Modeling the Dynamic Complexity of the Energy Policymaking Process

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Abstract

This paper presents a System Dynamics approach to modeling how electric energy policy is created and modified in democratic nations. The selection of future generation capacity depends upon the comparative economics between technologies. These economics are subject to variation as societal concerns about such issues as supply reliability, safety, and environmental effects change.

The model represents the issues that create concern and the various segments of society that articulate the concerns. The model incorporates a representation of how the political structure within the United States responds to concerns in terms of policy outputs that affect energy economics. Decisions regarding capacity additions are based upon the most profitable choice available to the utility at the moment of decision. Demand is treated as an exogenous variable. Energy production to meet the demand produces byproducts and consequences that in turn feedback to the societal sector concerns.

1. Introduction

Electric energy is a fundamental element of all national infrastructures. The generation, transmission, and distribution of electricity is an enormous enterprise that touches almost all aspects of industrialized societies. The electric power industry is a significant consumer of financial and natural resources; a significant producer of undesirable byproducts; and a significant source of social/political activities. Perhaps the largest social/political change in recent years has been the move away from an economically regulated electric industry towards a competitive system, particularly regarding electric energy generation.

New electric generation capacity must be created in the future in order to meet growing populations; to extend electric energy availability to less industrialized nations; and to replace aging equipment.

The selection of a technology for new generation capacity is an extremely complicated matter. The selection is based upon an economic analysis using well-known analysis tools. In a regulated environment, the analysis had to deal with a technology assessment and an assessment of the likely future of fuel costs. The owner/developer had the advantage that changing future fuel costs could be passed on to consumers. However, in an unregulated market the owner/developer must absorb risks associated with fluctuating fuel costs.

Of even greater significance to the selection is the impact of changing regulation on future costs, both capital and production. Growing concern about byproducts produced by energy production creates social/political pressures to impose regulations upon producers. The nuclear industry has suffered large increases in costs associated with assuring safety of plants, particularly after the Three Mile Island and Chernobyl events. The added costs have made new nuclear plants noncompetitive in the United States. Similarly, the concern about air quality and greenhouse gases is beginning to impact fossil electric energy costs.

Thus, the future of this fundamental element of the national infrastructure will be determined by the interactions between technology characteristics, societal values, and the political processes that govern national decision making.

System dynamics models have been developed on the past to study energy policies (Naill 1992, 10; Naill et al 1992, 120). These models focus upon supply / demand dynamics and how various policy devices can be used to influence these dynamics. For example, Naill et al explicitly addresses how policies can effect greenhouse gas production. Similarly, there are System Dynamics models of the electric supply sector (Ford 1997, 65; Ford and Bull 1989, 10). Again, the focus is upon representing supply/demand dynamics and developing insights into the impact of policies options including conservation and deregulation.

We focus on the converse problem, namely how electric energy production impacts the dynamics of policymaking. Thus, demand becomes an exogenous variable and supply / policymaking is the dynamic to be studied.

The goal of this research project is to create a quantitative model of the electric energy policymaking process. The model is to represent how various social concerns affect the policymakers, and how any subsequent policies impact the energy industry. The impacts will be reflected in the relative costs of nuclear versus fossil technologies, and thus the future generation mix. The generation mix, coupled with the electric demand, will lead to byproducts such as nuclear waste and greenhouse gases. The production of these byproducts will stimulate further social concerns thereby closing the feedback into the social/political system.

If a model can be built, it should then be possible to study the system from various viewpoints. For example, different energy policies will produce different overall responses. Frequently there are unintended consequences that are not foreseen and are counter to the policymakers intent. Having a simulation model opens the possibility of nondestructively testing policy options. It should be possible to compare numerous policies and generate quantitative insights into optimal choices.

A model may also make possible a determination of how to affect the system behavior most effectively. Advocates of a particular technology always face a choice of how and where to influence the system. Thus, should one invest in public information activities, in improving technology, in lobbying policymakers, or in trying to influence elections? It may be possible to understand how best to conduct such activities with a reasonable model of the decision making process.

Finally, it should also be possible to identify the most significant factors that most impact system performance. For example, are energy costs, energy availability, or energy byproducts of most concern to the public? And how does this concern influence the rate and amplitude of policymaking?

The model presented in the next sections should be viewed as the “first cut” or “zero level” model. It was created at an elementary level for the purpose of illustrating how such modeling can be done, what types of input are required, and how the model can be used to gain insight. It is surely not detailed enough in terms of the sectors of the social/political system. Further, many of the quantitative representations incorporated are plausible assumptions and not well-documented correlations. However, the results are suggestive of how the model could be used to answer real questions about the real system.

In section 2 of this report we present the model structure and the explicit numerical relations that are used. In section 3 we present a series of example results. These must be viewed as illustrative and not as quantitatively representative of the real system.

2. Model Overview

Our current model is based upon the structure of the energy policymaking process characteristic of the United States. It should be representative of many industrialized democracies, albeit with certain unique parameters. In particular, the major feedbacks between society, the political structure, and the industrial structure are represented.

The main elements of our model are graphically presented in Figure 1. As represented in this graph, the model is based on the following assumptions:

1. The federal government sector responds to public concerns on certain issues by generating policies that have as their main goal the reduction of the concern that gave rise to them. Policies comprise regulations, legislation, speeches, actions, or any other means of affecting the evolution of society and industry.

2. The policies generated by the federal sector may impact the production costs, capital costs or perceived risks of electricity of each type of technology. These parameters affect the levelized costs of each technology.

3. Utility owners base their electricity capacity decisions according to these levelized costs.

4. The production of electricity generates waste and increasing concerns related to the greenhouse effect, nuclear waste storage, safety, proliferation, cost, availability, and other environmental concerns, such as land utilization. These concerns generate the pressures necessary for the Federal Government to act, closing the main feedback loop.

In reality, the federal government comprises many entities including the White House, the Federal Agencies, and Congress. In addition, each of them produces their own policies. However, at this stage of development, we have not disaggregated the federal government in order to keep the model as simple and representative as possible. It is also worth noticing that the state level has been ignored in the current, simplified version of the model.

