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Estimating Historical Energy Security Costs

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Abstract

Energy security is of increasing importance in today's world, yet little research has been carried out on the costs or benefits of energy security policies. This paper looks at the period after the 1970s to estimate the cost premium of electricity generation due to energy security policies. The cost premium is estimated for France, Germany, Italy and Spain for the period 1980-2000 by estimating actual versus hypothetical lowest cost generation mixes. The cost premium is estimated to be lowest for France, which had a clear energy security policy based on developing nuclear power and reducing reliance on oil and coal.

1. Introduction

Since the oil shocks of the 1970s, energy security has been a concern for governments and policy-makers. At the time, different countries responded to these concerns in different ways. It may therefore be the case that the cost of these responses gives an important indication of the value policy-makers have placed upon energy security. Energy security is currently high on the agenda of the European Union's energy policy, and so it is a pertinent time to examine the costs of previous energy security policies. Recently, European gas insecurity has made headlines, but there are a number of additional issues that are less sensational but still worthy of research.

There exists a growing body of research into the costs of insecurity and the benefits from increased security of energy, but there is much less research available on the costs of providing the increased security. These costs can take a number of forms, such as increased fuel costs from sourcing secure supplies over insecure supplies, infrastructure costs arising from developing new and more secure systems and processes, and the political costs of securing and protecting energy supplies. That is, energy policies that seek secure energy will result in a different energy mix than policies that have sought the cheapest energy. Comparing the two should give some indication of the cost of energy security policies.

This paper therefore attempts to measure the costs of the energy security policies in four European countries from 1980-2000 by comparing the estimated lowest-cost electricity generation scenario with the estimated costs of generation at the actual historical levels.

2. Policy Background

In order to assess the extent to which the difference between actual and predicted lowest cost is attributable to energy security measures, we first provide a brief outline of energy security policies in France, Germany, Italy and Spain. France made a clear shift in policy over the 1970s, with the revised policies being in force by the 1980s. Across all of

This paper presents research carried out under the CASES project, a Co-ordination Action on "Cost Assessment for Sustainable Energy System" financed by the European Commission under the Sixth Framework Programme. CASES assessed internal and external costs of electricity generation from different energy sources in the EU and in selected third countries by the year 2030. It evaluated policy options for improving the efficiency of energy use and disseminated the related research findings to energy sector producers and users and to policy-makers. The project started in April 2006 and ended in September 2008. Information on the consortium, the findings and the meetings of CASES are available on the official website (http://www.feem-project.net/cases/index.php).

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Europe, energy policies have been affected first by the oil price shocks in the 1970s and early 1980s, then by increasing pressure for deregulation through the 1980s and 1990s. It is important therefore to focus on the changes that governments and energy utility companies made in response to the energy insecurities of the 1970s, and to a lesser extent the early 1980s. This section is not an in-depth analysis of institutional or economic factors, but rather a simplified overview to give some context to the rest of the paper.

French energy policy in the 1980s was very much a response to events of the 1970s. France had been very dependent on cheap oil imports from Algeria, but after Algerian independence, the favourable trading position was lessened; this happened shortly before the Yom Kippur War and OPEC-led oil shortages. French policy-makers decided to pursue a less oil-dependent path, and with limited domestic gas and coal supplies becoming increasingly expensive, they looked to the opportunities available from nuclear power (Lucas, 1985; Matláry, 1997). There was already a significant atomic industry in France which enabled a relatively swift proliferation of atomic power stations in France, as well as developing the up- and down-stream industries necessary. Of course, such changes were not the only French policy response to energy insecurities and it is not the case that the policy direction was chosen solely in respect to energy security concerns, but looking at this aspect allows for a measurable understanding of the costs of energy security policies.

In Germany, coal was a politically sensitive industry because of its employment potential, and so was supported by government subsidies and pro-coal policies for longer. Also, since it had large domestic supplies, coal was a viable source of secure energy. On the other hand, gas from the USSR was relatively cheap but had certain energy security risks. However, as Lucas (1985: 255) points out, whilst West Germany was reliant on Soviet gas supplies, the USSR was reliant on foreign exchange from West Germany. Nuclear was also seen as an increasing useful option after the oil price rises (Weyman-Jones, 1986). Of course, German reunification is a key event and process in the midst of our period of analysis, which meant a number of discontinuities. For example, East German nuclear power plants did not meet West German safety standards, and so were shut down (Gröner, 1993).

