Inertia in the North American Electricity Industry: Can the Kyoto Protocol Objectives Be Realistically Met?

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Abstract

If they are to be attained, the objectives set in the Kyoto Protocol will impose fundamental changes on the structure of North America s economy. This text highlights the extent of the Kyoto challenge by clearly describing the historical inertia in terms of total market shares for different production technologies of the North American electricity industry. It also compares two potential scenarios of the industry changes needed to attain the Kyoto objectives. The results obtained suggest that it will be virtually impossible to reach the Kyoto objectives within the electricity industry.

Keywords: Kyoto Protocol, electricity industry, technological change.

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1. Introduction

In November, 1997, the Kyoto Conference on Climate Change sparked a world-wide examination of the measures needed to reduce greenhouse gas (GHG) emissions. The Kyoto Protocol specifies average reductions of GHG emissions of 7% for Annex I countries for the period 2008-2012. For Canada and the United States the specified reductions are 6% and 7%, respectively.[1] Even though ratification of the protocol is far from certain[2], a large number of domestic as well as international working groups have been exploring different ways of contributing to a reduction in greenhouse gas emissions for the 2008-2012 timeframe.[3]

It is reasonable to believe that if this protocol is ratified and honoured, the world will undergo technological revolutions in all industrial areas directly or indirectly related to energy. However, some economic sectors will be more heavily hit than others. In the business-as-usual (BAU) forecasts, absolute levels of CO_2 emissions as well as projected increases in emission levels in the electricity sector continue to be very high relative to other industrial sectors in North America. The United States government forecasts emission increases of 43% in this sector between 1990 and 2010 (see figures 1 and 2, drawn from EIA (2000)). Accordingly, if the U.S. electricity sector is to meet the Kyoto commitments, the 7% reduction in CO_2 emissions with respect to the 1990 level will require a 54% reduction relative to the BAU scenario.[4] This staggering figure is what originally prompted us to analyze the electricity industry.

The paper is organized as follows. Section 2 sets the stage by presenting a picture of historical and forecasted market shares for the major electricity generation technologies in the United States. Section 3 proposes two stylized alternative solutions for market share changes which would meet the Kyoto targets in the U.S. electric industry. Section 4 analyzes and compares historical market share adaptation rates to the adaptation rates

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[1] All emissions reductions are measured with respect to 1990 emission levels.

[2] As of January 13 2000, 84 countries had signed the the Protocol, while only 22 countries had ratified it. No Annex I countries have ratified the Protocol. More importantly, ratification by the United States remains in serious doubt.

[3] The world wide web provides a wealth of information on climate change and on the different areas of negocitation and research. A good place to begin searching for international information is the United Nations Framework Convention on Climate Change site (UNFCCC): http://www.unfccc.de/. Information on the process in the United States can be found at http://www.epa.gov/globalwarming/. Information on the current status of the Canadian process is available at http://www.nccp.ca/html/index.htm .

[4] In Canada, the projected increase of emissions over the same period is 24% (NCCP (1999)). The required percentage reduction of emissions would be somewhat smaller than in the U.S., yet would still be an important amount. Because of the relative size of the U.S. electricity industry in the North American market, and the more important reductions for the U.S. industry than the Canadian industry, the rest of the paper focuses on the U.S.

implied by the stylized alternative solutions. Section 5 sheds more light on the question by discussing several factors which might affect the speed with which the electric industry will be able to adapt. Finally, Section 6 offers some concluding remarks.

2. Market shares in the U.S. electricity generation sector

An analysis of figure 1 shows the following transitions in past and forecasted market shares for electricity generation in the United States[5].

- Coal s market share grew until the middle of the 1950s, dropped sharply between 1965 and 1972 due to increased oil consumption, then rose markedly once again from 1978 to 1985. Since this time, coal-fired power stations have had a fairly constant market share. The inherent flexibility of these power stations seems to provide a way of adjusting generation so as to respond to variations in demand.

- Contrary to coal, which, year in year out, has kept its market share, oil was only popular for a short time, namely between 1964 and 1973. After a hesitant few years, the second oil crisis in 1979 convinced the electricity industry to abandon oil once and for all. Between 1979 and 1985, oil lost all the market share it had gained in the 1960s, and, since 1985, oil accounts for a only small share of the American electricity generation market.

- Natural gas was likewise affected by the oil crisis of the 1970s. After undergoing constant growth in the 1950s and 1960s, the market share of natural gas began to drop in the 1970s. It was not until 1989 that this energy source was once again considered as an alternative to nuclear energy and coal. Since this time, natural gas has become the preferred source of energy for new electricity generation. However, as demand for electricity is growing more slowly than in the past, the portrait of electricity generation is also changing slowly and the natural gas market share has thus not grown significantly in the last 10 years.

- Nuclear energy and renewables (principally hydroelectricity, at least in the historical data) show decreasing market shares for several reasons. With regard to the former, public opposition and the changing perception of risk due to deregulation have resulted in little hope for capacity additions, or even plant-life extensions, in the decades to come. For the case of hydroelectricity, the exhaustion of economically developable sites as well as increased environmental concerns with site development are important constraints to future development, and as a result, market share falls. Other forms of renewable do not, as yet, offer sufficient promise to increase market share of this segment.

[5] Source°: EIA (2000)

The above scenario, the EIA business-as-usual (BAU) scenario which does not integrate the Kyoto concerns, thus offers no surprises. Seen from this viewpoint, only the natural gas and coal industries are able to maintain or increase market share between now and the year 2020. This tendency thus gives us an indication of the extent of the change needed if the American electricity industry is to comply with the Kyoto Protocol. Given that the emissions from the electricity sector in 2010 will be 43% greater than in 1990 in the American scenario in question, there is good reason to conduct a specific analysis of this sector.

