fuel concern in the United States.

Appendix 2: Components of a Wind Turbine [25]

Wind turbines converts the kinetic energy of the wind into electrical energy and deliver it to the electrical grid. Wind turbines basically comprise the following components, described below: nacelle, rotor blades, hub, low speed shaft, gearbox, high speed shaft with its mechanical brake, electrical generator, yaw mechanism, electronic controller, hydraulics system, cooling unit, tower, anemometer and wind vane.



The **nacelle** contains the key components of the wind turbine, including the gearbox, and the electrical generator. Service personnel may enter the nacelle from the tower of the turbine. To the left of the nacelle we have the wind turbine rotor, i.e. the rotor blades and the hub.

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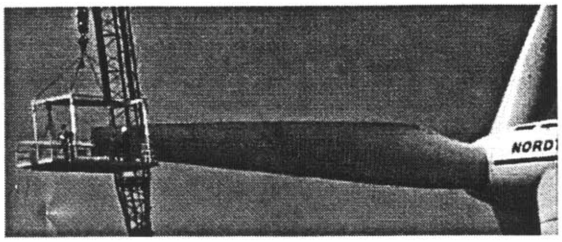
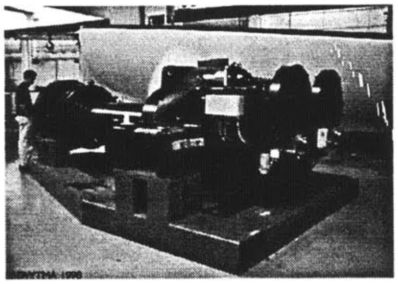
[25] Source of this information: Ref. [28]. www.windpower.com

The **rotor blades** capture the wind and transfer its power to the rotor hub. On a modern 600 kW wind turbine each rotor blade measures about 20 meters (66 ft.) in length and is designed much like a wing of an airplane.



The **hub** of the rotor is attached to the low speed shaft of the wind turbine.

The low speed shaft of the wind turbine connects the rotor hub to the gearbox. On a modern 600 kW wind turbine the rotor rotates relatively slowly, about 19 to 30 revolutions per minute (RPM). The shaft contains pipes for the hydraulics system to enable the aerodynamic brakes to operate.



The **gearbox** has the low speed shaft to the left. It makes the high speed shaft to the right turn approximately 50 times faster than the low speed shaft.

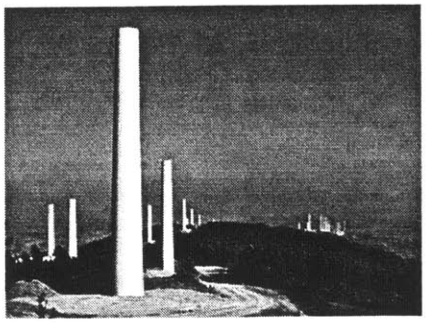
The **high speed shaft** rotates with approximately. 1,500 revolutions per minute (RPM) and drives the electrical generator. It is equipped with an emergency mechanical disc brake. The mechanical brake is used in case of failure of the aerodynamic brake, or when the turbine is being serviced.

The **electrical generator** is usually a so-called induction generator or asynchronous generator. On a modern wind turbine the maximum electric power is usually between 500 and 1,500 kilowatts (kW).

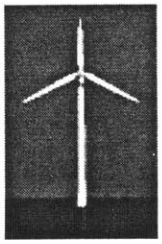
The **electronic controller** contains a computer which continuously monitors the condition of the wind turbine and controls the yaw mechanism. In case of any malfunction, (e.g. overheating of the gearbox or the generator), it automatically stops the wind turbine and calls the turbine operator's computer via a telephone modem link.

The **hydraulics system** is used to reset the aerodynamic brakes of the wind turbine.

The **cooling unit** contains an electric fan which is used to cool the electrical generator. In addition, it contains an oil cooling unit which is used to cool the oil in the gearbox. Some turbines have water-cooled generators.

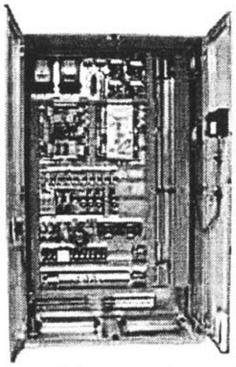


The **tower** of the wind turbine carries the nacelle and the rotor. Generally, it is an advantage to have a high tower, since wind speeds increase farther away from the ground. A typical modern 600 kW turbine will have a tower of 40 to 60 meters (132 to 198 ft.) (the height of a 13-20 story building). Towers may be either tubular towers (such as the one in the picture) or lattice towers. Tubular towers are safer for the personnel that have to maintain the turbines, as they may use an inside ladder to get to the top of the turbine. The advantage of lattice towers is primarily that they are cheaper.



The **yaw mechanism** uses electrical motors to turn the nacelle with the rotor against the wind. The yaw mechanism is operated by the Electronic controller which senses the wind direction using the wind vane. The picture shows the turbine yawing. Normally, the turbine will yaw only a few degrees at a time, when the wind changes its direction.

The **anemometer** and the **wind wane** are used to measure the speed and the direction of the wind.



The electronic signals from the anemometer are used by the wind turbine's **electronic controller** to start the wind turbine when the wind speed reaches approximately 5 meters per second (10 knots). The computers stops the wind turbine automatically if the wind speed exceeds 25 meters per second (50 knots) in order to protect the turbine and its surroundings. The wind vane signals are used by the wind turbine's electronic controller to turn the wind turbine against the wind, using the yaw mechanism.

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