Both Italy and Spain were affected by the oil price shocks, and responded in relatively similar ways. Due to their position on the Mediterranean Sea, they both pursued oil and gas pipelines with Northern African producers. However, this was a long process, and plans to increase the share of coal and nuclear, at least in Italy, were drawn up. In the 1998 plan, however, contributions from nuclear power were switched to plans for natural gas power plants due to public opposition to nuclear. In Spain, plans to develop nuclear power were also dropped after a moratorium on further construction (Matláry, 1997).

3. Methodology

In order to assess the cost of the electricity generation policies of governments, we compare the actual economic costs of electricity generation with the costs of the policy they would have otherwise undertaken if they had no concerns for energy security. Therefore, we create an electricity generation counterfactual scenario based upon the lowest cost, and measure the ES premium as the difference between the actual cost and the estimated lowest cost.[1]

The counterfactual ('lowest cost') model makes a set of assumptions which are outlined below:

1. *All the extra cost is due to energy security issues*. We recognise that a number of factors may have led to the least-cost option not being chosen, including uncertainty, politics or contractual restrictions.
2. *We use average data over the whole of the time period***.** This is due to data limitations. This assumption makes it possible to avoid highly complex modelling of demand and supply over the time period, including delays of data availability and construction delays.
3. *The capacity available at the beginning of the period is maintained throughout, thereby negating the need for additional capacity, and therefore construction costs*. This is a necessary simplification for the model. This assumption places extra emphasis upon the fuel and operating costs of power stations as there will be less construction modelled. However, in practice, it is not unusual to extend the life of power stations with refits or refurbishment. We take the 1980 generation levels to be the levels available without extra construction for the whole period**.**

[1] Of course there can be other reasons why the actual costs were higher than the least-cost solution. One is incompetence – governments make mistakes in selecting the expansion paths. Second is that they make errors when estimating future costs. Third, they face domestic pressures to keep certain high costs open. We cannot account for errors and mistakes and it is common to assume that they average out at zero. Other reasons for divergence should be considered, and in the last section we reconsider these in interpreting the results.

4. *There are no additional costs to stopping generation from one fuel.* This includes any social costs of a halt in electricity generation from one fuel, for example coal miner protests. Foreseeable decommissioning costs are included in the operating costs of plants.

5. *There are no limitations to capacity in each country for each fuel*, that is, if it was cheapest to do so, 100% of each country's electricity could be provided for by just one source.

6. *There are no requirements for diversity in energy supply*. That is, there are no contractual or political requirements for a minimum or maximum level of electricity from one source.

7. *Each country is a price taker in the fuel markets and that the prices would be the same regardless of the quantities used.* However, it is noted that the prices do show a difference between countries even in internationally traded goods.

8. *There is no trade in electricity between countries* but the target generation for the model is the average generation of each country between 1980-2000. That is, we do not model any specific policies to engage in electricity trading even if it is the lowest cost option to do so.

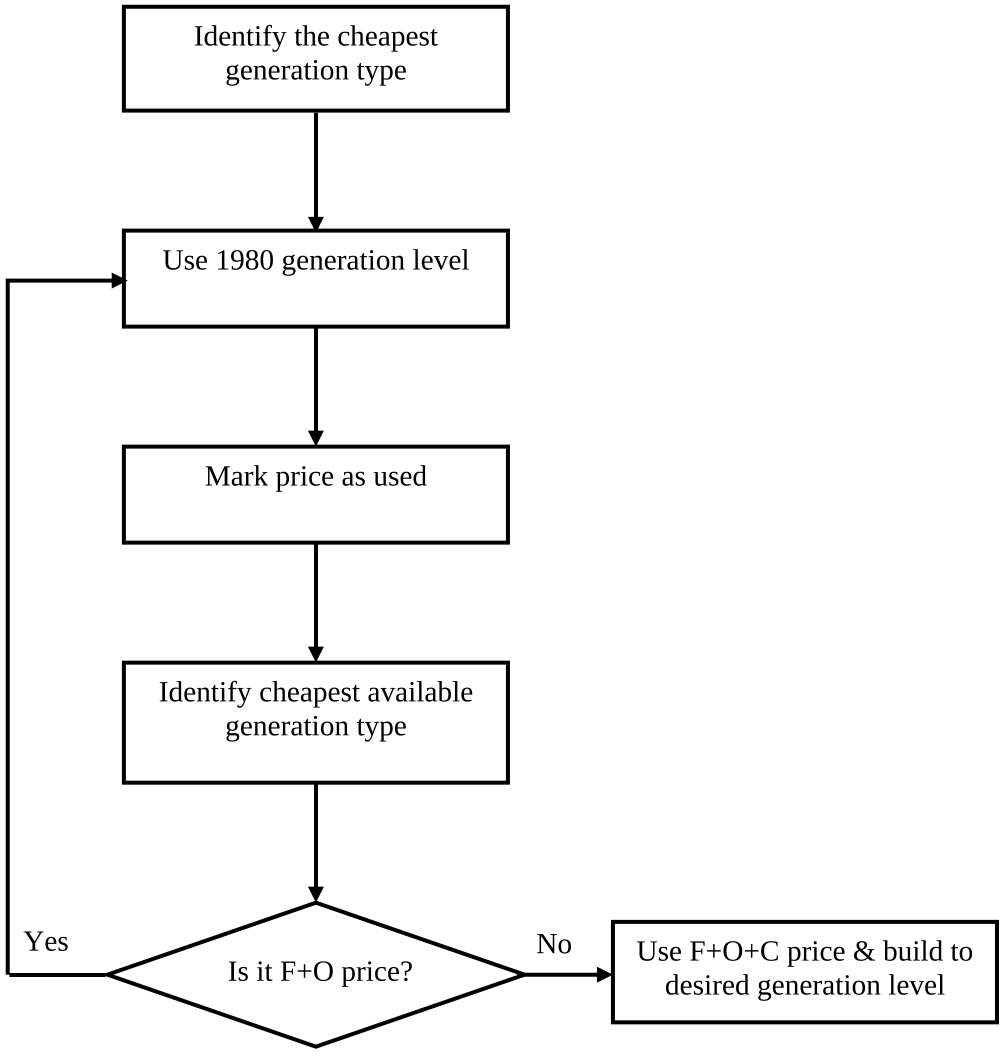
The counterfactual scenario uses the following algorithm, also shown in Figure 1:

1. Generate at the 1980 generation levels using the cheapest technology at F+O (Fuel plus Operation) cost. This is thought to be realistic since it is a good indicator of the usable capacity at the start of the scenario, so construction costs need not be considered (they are sunk costs). We refer to the cheapest technology as Technology A

2. Consider the F+O costs for each fuel and the F+O+C (Fuel + Operation + Construction) cost of Technology A. If Technology A is the cheapest based on F+O+C then build up to the target output (1980-2000 average generation) using A, OR use up to the 1980 capacity of the cheapest unused technology.

3. If the target capacity has not been reached, repeat step 2.

Figure 1. Flow chart showing how to develop the counterfactual generation scenario



Given the lack of data availability, and for consistency, the actual costs were estimated using the following procedure. Instead of using the 1980-2000 average total generation as the target, the target was the 1980-2000 average generation by fuel. So, for each country and each technology, we took the F+O costs of generating at the 1980 level and the F+O+C costs of generating the difference between the 1980 and the 1980-2000 average level. Where the 1980-2000 average was lower than the 1980 level (i.e. capacity declined) we took the average level of generation at the F+O costs.

4. Data

The model examines four large European nations: France, Germany, Italy and Spain, over the period 1980 to 2000. The reason for looking at the 1980-2000 period is that it occurs after the oil price shocks of the 1970s which prompted many governments to examine their energy policies. By 1980 these policies would have just started to be implemented. France was chosen as it had a clear shift in energy policy in the period leading up to 1980, when the policy to concentrate on nuclear generation was implemented. The first hypothesis of the model was that this policy increased the cost to the French economy in order to increase energy security. The other countries appeared not to have such a distinct shift in policy and provide the basis of comparison with France. The UK and the Netherlands were not examined since their energy security policies were based around the development of North Sea gas.

The IEA's energy database provided data for the energy balances of the countries over the relevant period. The fuels used to generate electricity were coal, oil, gas, nuclear and renewables, which includes hydroelectricity, geothermal, combustible renewables and waste, and 'solar, wind and other'. The energy balances show the total energy from that source going to the four types of electricity generation plants – the figures are negative because the fuels are an input into that process.

Table 1 and Figure 2 show how the countries' average energy mixes over the period compare. It shows that each country had a large proportion of their generation from one particular source: in France it was nuclear, there was a very high proportion from coal in Germany and Spain, and petroleum (oil) in Italy. However, only France had a very dominant source, with the others having a more diverse portfolio. Spain's share of nuclear is almost as large as its coal.