Table 1 and figure 2 summarize the EIA BAU emission projections for oil, gas and coal in the electricity sector.

Table 1: Annual CO_2 Emissions in the U.S. electricity sector (Megatons)

	1990	1997	2010	2020
Emissions by energy form				
Oil	26	17.5	10.2	7.7
Gas	40	43.5	95.0	136.2
Coal	409	471.5	575.8	613.9
Total	475	532.5	681.0	757.8

Source: EIA (2000)

In short, if the Kyoto Protocol is ratified, the U.S. electricity industry will have to undergo drastic changes to meet the GHG emissions reduction targets.[6] In order to abide by the Kyoto Protocol, the first task will be to reverse the current tendency clearly in favour of thermal generation. Favourable conditions must then be created to allow cleaner forms of generation to penetrate the market. This raises a fundamental question, namely what are reasonable deadlines for these conditions to be met? Furthermore, assuming that governments agree on an efficient process to convert the current energy system, how fast could this be accomplished?

3. Alternative Solutions

Assuming that electricity demand continues to grow, meeting the objectives of the Kyoto Protocol would require alternative solutions that would completely change the portrait of the North American electricity industry. There are obviously several possible scenarios

[6] This paper will not address the issue of the allocation of emission reduction targets between sectors of the economy. Obviously the electricity sector would be able to reduce emissions by less if other sectors of the economy reduced by more. The point being made here is that emissions in the electricity sector are so important, and forecast to grow by so much, that fundamental changes in this sector will be required in order for the U.S. to meet the objectives set out by the Kyoto Protocol.

and the optimal solution might well be a combination of various new energy technologies. So as to illustrate the overall context and provide an idea of the scale of the expected changes, we have contrasted two potential scenarios.

Scenario 1: Natural gas and coal are replaced by sources with very low CO_2 emissions. There is increased electricity trade between Canada and the United States. Canada s economically developable hydroelectric potential, a total of roughly 190 TWh, is developed for export to the United States. A large number of coal-fired power stations are replaced by nuclear power stations. The lifetime of current nuclear power stations is extended.

Scenario 2: North American coal-fired power stations are replaced by high-performance natural gas power plants, for the most part combined cycle units.

These scenarios obviously do not take into account all possible changes, such as the impact of local wind power stations, demand side management and the replacement of current coal-fired power stations by better performing stations using CO_2 sequestration. Nonetheless, the two chosen scenarios each represent, in their own way, possible tendencies that have been observed in the past. It must be understood that any other scenarios should be on the same scale since the costs of the different alternative energy forms must be considered.

The implementation of scenarios 1 and 2 to attain the Kyoto objectives within the electricity sector is illustrated in figures 3 and 4. These figures clearly indicate that such scenarios bring about large discontinuities in market shares. It is thus far from obvious that the electricity industry can change at this rate, an observation which is at the heart of our analysis, described in the next two sections.

4. Market Adaptation Rate

By estimating each energy form s market share in the electricity sector, a graph of the historical rate of change of the particular energy form s market share is drawn. This rate of change is interpreted as the technology s ability to adapt or to respond to market signals. This historical market share, and characteristics of the evolution or change in market shares can then be compared to Kyoto-type scenarios so that the realism of the latter can be judged.

To estimate the evolution of market share, the following methodology was used:

- Market share was smoothed for each electricity generation technology using a spline function.
- This function was then differentiated to obtain the rates of change of these market shares.

The results of analysis for coal, natural gas and nuclear are presented in figures 5 through 10.

The comparative analysis of past rates of change with those that would ensue from the two Kyoto scenarios leads to certain conclusions for each scenario:

Scenario 1: a marked increase in nuclear energy and hydroelectricity

- In scenario 1, the rate of decline of coal market shares seems not completely unrealistic. With respect to coal, for example, the market share would drop from 57% to 26%. Over 10 years, the annual decrease in market share would be around 3.0%. It is worth noting that, from 1965 to 1971, the average decrease in market share for coal was 1.66%. However, the maximum decrease was 2.5%.

- On the other hand, the growth rates proposed for nuclear and renewable energy have never occurred in the past. Scenario 1 presupposes that the capacity of the nuclear industry would increase by a factor of 2.2 over 10 years from 2000. The annual required growth rate would be 8.2%. This would obviously be an extraordinary change when we stop to think that the maximum market share increase that this industry has ever seen was around 2% per year and that, in addition, this industry is currently in decline.

- With respect to hydroelectricity (or renewables), the scenario proposes two drastic changes. First, the proposed growth rate is in the order of 5.1% per year. Not once since World War II, however, has hydroelectricity seen such growth rates. What is more, this scenario implies that Canada exports to the south will increase by a factor of at least 13. It seems highly unlikely, if not impossible, to imagine this level of construction of hydro (generation and transmission) capacity in the next decade, both because of the lack of economical sites and the intense public opposition to such massive development. Likewise, such a substantial increase in other forms of renewable is highly unlikely.

Scenario 2: replacement of coal by natural gas

- In the past, the greatest annual decline that has ever been observed in coal s market share was roughly 2.5%. Scenario 2 proposes an annual decrease of 4.2% between 2000 and 2010. Though this is possible, this decline would create significant social and economic disturbances and seems highly unlikely.

- Scenario 2 presupposes a sustained growth rate over 10 years that would allow natural gas to increase market share by 4.8% annually. This implies an annual growth rate in the demand for gas in the order of 19.4%. The objective would be to multiply the 2000 capacity of natural gas power stations by a factor of 5.9. However, analysis of the recent past shows us that, despite the very favourable context for natural gas, its

market share has stagnated in the last few years. Scenario 2 therefore seems rather implausible.