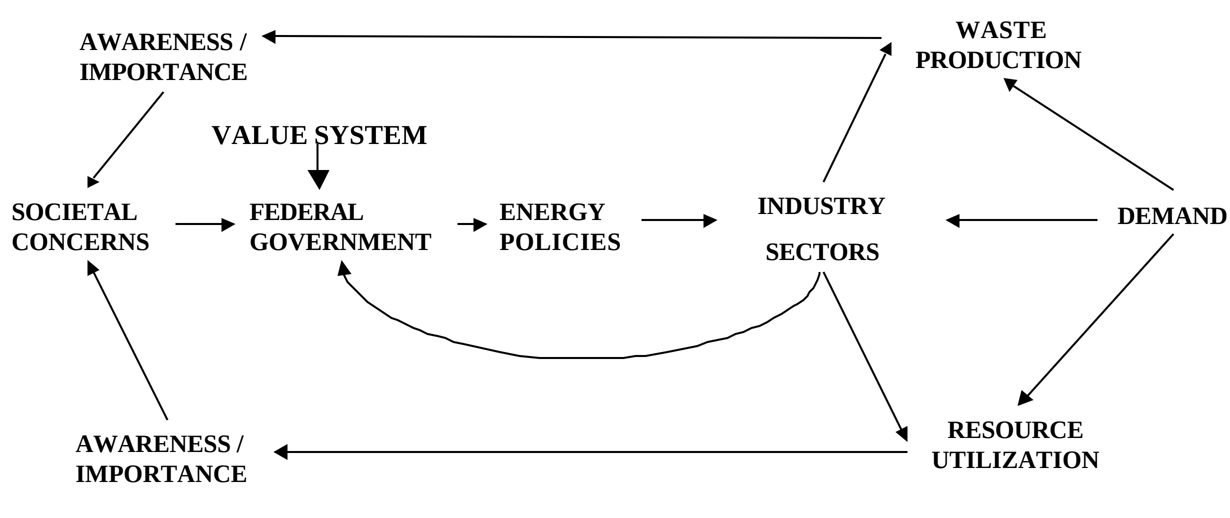


Figure 1: Energy Policymaking Model Overview.

Regarding the electric industry, we consider the nuclear sector, the fossil sector (including gas, oil, and coal), and wind turbines as representative of the renewable sources of energy. The model then generates different policies for each of these three sectors. Each of these policies modifies the capital costs, the production cost and the perceived risk of each of the three types of electric technology.

Each of these means of generating electricity raises public concerns regarding different issues, including electricity costs and availability, proliferation, safety, nuclear waste, greenhouse effects, and environmental concerns related to renewable sources of electricity. For example:

- Nuclear generated electricity yields nuclear waste and thus affects public concerns regarding nuclear waste storage, proliferation and safety.

- Fossil fueled power plants release gases which have adverse environmental impacts, such as the greenhouse effect.

- Wind turbines have an impact on environmental concerns, mostly related to the area of land needed for their deployment, and the effect on birds' migration paths.

Regarding society, there are many different groups including the general public, the elite and special interests groups. The latter includes pro and anti-nuclear groups, and independent non-government organizations (NGOs). In our model, the activities and influence of these societal groups are represented in several ways: (a) the interest groups influence policymakers and the general public through lobbying activities and reports in the media; (b) the elite has a strong influence on the general public and policymakers, and they are the ones with interest and influence on issues regarding the greenhouse effect, nuclear waste storage facilities and proliferation; (c) the general public is mainly concerned about electricity costs, availability and safety, and they influence the policymakers' decisions through their votes.

Other factors must also be considered besides the public's concerns. These factors include lobbying activities, public information, political bias and perceived merits of technologies; each of them are briefly explained below:

- Lobbying activities are activities performed by the interest groups that inform congressmen of what the important issues are. Through these activities, lobbyists frequently modify the biases of policy makers and, subsequently, the nature of their decisions.

- Public information is mainly achieved through the mass media and can modify the preference of voters.

- The political bias may be changed by: (1) elections, through which the dominant parties in the government may be changed and (2) lobbying activities. As an example, in the United States, the Democratic Party has traditionally not supported nuclear energy development while the Republican Party has shown a tendency to support the nuclear industry. However, the degree of nuclear support by one party or the other depends on the historical context.

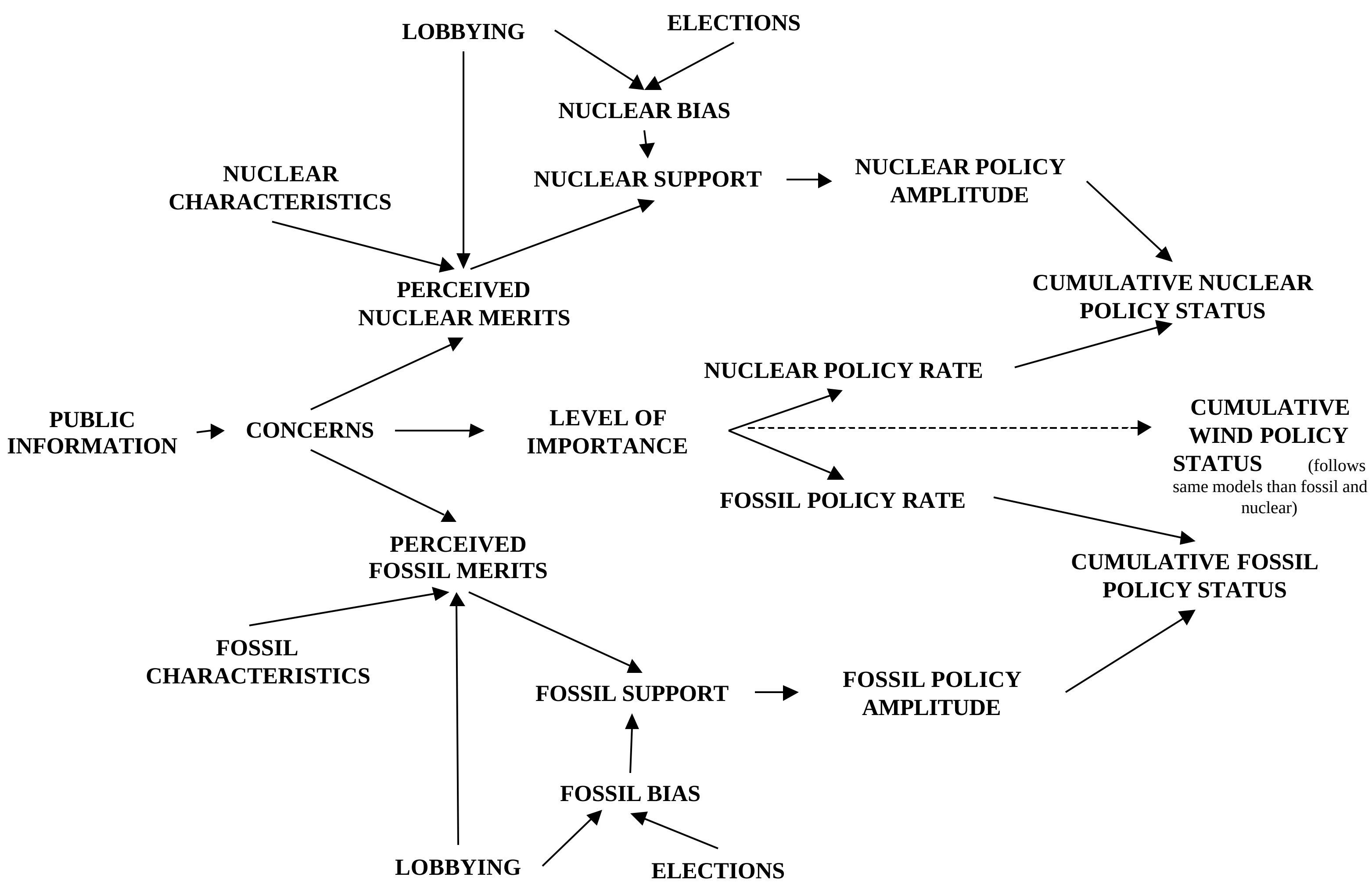
- The perceived merits of technologies are factors that represent the policymakers' perception of each technology as a solution or a contributor to a particular problem. As an example, nuclear power plants have a positive merit regarding the greenhouse effect, while fossil plants have a negative merit.