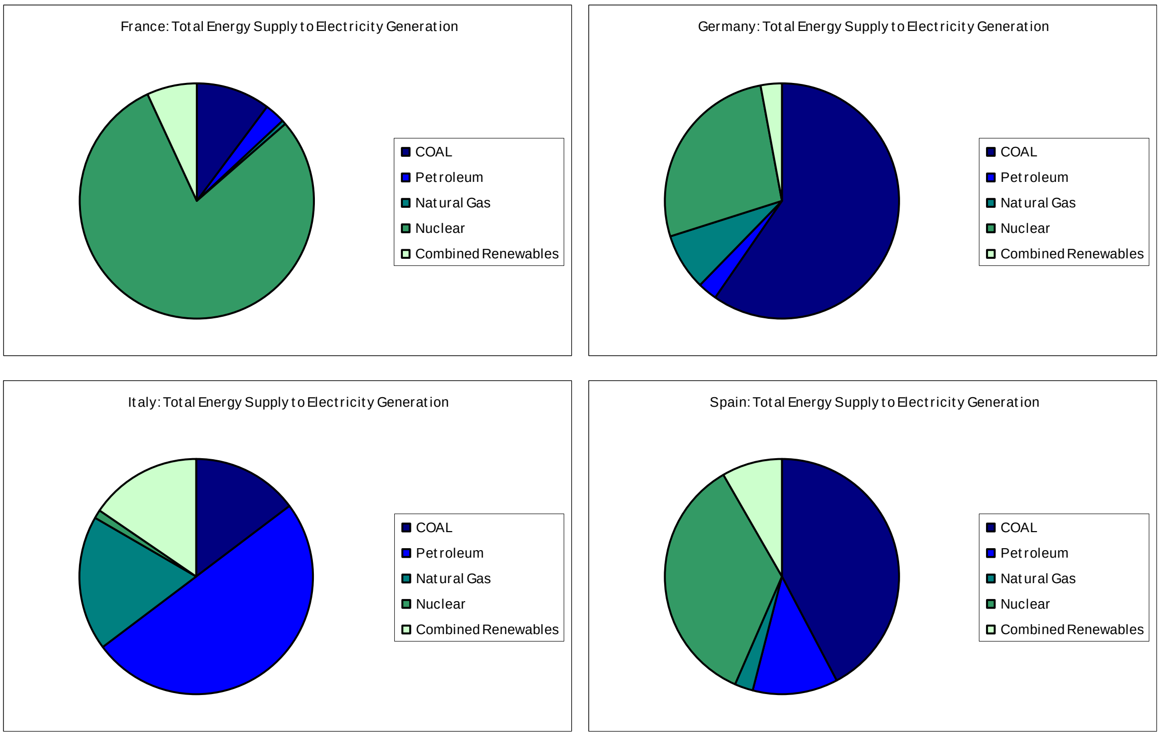
Table 1. Historical generation by type, 1980-2000 (figures rounded to 2sf)

		1980 Generation (GWh)	2000 Generation (GWh)	Average Generation (GWh)	Maximum Generation (GWh)	Year of max generation
France	Coal	**70,000**	31,000	40,000	70,000	1980
	Oil	**48,000**	4,800	12,000	48,000	1980
	Gas	**7,000**	11,000	4,500	11,000	2000
	Nuclear	**61,000**	420,000	290,000	420,000	2000
	Renewables	**70,000**	72,000	68,000	81,000	1994
	Total	**260,000**	530,000	410,000	-	
Germany	Coal	**290,000**	300,000	310,000	330,000	1984
	Oil	**27,000**	4,800	12,000	27,000	1980
	Gas	**66,000**	52,000	42,000	66,000	1980
	Nuclear	**56,000**	170,000	140,000	170,000	1997
	Renewables	**25,000**	41,000	26,000	41,000	2000
	Total	**470,000**	570,000	530,000	-	
Italy	Coal	**18,000**	31,000	27,000	36,000	1990
	Oil	**27,000**	86,000	100,000	120,000	1995
	Gas	**9,200**	100,000	39,000	100,000	2000
	Nuclear	**2,200**	-	1,900	8,800	1986
	Renewables	**49,000**	52,000	46,000	53,000	1999
	Total	**110,000**	270,000	210,000	-	
Spain	Coal	**33,000**	81,000	57,000	81,000	2000
	Oil	**38,000**	23,000	16,000	38,000	1980
	Gas	**2,900**	20,000	5,600	20,000	2000
	Nuclear	**5,200**	62,000	43,000	62,000	2000
	Renewables	**30,000**	36,000	29,000	42,000	1995
	Total	**110,000**	220,000	150,000	-	

Oil data is from the "Liquid Fuels and Refinery Gas" data series, and Gas is from "Natural Gas and Gas Works Gas".

Source: IEA Energy Balances.

Figure 2. Average annual energy supply to electricity generation, 1980-2000 (Ktoe)



Source: IEA Energy Balances.