Table 2 summarizes the market share variations and annual growth rates associated with the BAU scenario as well as with the two proposed scenarios.

Table 2: Changes in Energy Technologies from 2000 to 2010

	Coal	Gas	Nuclear	Renewable
Market share variation				
BAU scenario	-1.8%	+8.1%	-4.4%	-0.6%
Scenario 1	-28.9%	+8.1%	+18%	4.2%
Scenario 2	-41.7%	+48.1%	-4.4%	-0.6%
Annual growth rate (Generation)				
BAU scenario	1.2%	6.0%	-0.9%	0.9%
Scenario 1	-5.7%	6.0%	8.2%	5.1%
Scenario 2	-11.8%	19.4%	-0.9%	0.9%

5. Reaction Time to an Event

The extent of the Kyoto challenges are easily understood when examined from another angle, namely the market s reaction time to significant events or changes in economic trends. Several major events have influenced energy market decision makers since 1949. Namely the construction of the first nuclear reactor in 1956; the oil crises in 1973 and 1979; the Public Utilities Regulatory Policies Act (PURPA) in the United States in 1978; the oil slump impact in 1985; the American deregulation of natural gas in 1985; and, more recently, the deregulation of the electricity sector. All of these events have had short or long term impacts on changes in market shares. An examination of figures 1 and 5 to 10 in terms of these events allows us to deduce the reaction time by energy form.

5.1 Short Term Reactions

When examining short term reactions, a distinction must be made between a variation in the use of an existing capacity and a change in capacity as such. Producers can generally choose among various solutions to meet demand. Furthermore, they leave themselves some latitude to be able to respond to the vagaries of supply and demand. The graph for

coal from 1980 to the present clearly shows that existing capacity has acted as a buffer. The variations in coal shares fluctuated by roughly 2% during this period.

This buffer phenomenon can be seen elsewhere, each industry displaying the ability to react rapidly enough to events. For instance, following the 1973 oil crisis, the market share of oil stabilized fairly quickly. On the other hand, it was not until the second oil crisis in 1979 that the market reacted strongly and abandoned oil altogether.

The same phenomenon can be observed in nuclear energy. Though the growth of nuclear energy s market share slowed down after 1978, it was not until 1989 that the industry fell definitively out of favour.

In short, there is a wait-and-see phenomenon that occurs before the market makes its long-term reaction. On the other hand, though short-term reactions are quick, they usually represent adjustments in the use of existing capacity.

5.2 Long Term Reactions

An analysis of each energy form provides no major surprises. Technologies that require relatively little capitalization, such as oil and coal, can win or lose market shares fairly quickly. For instance, these two energy forms had annual growth and decline rates in the 2% range after the second oil crisis.

As for technologies that require sizeable capitalization, such as nuclear energy, the reaction time is obviously longer since the period between the decision to build and the beginning of construction is at least ten years. Another characteristic of nuclear energy is the fact that the accompanying environmental appraisals receive considerable media coverage, which only adds to the time before construction begins. In other words, since we know that there are presently no new American projects for nuclear power stations, it is safe to say that it would be impossible to add to the current capacity of the nuclear industry in the United States by the year 2010.

5.3 The Specific Case of New Technologies

An analysis of the nuclear industry shows us the time required for a new technology to reach its maximum rate of market penetration. The first American nuclear reactor was built in 1956. The maximum growth rate in market share occurred 18 years later, in 1974.

In any attempt to extrapolate from the above case to those of wind and solar power, the limited potential of these renewable energy forms must be considered. Still, the rate of growth of these energy forms is such that it is reasonable to believe that they will have a long term impact on the world s energy balance. On the other hand, the fact of the industry s inertia would seem to suggest a more cautious forecast as to the real impact of these energy forms by the year 2010 and even 2020 or 2050. In the words of the World

Energy Council (WEC (1993)), it is difficult to believe that government leaders and policies, consumer behaviour, technology and the ability to produce and install this technology will change the time limit set to meet the too optimistic estimates found in the literature.

5.4 Capital Stock Renewal

There have always been sizeable capital needs in the energy industry, but these needs have always been consistent with the time frame of investment profiles. The scenarios proposed in this study would require greater capital stock renewal than has ever occurred in the past. The optimal investment rate varies considerably depending on the various economic sectors. Historically, the annual growth rate of capital stock has, on average, been below 5% since World War II. This historical rate is well below the rate needed to attain the optimal results identified in reference scenarios 1 and 2.

5.5 Other Constraints

The above analysis of reaction time implicitly takes into account several of the constraints of industry inertia, namely cost, the political context, equipment life-span, technological maturity and the availability of capital stock. Our analysis of past experiences tells us that political constraints and market mechanisms keep rapid change in check.

The useful life-span of thermal power stations is 20 years and that of nuclear power stations, 30 years. In practice, however, it is well known that the decision to switch fuels or change procedures takes much longer. Conservative industries and the strength of their lobbies undoubtedly play a role. The nuclear industry, for instance, asserts that it is possible to extend the life-span of currently existing plants. One thing is certain, however: if all the nuclear power stations in North America were shut down in favour of thermal power stations, the new choices discussed here would be delayed well beyond 2010. By the same token, if the nuclear industry becomes lethargic in years to come, how soon would a massive return to this energy form be possible?

Technological maturity represents another important factor in the analysis. Gas turbines are now commercially available. Their competitiveness depends on changes in the price of gas with respect to that of other energy forms, including coal. With respect to new alternative energy forms, only the wind power industry can hope to survive one day without subsidies. Its exceptional progress in the last decade makes this a distinct possibility. Nonetheless, it is perhaps unreasonable to believe that this energy form will be able to replace a significant number of thermal power stations by 2010.