The influence diagram showing our representation of the energy policymaking process is presented in Figure 2. In order to facilitate the description and interpretation of this model, we have divided it into the social/political, the economic and the technical sub-models.

The outputs of the social/political part are the variables representing the policies for the fossil, nuclear and wind technologies. A portion of its many inputs are the social concerns.

At the same time, the inputs of the economic sub-model are the variables representing the policies which affect the levelized costs of electricity production and therefore the electricity capacity decision-making. The outputs of the technical sub-model are the electricity share for each electricity technology. They are then used to estimate the average electricity costs, the electricity supply, the amount of waste produced and the associated societal concerns.

Figure 2: Overview of the Model Approach for the Energy Policymaking System.



2.1 Representation of the Energy Policymaking Process

From the overview of our model of the energy policymaking process, it is clear that our representation considers a great number of societal concerns and factors that are the main determinants of the policies generated. In this first representation of the system, the way we have aggregated them is schematically represented in Figure 3 and explained in what follows.

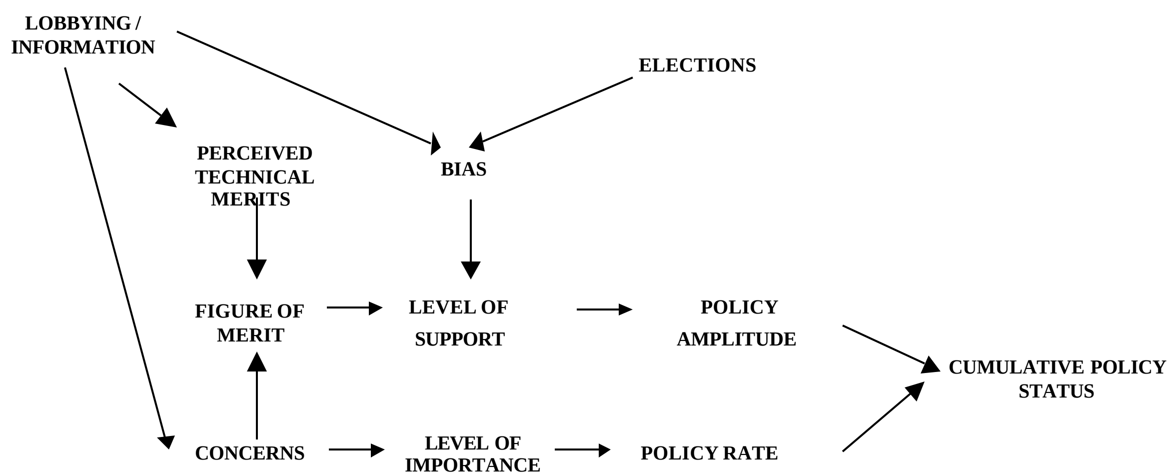


Figure 3: Estimation of Cumulative Policies.

Policies for each type of technology are represented by an amplitude and a rate.

Regarding the policy rate, we know that it is a function of the existence of a crisis or a particular event because the Federal government is basically reactive. For this reason, this variable is determined as being linearly proportional to the level of importance of electricity issues, ranging from a minimum policy rate to a maximum policy rate. The minimum represents the continuous active programs of the US Federal Agencies such as the DOE (US Department of Energy), the EPA (US Environmental Protection Agency) and the NRC (Nuclear Regulatory Commission). The *level of importance* is thus calculated as the sum of all societal concerns, including electricity cost and availability, the greenhouse effect and other environmental issues including nuclear waste management, windmill drawbacks, safety and proliferation. In this way, the *level of importance* ranges from 0 to 7.

The estimation of the *policy amplitudes* is more complex. These variables (one for each type of technology) represent how favorable or unfavorable a policy is to a certain type of technology. This variable varies from -1 to 1, and depends on the *level of political support* for a type of electricity technology. The policy amplitude as a function of the level of support is given in Figure 4.

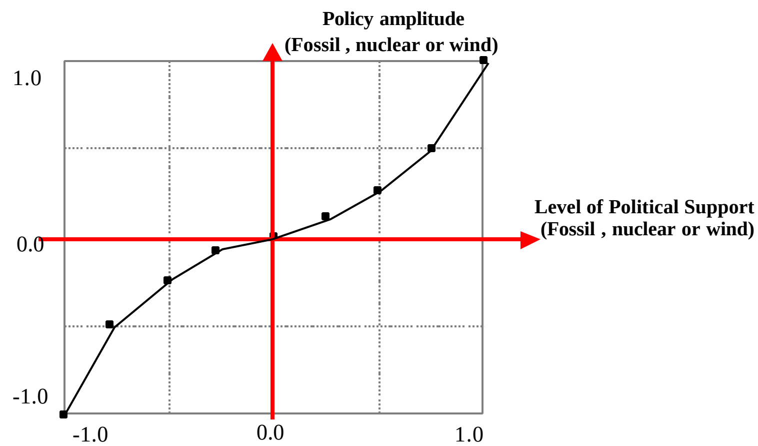


Figure 4: Policy amplitude as a function of the level of support.

The level of support for a certain type of technology depends on its *figure of merit* and the policymaker's bias, and is shown in Figure 5. 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 concern. 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. Mathematically, the figures of merit for each technology X is given by: $FOM^X = \sum_{i=1}^{6} w_i F_i^X$

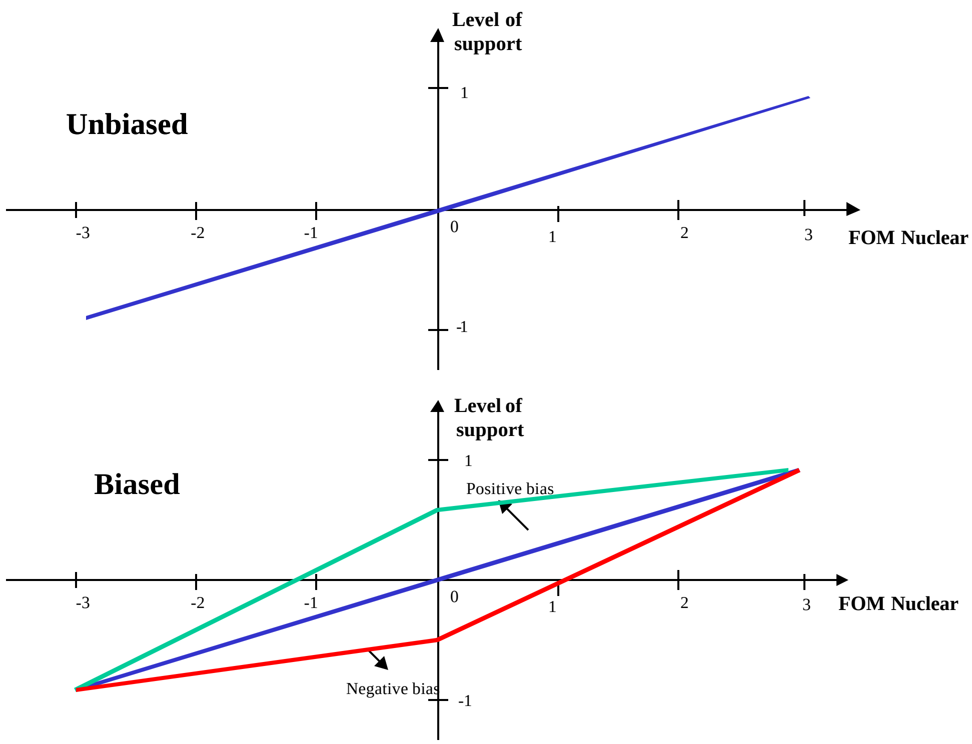


Figure 5: Level of Support for Nuclear Power Plants as a Function of their Figure of Merit and Political Bias.