Given the planetary objective set by Kyoto, will international cooperation necessarily follow? Will there be increased availability of international development funds to make the needed investments in developing countries? What risks will be acceptable? Which energy forms will be promoted? How can another cause of this industrial inertia, namely

the tendency of countries to give precedence to regional affairs over everything else, including common international challenges, be circumvented? For example, how could the development in Canada of sizeable hydroelectric projects for export to the United States be encouraged? This constraint is obviously difficult to quantify.

6. Conclusion

In order to illustrate the extent of the changes required to honour the Kyoto Protocol, the American electricity generation sector was briefly studied for the period 1949-1996. The industry s historical inertia, represented by change in market shares, was compared to the expected rate of change in the generation system by 2010. This comparison of the past with the future leads us to an obvious conclusion, namely that there is every reason to be sceptical about the American electricity industry s capacity to change its generation system in time to meet the Kyoto objectives.

The required rate of future change of market shares is quite different from past rates, which have rarely surpassed 2% per year. With respect to nuclear energy, for example, the results show that a favourable context for the industry in the 1960s, combined with a strong growth in electricity demand, gave rise to considerable growth in the share of nuclear energy, with an average of 0.9% per year from 1967 to 1991. However, this 20% increase of the nuclear energy market share over 24 years would have to be repeated in 10 years if a nuclear energy scenario was chosen.

The changes are just as unimaginable in a natural gas scenario in which coal would disappear. On the one hand, the generation capacity of natural gas technologies would have to increase by a factor of 6 by 2010. Despite a highly favourable context, however, natural gas has stagnated over the last few years. What is more, such a scenario would entail the disappearance of coal from the electricity industry. How believable can this scenario be when one considers the fact that coal has maintained a relatively stable market share of around 55% over the past 15 years? This scenario seems all the more unlikely when we note that the main historical competitors of coal have been oil and nuclear energy, not natural gas.

Another interesting phenomenon that this historical analysis has brought to light is the industry s reaction time to events. Each industry can react fairly quickly to events. For instance, the market share of oil stabilized fairly quickly after the 1973 crisis. However, it was not until the second crisis that the market reacted strongly and abandoned oil. This quick reaction time is less true, however, for capital intensive industries such as nuclear energy and hydroelectricity where the reaction time is even slower.

Finally, by basing the analysis on past changes, it can be fairly confidently stated that relative prices and resource availability were the main factors in electricity generation choices.

This analysis is evidently incomplete and deserves to be further developed. Several different leads should be examined if we are to better understand the changes that are possible at the North American scale. First, a regional analysis is necessary. Second, a correlation analysis of the various economic factors that have influenced decision makers in the past would also seem to be important. However, the main message, that historical evidence suggests that the Kyoto objectives will be difficult to achieve within the U.S. electricity sector, appears to be quite robust.

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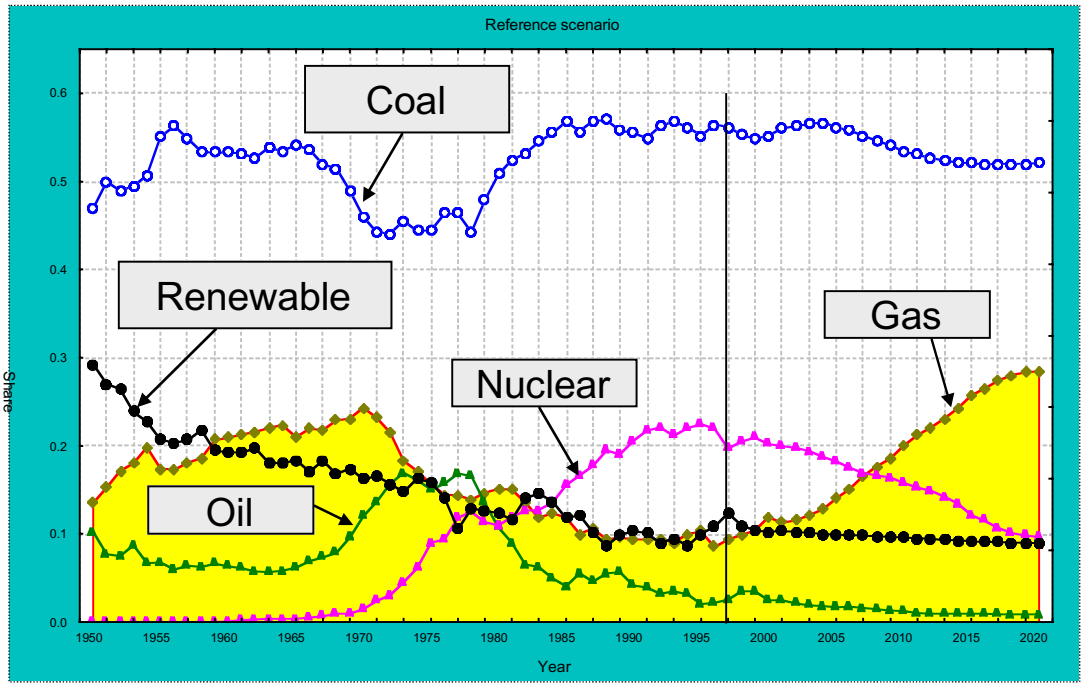
Figure 1 Electricity Generation Share by fuel type (1950-2020)