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^X merits of technology X for issue i. This will be explained later.

For nuclear, FOM^N ranges from -3 to 3. This is because nuclear can have a positive, +1, merit for availability, the greenhouse effect, and environmental problems related to windmills; and it can have a negative, -1, merit regarding nuclear waste, safety, and proliferation issues.

For fossil plants, FOM^F ranges from -1 to 5. This is because fossil can have a positive, +1, merit for availability, nuclear waste, safety, proliferation, and environmental problems related to wind energy; It can have a negative, -1, merit for greenhouse effect.

For wind energy, FOM^W also ranges from -1 to 5. This is because windmills can have a positive, +1, merit for availability, nuclear waste, safety, proliferation, and the greenhouse effect; and it can have a negative, -1, merit for environmental problems related to wind energy.

The *perceived merits* are variables that represent the perceived value of each technology for helping to solve or to make worse each of the issues that we are considering. There are 18 variables summarized in Table 1 and their individual value range from –1 to 1.

The fixed values of the *perceived merits* that we have in our model are included in Table 1. The values that are not fixed are estimated as a function of other variables. An example of the latter is given in Figure 6 which represents the merit of each type of technology regarding electricity availability as a function of their construction time.

Regarding the *concerns*, they are mainly driven by the accumulation of the byproducts of nuclear, fossil, and alternatives, thus closing the overall loop. The present version of the model assumes prompt, accurate awareness to any changes in byproduct production. In later models we will introduce a *public information* pathway given by the *media sector*, which is the vehicle by which most elements of society become aware of matters.

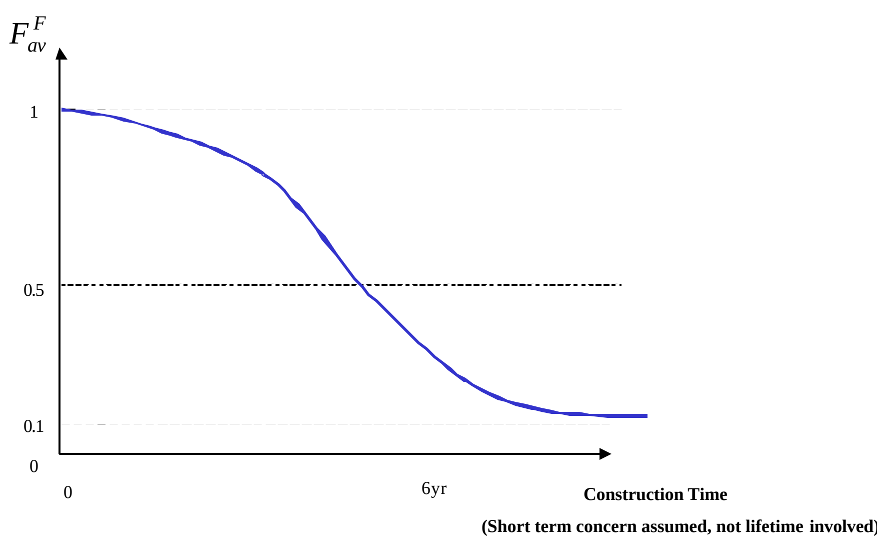


Figure 6: Nuclear and fossil merit for the energy availability issue.

In Figure 7 we present a picture of the various components of societal concerns. In our model, concerns are represented as variables ranging from 0 to 1. A value of 1 is to be interpreted as the maximum degree of concern within the affected population. The concerns are estimated using tables where the abscissa is the ratio of some variable representing the issue to its maximum allowable value and the ordinate is also a dimensionless quantity that is a measure of the degree of concern.

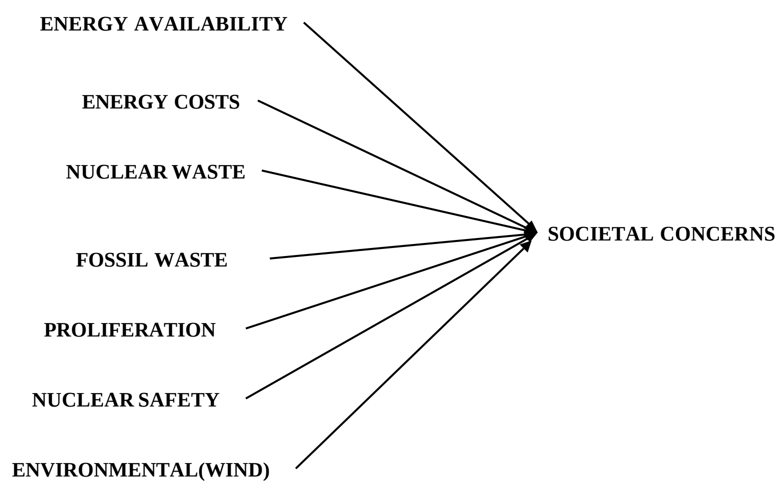


Figure 7: Societal Concerns

As an example, energy availability relates to having adequate electric energy available to users at all times. We illustrate how the concern is quantified in Figure 8. The ratio of time-dependent demand to the time-dependent supply is the energy availability factor. When the ratio is much less than 1 there is plenty of available electricity. As the ratio approaches unity we would expect the appearance of brownouts with increasing frequency and duration. This behavior would dramatically increase concern, as suggested in Figure 8. Because electricity is such a key commodity in life in the United States, any lack of availability would affect all aspects of society. Thus, the availability concern would be expressed by the general public, industry, and commercial organizations. A concern of unity would be a very strong signal to the federal government that the issue is extremely important.

Table 1: Merits of Nuclear, Fossil and Wind Power Technologies.

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

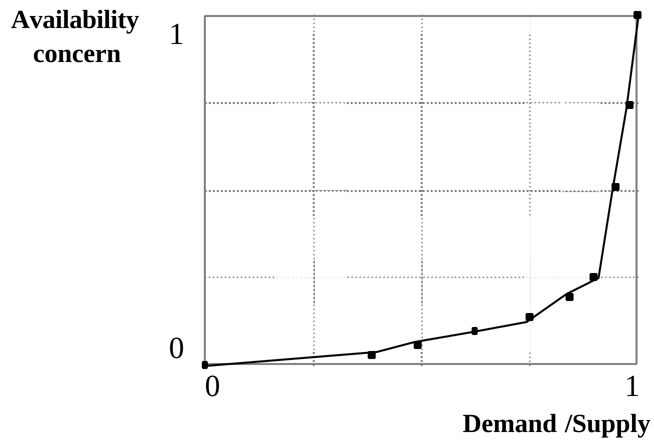


Figure 8: Availability concern

The same methodology is used for the rest of the concerns, although the shape of the curves changes from case to case. For *electricity costs*, the abscissa is given by the ratio of the electricity costs to the maximum that people are willing to pay. For the *nuclear waste* it is represented by the ratio of accumulated high-level nuclear waste to the available storage capacity. The available storage capacity is calculated as the sum of available on-site storage space and the possibility of an ultimate repository being built at Yucca Mountain, Nevada, USA. Of huge impact in the results of the model, is the decision to open Yucca Mountain, which is a variable exogenous to the model. A delay of ten years is introduced between this decision and the actual opening of Yucca Mountain. After Yucca Mountain opens, the remaining concern is because of high-level nuclear waste transportation issues.

For the *fossil waste*, the abscissa (i.e. determinant of its value), is represented by the ratio of the production rate of fossil pollutants to the maximum allowable. The *proliferation* issue is considered a function of the number of nuclear power plants with once-through cycles. For the *safety* issue, it is a function of the time after a hypothetical accident. Finally, for *windmills*, which we have considered as the only viable alternative renewable source of energy for the next 20 to 40 years, *the associated environmental problems* cause concerns which we consider a function of their number, related to the area of land covered by them. We remark here that, in our simulations to date, windmills have not become a significant part of the generation mix due to their economics. Thus, concern about windmills never became a significant factor in our results.

As for the final quantification of the concern curves which we are discussing, we also consider the relation of the different sectors of society to each of these issues of concern. For example, elite and NGOs are the societal sectors to look at when studying proliferation issues; the public in Yucca Mountain's state (Nevada), the nuclear industry, and the elite are the sectors to look at in order to obtain concern data relative to the nuclear waste storage issue; the general public is important relative to electricity availability and costs; and the elite opinion is the most important relative to greenhouse gas emissions.

The *political bias*, *lobbying* and *media activities* are also exogenous to the model and they modify the level of political support and the public concerns.

The aim of the representation of the energy policymaking process that we have presented in this section is to calculate the *Policy Amplitude* and the *Policy Rate* for each type of technology. These variables are used to calculate the *Cumulative Policy Status*, which represents the summation of past policies, both positive and negative.

2.2 The Economics Part of the Model

In our model, we assume that the *cumulative policy status* influences both the capital cost and the operating costs of power plants. We consider that the production cost is composed of fuel costs, and of variable and fixed O&M costs. As the cumulative policy status decreases, we assume costs increase, as seen in Figure 9. At this stage, we have relied on our intuition for the shape of the curves representing the impact on costs of the cumulative policy status.

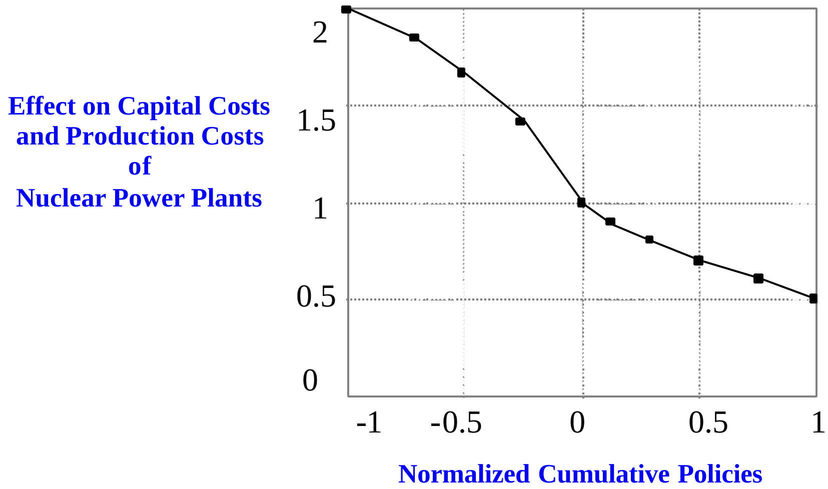
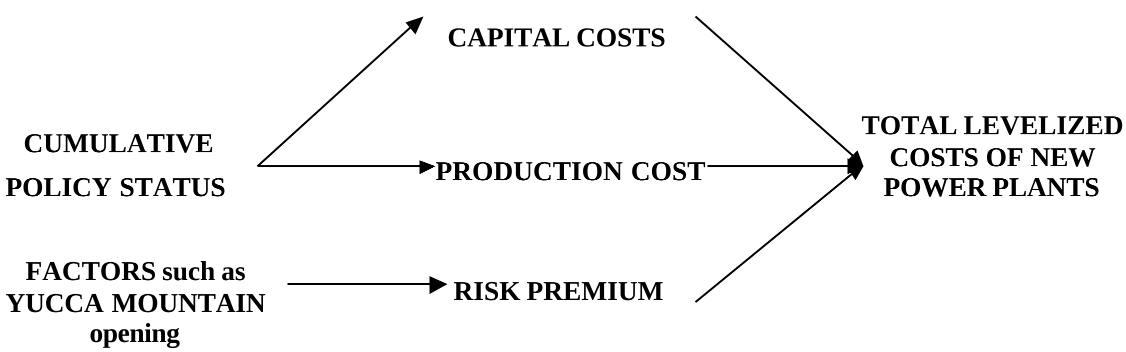


Figure 9: Cumulative Policy Effect on Costs.

The decision on what type of additional plant to build is influenced by the relative costs of fossil versus nuclear versus windmills. Figure 10 shows the impact of policies on electricity cost for the considered sources of electrical 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; as well as the factors influencing the risk premium.

Figure 10: Impact of Cumulative Policies on the Cost of Power Plants.

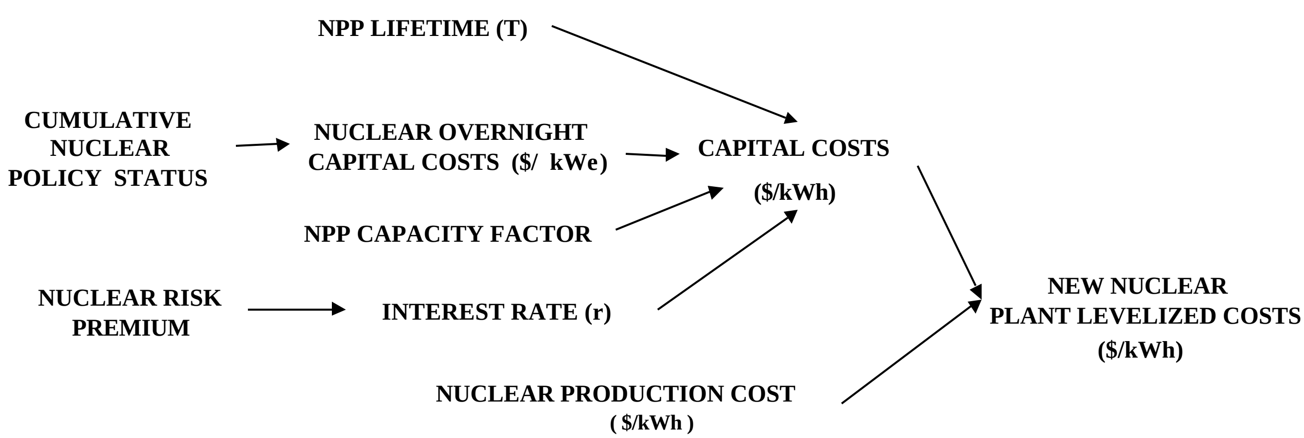
For every means of electrical energy production, the total costs are the result of adding the operational costs and the levelized capital costs. The overnight cost, the lifetime, the internal rate of return, and the capacity factors must be considered. Mathematically:

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

Where:

i represents the different means of producing electricity (i.e. nuclear, fossil, wind)
r = internal rate of return

As an example, Figure 11 shows the influence diagram for the costs of nuclear power plants. We consider that the main impact of policies and regulations are on the capital costs. This is because policies and regulations modify the safety requirement on nuclear power plants, which impact mainly on the equipment and containment needed for safety reasons. A similar calculation scheme has been adopted for fossil power plants and windmills.



Data used in the base case:

Nuclear overnight capital costs:	$ 2000 /kWe (initial value)
Nuclear internal rate of return:	12.8% (initial value, includes risk of not having Yucca Mountain built)
Nuclear production cost	$0.020/kWh (includes O&M and fuel costs)
NPP Lifetime:	40 years
NPP Capacity factor:	90%

Figure 11: Calculation of Total Levelized Costs of Nuclear Power Plants.

We assume that the utility decision-making on how to cover the new electricity capacity is purely based on these levelized costs. Once this is done, the added power plants start delivering electricity to the grid within a period of time equal to the construction time of each type of technology: 3 years for windmills and fossil plants, and 6 years for nuclear power plants.

2.3 Technical Calculations

While new plants of each type are added to the electrical grid other plants retire due to the end of their lifetime. This, together with the initial number of plants of each type, determines the power, in GWe, delivered to the electrical grid by each type of technology. This power is used to determine the following:

- The total volume of high-level nuclear waste generated: This variable, together with the available storage capacity is used to estimate the societal concern regarding nuclear waste.
- Greenhouse gas production rate: This is the variable we use to represent the greenhouse effect due to the fact that in the 1997 Kyoto protocol the United States agreed to a 7% reduction in the production rate of greenhouse gases without considering the type of gas being released. For this reason we calculate the production rate of greenhouse gases due to fossil power plants as the sum of carbon dioxide and methane release.
- Energy costs: This is considered as the weighted average of the levelized costs of each type of technology.
- Availability: This is the result of comparing the available electricity capacity with the demand. We have introduced the electricity demand as an exogenous variable, increasing 10 GWe per year from an initial value of 500 GWe.
- Area occupied by windmills. We believe this variable is representative of the main concern regarding wind turbines, besides their high capital costs at present.

Regarding safety and proliferation, our first approach is to consider them as exogenous variables, unrelated to the electric power capacity.

All these variables feed back into the concerns calculation, closing the feedback loops.

3. Preliminary Results

The model that we presented in the previous sections was programmed using VENSIM (Ventana Systems). Here we present some preliminary results obtained by this simulation tool. Four cases are analyzed:

CASE 1 is **THE BASIC CASE.** We assume that the decision to open Yucca Mountain is made 1 year from now.

CASE 2: The decision to open Yucca Mountain 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.

The results of all these cases are based on the intuitive data and curves, some of which has been previously presented in this paper.

3.1 Case 1: The Basic Case

The assumptions for the basic case are:

- Electricity demand: It grows at a rate of 10 GWe/yr with an initial value of 500GWe.
- Plants lifetime: 40 years for nuclear and fossil power plants (NPP and FPP); 20 years for wind turbines.
- Construction time: 3 years for windmills and fossil plants, 6 years for nuclear plants.
- Power Capacity: 1.0 GWe for NPP, 0.5 GWe for FPP and 1.5 MWe for wind turbine
- Yucca Mountain: the favorable decision to open it is made in 1 year, and it opens 10 years after the decision, allowing for legal delays.

- The maximum allowable increase of greenhouse gas emissions due to fossil powered plants is 3%.

Based on these assumptions, the resulting electricity supply for each type of power plant is presented in Figure 12.

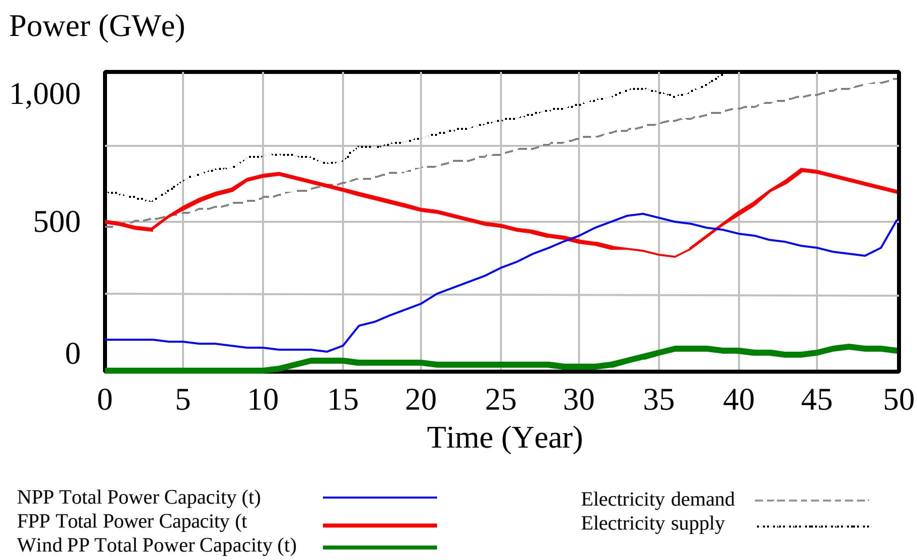


Figure 12: Power capacity, by power plant type, for the basic case. Total power demand and total supply.

Under this scenario, it is seen that the nuclear power plants can reach up to 50% share within 30 years. Also, 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 are based on their economics, as seen in Figure 13. It is then not surprising that the periods when the number of power plants of a type increases correspond to the periods of minimum costs. This more favorable economic environment is driven by a positive accumulation of nuclear policies affecting the base capital and production costs, as observed in Figure 14. As a reminder, the policy accumulation is the result of the integral of the multiplication of the resulting policy amplitude and the policy rate with a decay period of 10 years. In this basic, simple case, where the main drivers of policies are the societal concerns, it is not surprising to see a correlation between the evolution of the societal concerns and the cumulative policy status. The evolution of these concerns with time is presented in Figure 15.