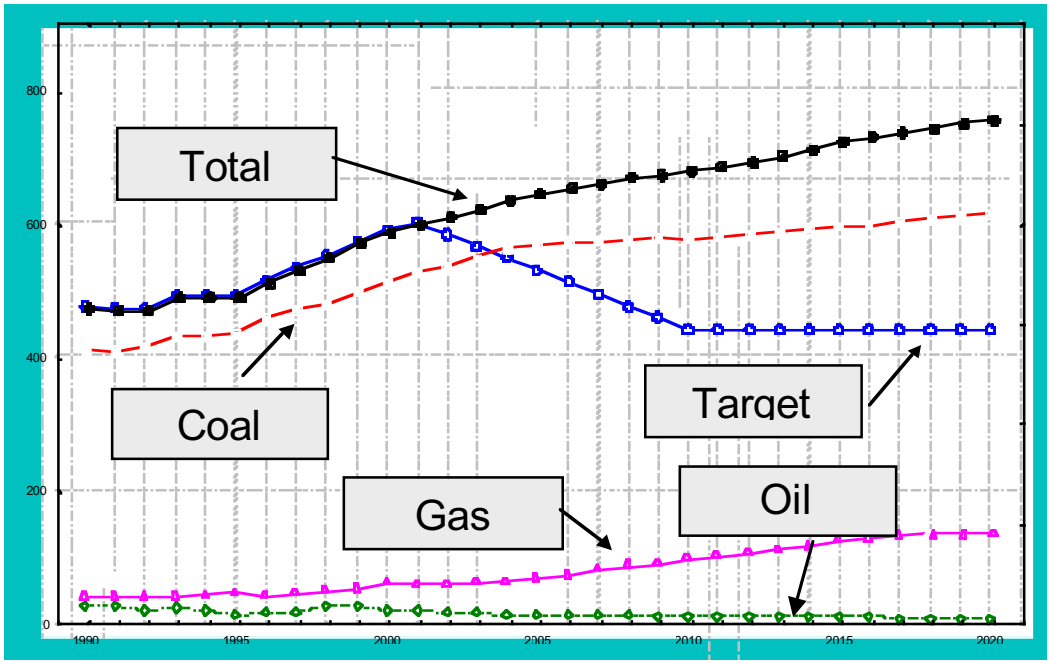
United States



Source°: EIA Outlook 2000

Figure 2 Carbon Emissions°: U.S. Electric Generators

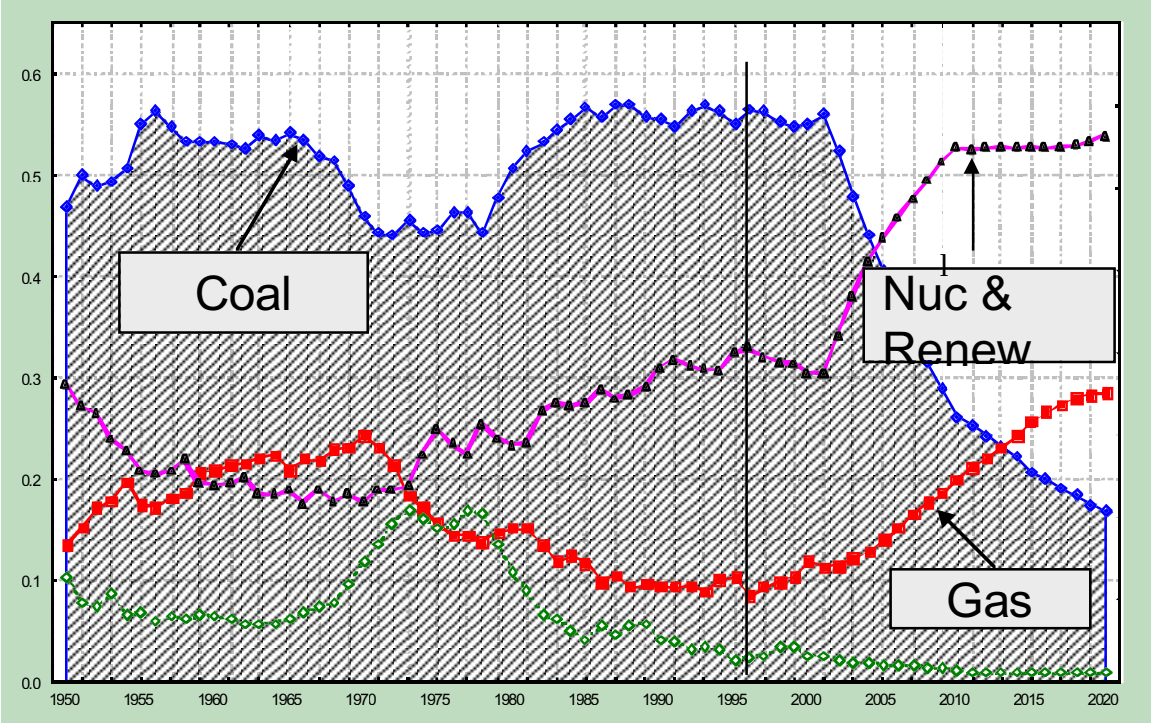
(Million Metric tons per year)



Source EIA Outlook 2000

Figure 3 Electricity Generation Share by fuel type (1950-2020)

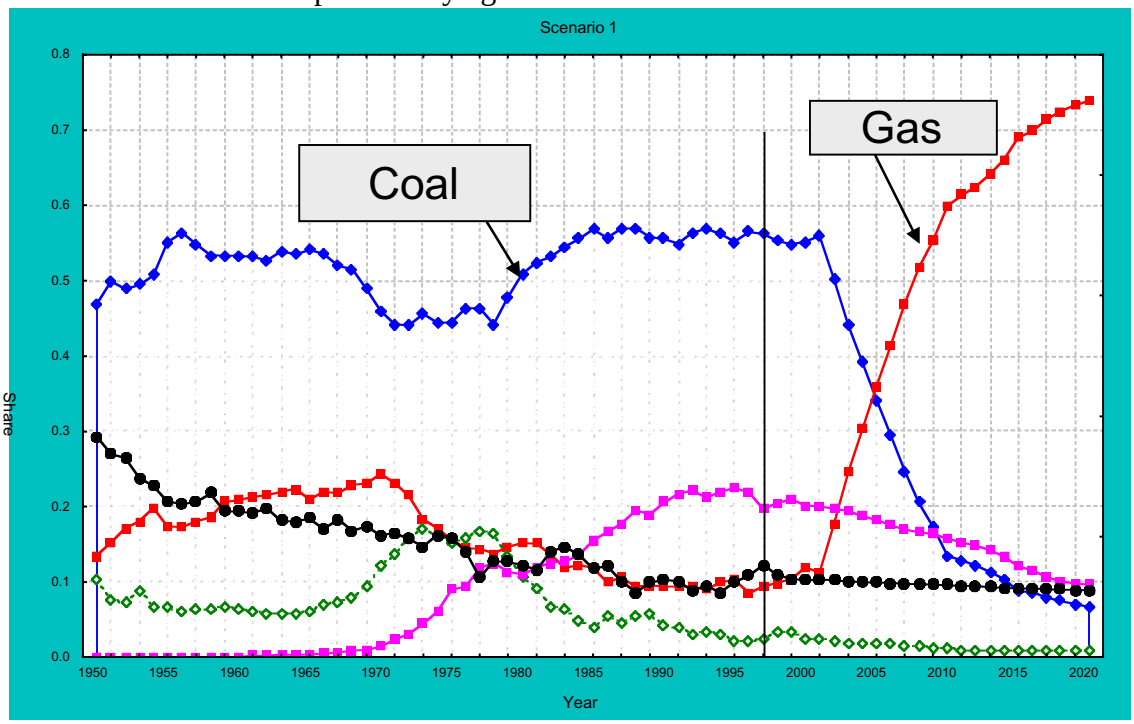
Scenario 1˚: Coal replaced by low gas emission fuel including renewable and nuclear



Note: the lowest curve on the above graph represents the market share of oil.

Figure 4 Electricity Generation Share by fuel type (1950-2020)

Scenario 2˚: Coal replaced by gas



Note˚: for ease of exposition, only the coal and gas curves are labelled in the above graph. The other curves correspond to the market shares of renewables, nuclear and oil.