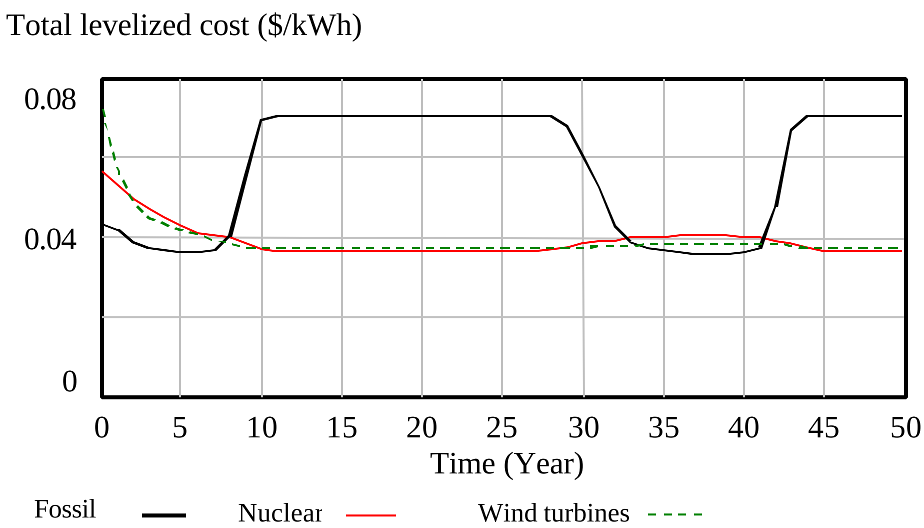


Figure 13: Total levelized cost of electricity production, by power plant type.

It is seen that the periods when the cumulative policy status for fossil decreases and the cumulative policy status for nuclear and wind increase correspond to high concerns on greenhouse gases. Accordingly, 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 regarding high-level nuclear waste is high at the beginning and decreases after the first 10 years due to the opening of Yucca Mountain. The residual concern after that period is due to perceived risk of occurrence of sabotage or accident during transportation or storage.

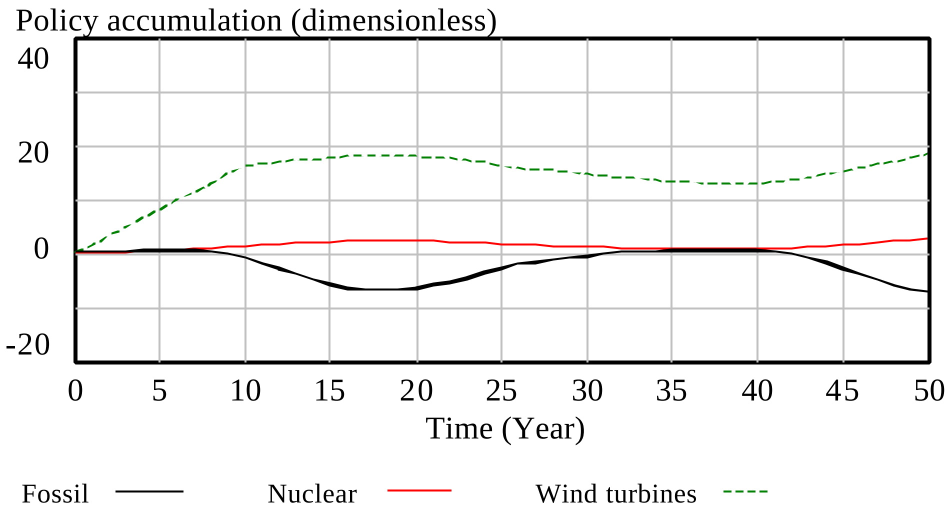


Figure 14: Policy accumulation in the last 10 years, by power plant type.

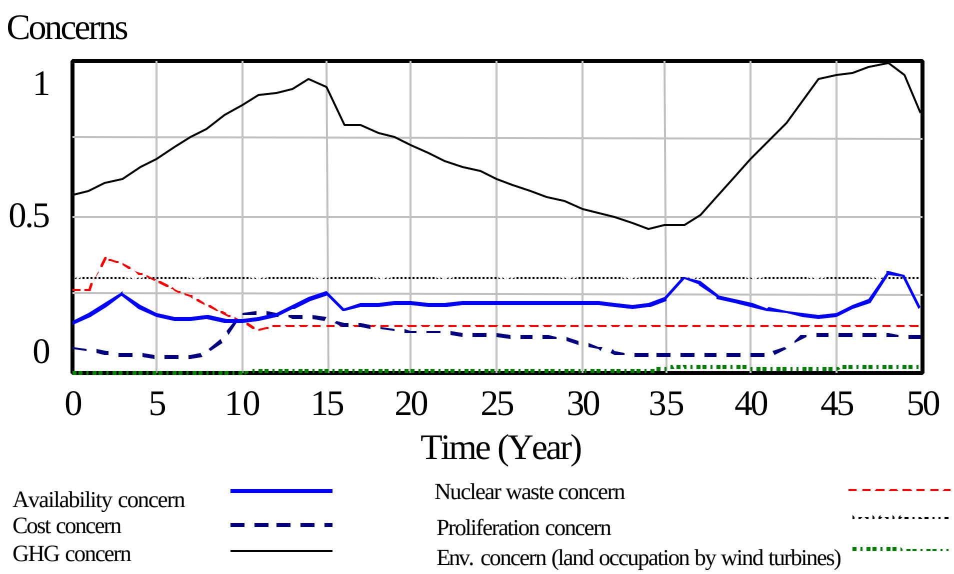


Figure 15: Perceived public concerns.

3.2 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 16.

We can see that these delays are translated into delays in the recovery of the nuclear industry, the place of which is taken by renewable sources. This may happen in the 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 year delay would mean the loss of expertise needed to make a nuclear project viable. Also, during this first stage of our project, we have not considered the constraint 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.

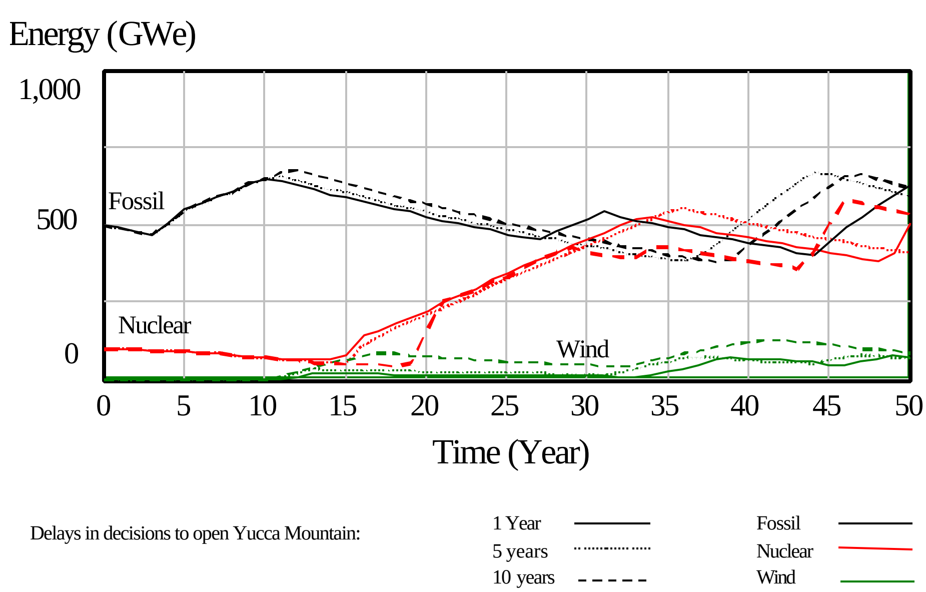


Figure 16: Power capacity, by power plant type for the case when Yucca Mountain repository is delayed.