Figure 5 Coal Market Share fit with spline function

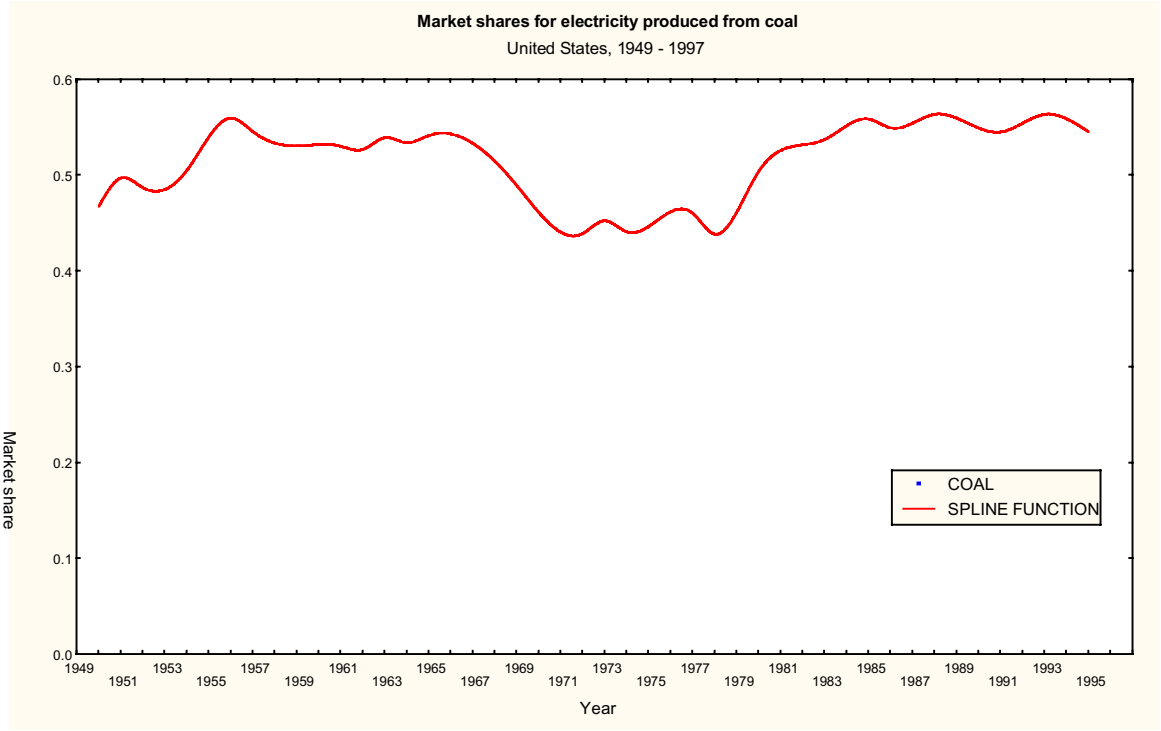


Figure 6 Change in coal market share

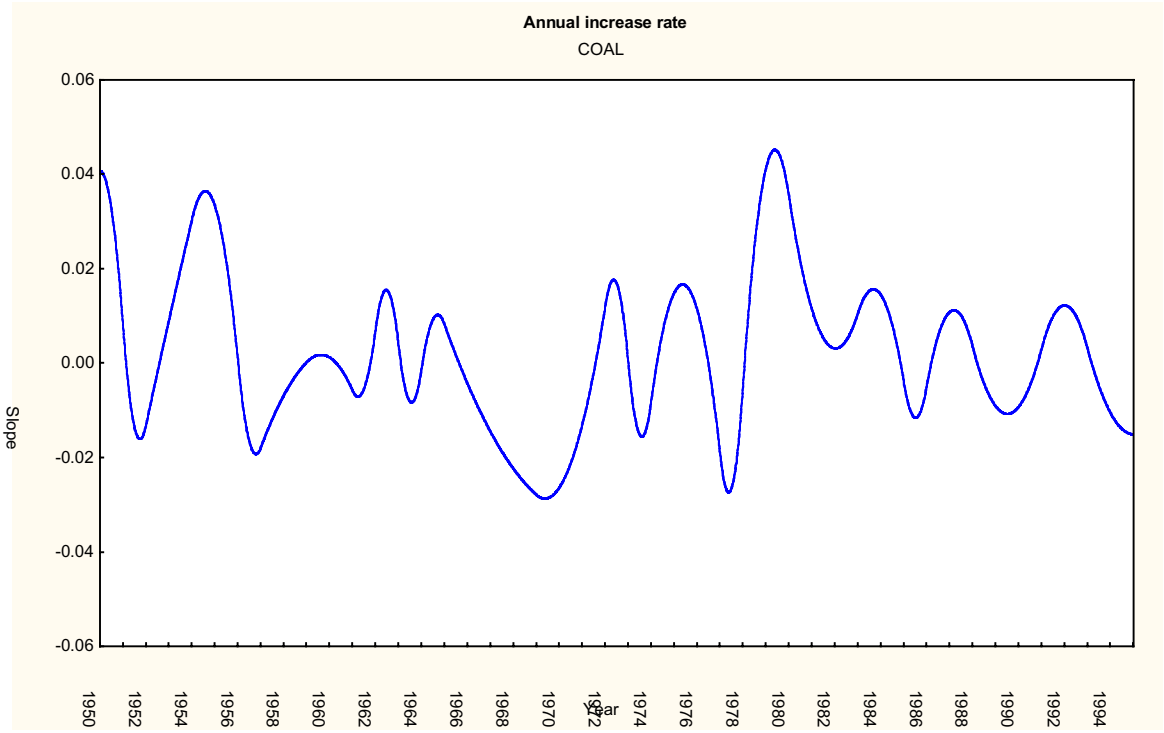


Figure 7 Natural gas Market Share fit with spline function

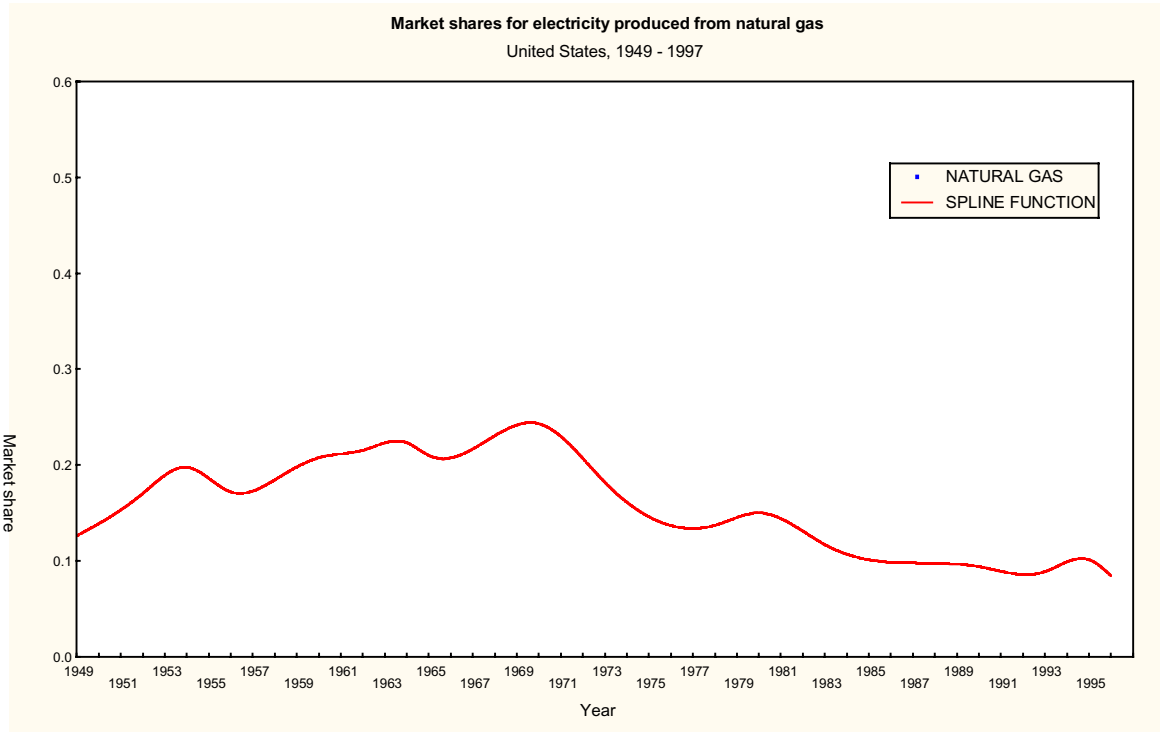


Figure 8 Change in natural gas market share

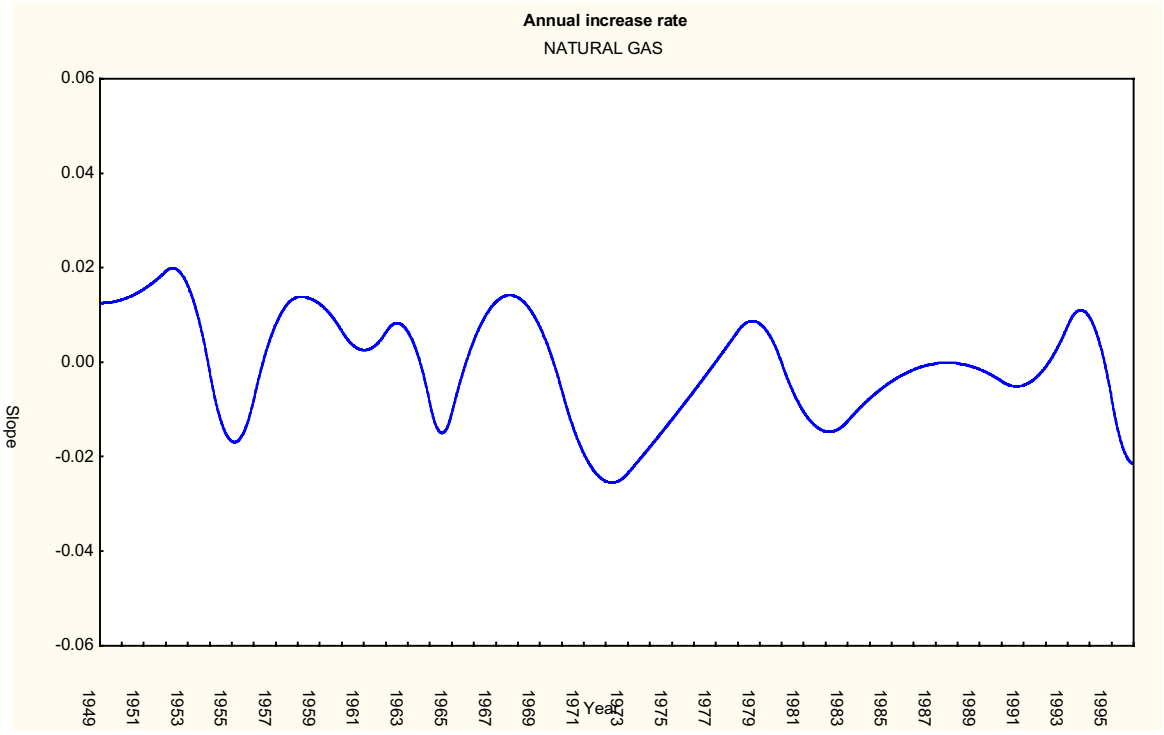


Figure 9 Nuclear Market Shares fit with spline function

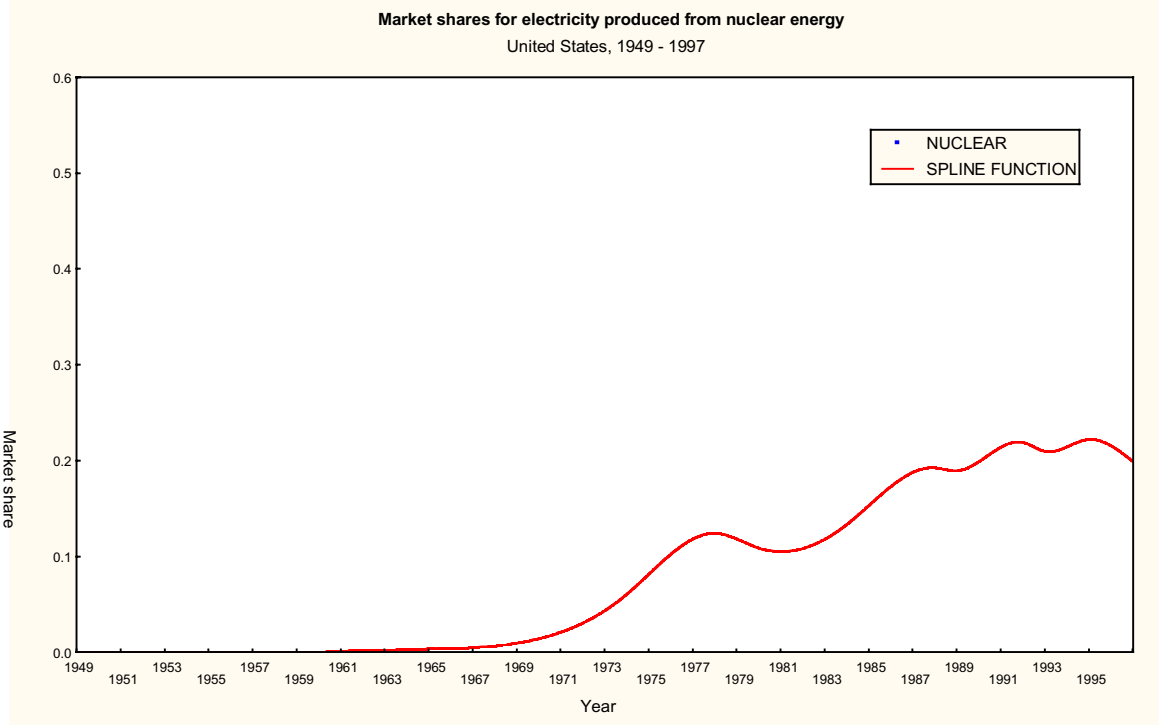


Figure 10 Change in nuclear market share