3.3 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. This is the reason why we have studied the sensitivity of our results to this effect.

The results of these simulations are shown in Figure 17. The resulting share of energy between fossil and nuclear (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. A real case would be that the US government does not react to the international pressures to reduce the greenhouse gas emissions, in which case no tax would be imposed on carbon emissions. The total cost of fossil power plants would continue to be lower than that for nuclear power plants unless new power plant designs with reduced capital costs are licensed.

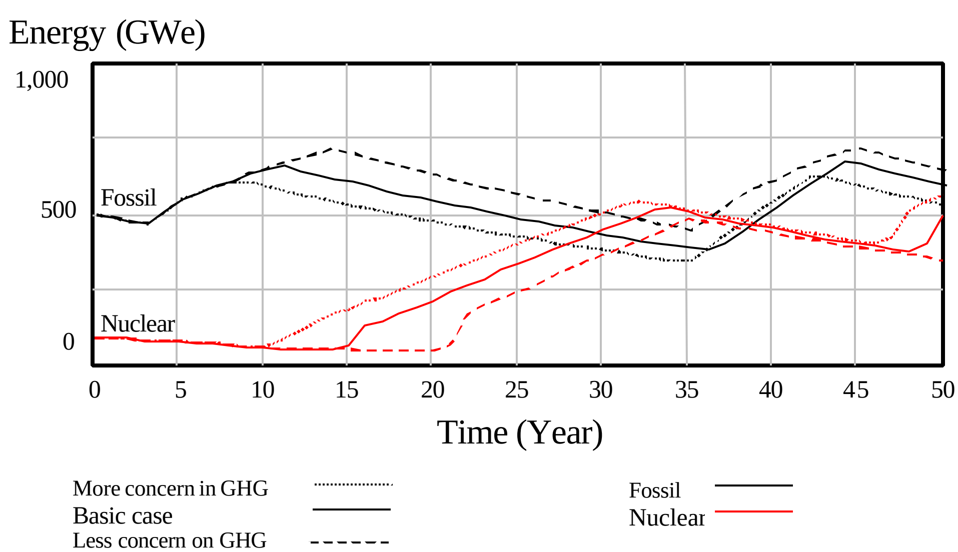


Figure 17: Power capacity, by power plant type for the case when greenhouse gas maximum allowed rate is changed.

3.4 Case 4: Negative Bias for Nuclear Power Plants Introduced

Figure 18 shows the basic case compared to the case where a constant negative bias for the nuclear industry is introduced in the model.

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

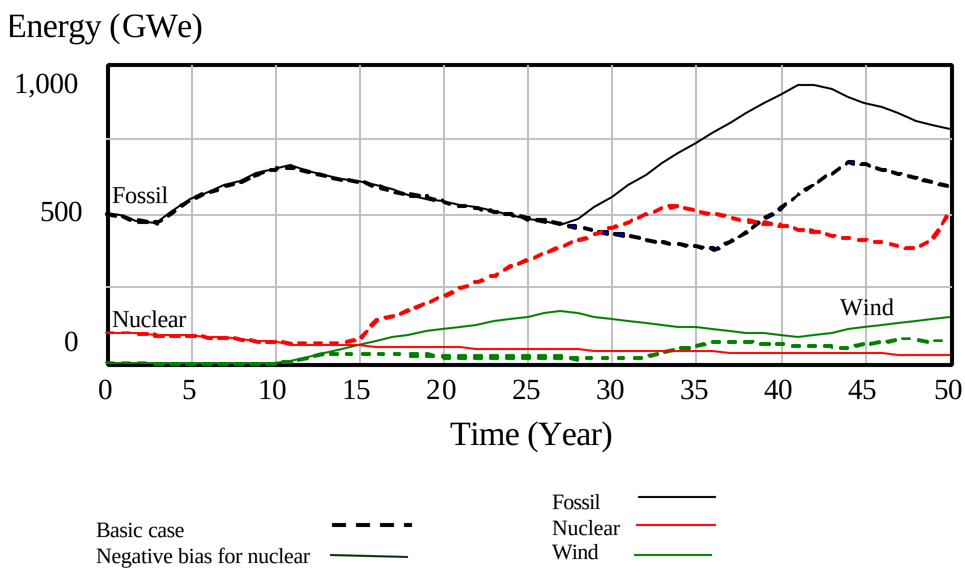


Figure 18: Power capacity, for fossil and nuclear power plants. Case: Negative bias for nuclear power plants.

3.5 Data Gathering, and Model Verification and Calibration

The representation that we have made of the energy policymaking process in the United States, is based on extensive literature research and a number of meetings with various members of US NGO's and US governmental agencies.

Currently, the direction of our research is towards the verification and calibration of our model. To achieve this goal, we are gathering historical data regarding: 1) public concern and actions for the different types of public and organizations and for all the issues we are considering; 2) policy rate generation mainly for nuclear and fossil power plants; 3) operations and maintenance, and capital costs for fossil plants, nuclear plants, and windmills; 4) policy impact on costs 5) Lobbying activities and 6) Political parties of the majority and minority parties in Congress, the Senate and the White House. The source of data for this study regarding the elite level of concern for safety, proliferation, and nuclear waste issues is the Reader's Guide to Periodical Literature 1984-2001. We assume that the number of publications of articles in English language popular magazines, news magazines, and general interest periodicals correlates to the concern relative to the nuclear industry.

For general public concerns regarding electricity availability and nuclear safety, various editions of Nuclear News publications are being used, among many other sources including the Reader's Guide to Periodical Literature 1984-2001.

The operations and maintenance costs, the capital costs and fuel costs of fossil power plants, nuclear power plants and windmills required the search over a big number of resources, including the NEI (US Nuclear Energy Institute), DOE (US Department of Energy), IAE (Institute of Atomic Energy) and Science Magazine 2001, 1438.

As for the rate of policies generated by the NRC (for nuclear issues) and EPA (for fossil and environmental issues), data is obtained from the Federal Register Index 1975-2001. For the policy output of congress, we used a database compiled by Professor Mayhew from Yale University and MIT Professor James Snyder.

Conclusions

The goal of this project has been to create a model of the processes by which electric energy polity is created and modified in an industrial democracy. Each energy technology is characterized by its costs and byproducts. These characteristics create concerns in some segments of society which are relayed to the political structure of a nation. The outputs of the political system are the policies that influence technology costs, and future use of that technology.

The representations chosen for this large-scale system are discussed in Section 2. The results in Section 3 illustrate the sensitivity of the future to certain key factors; for example, the sensitivity of the future role of nuclear power to opening of a repository.

Although much work remains to make the model more complete, the results to date suggest that it would be useful to pursue the development of models for many examples of the feedbacks between technical systems and the society those systems serve. It is our belief that system dynamics is a unique and appropriate tool with which to approach this important task.

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