The next data needed were the costs of the electricity generation processes, which fall into three main categories: construction and investment costs, operation and maintenance costs and fuel costs. Nuclear energy also incurs decommissioning costs, and these are included in the construction costs (see Carle & Moynet, 1993).

Data availability for the total costs of each generation method for each country over the time period is extremely limited in the public domain, and due to the politicised nature of the generation industry, some industry-based sources for costs may be less than ideally transparent. Where possible, we used representative cost breakdowns available in the literature to find the proportion of the total cost of generation that arises from fuel, operating costs and construction costs. We then used the fuel prices to estimate the operating costs, construction costs and total costs. This is because the most detailed data by country was for the fuel component, so each country's cost differences could be estimated best using this method.

The fuel costs for coal, oil and gas have been obtained from the IEA's database, which contains quantities and prices for fuel inputs to electricity generation and for industry. The prices used were for steam coal, high sulphur fuel oil, and natural gas. Where possible, we used the prices for electricity generation, but for French coal and gas we used the prices to industry as the prices to electricity generation were unavailable. A comparison between the industry and generation prices for other countries showed that this is a reasonable substitution to make. The operation and construction costs for coal and gas were estimated from these fuel costs using cost breakdowns from Küffer (1993) for Swiss electricity generation in the early 1990s. These data were chosen as they were the most complete dataset. Cost breakdowns for oil-fired generators for the period were harder to obtain, but Yoda et al. (1993) provide detailed figures for Japanese generators from 1982-92. They also provide cost breakdowns for the other fuels that are comparable to the other sources.

Fuel costs for nuclear and renewables are more complex. Uranium costs are usually withheld as confidential for security reasons, and only represent a small part of the total fuel costs to generation since processing costs have to be considered. These are often linked to long-term agreements with preferential rates and are rarely made public. For renewables, the fuel costs are effectively zero (or there may be transport and processing costs for waste generation). The costs for nuclear and renewables are therefore more linked to construction, maintenance and decommissioning costs. These vary widely between the technology used and often contain site-specific costs. Construction and investment costs are also paid over a long time-span, and so the accounting/discounting method used can affect the cost considerably. The following paragraphs outline our estimations for nuclear and renewable costs.

The primary source for nuclear power in France is Carle & Moynet (1993). They present costs for the construction and running of nuclear, coal and gas power stations and the date of publication suggests that these would be representative figures for the central period we are modelling. As a comparison, their costs for coal and gas generation correspond with those derived from the IEA statistics above. Since there was greater investment in the French nuclear industry (including the upstream industries) in the 1970s, we assume that the French nuclear costs are lower than the other countries. The costs include dismantling, fuel waste treatment and R&D.

To estimate the price of nuclear power for Germany, Italy and Spain, figures from Küffer (1993) were used. This source presents Swiss data, but it is reasonable to assume that given the investments mentioned above, the Swiss costs are similar to the costs in these countries. This includes the "back-end of the fuel cycle, decommissioning and final storage" of the nuclear waste (p. 269).

Estimating a unit price for renewables is perhaps the most problematic, since they are highly dependent on construction costs, which are likely to be highly site-specific. Table 2 shows the quantity of electricity generated in the relevant countries by the different renewable sources. It shows that hydroelectricity is the dominant type of renewable electricity for all countries, and that combustible renewables account for about a quarter of Germany's renewable electricity generation, and the other sources provide much less.

Table 2. Renewable electricity generation by source (average for 1980-2000)

	Hydro		Geothermal		Solar-wind-other		Combustible Renewables	
	GWh	% of renewable generation	GWh	% of renewable generation	GWh	% of renewable generation	GWh	% of renewable generation
France	66,000	97%	-	0%	580	1%	1,400	2%
Germany	19,000	72%	-	0%	1,400	5%	6,100	23%
Italy	41,000	90%	3,300	7%	290	1%	730	2%
Spain	28,000	95%	-	0%	510	2%	980	3%

Source: IEA Energy Balances.

In the light of these figures, it seems reasonable to suggest that a figure for the cost of hydroelectric power could be a suitable benchmark cost for the model. However, due to the high site-specific nature of hydroelectric generation, such costs are not easily available. Table 3 shows that the estimated variable costs of hydroelectric power (estimated for the south-west region of the UK) vary from €35,000 to €210,000 per GWh, which when compared to the other costs in Table 3, it can be one of the cheapest or the most expensive technology. As a comparison, Küffer (1993) estimates Swiss hydroelectricity generation costs to be from €81,000-120,000 for run of river plants and €130,000-€200,000 per GWh for high-pressure hydro plants with reservoirs (prices in €2,000). The variation in costs here arises from the capital costs. Although it is not made explicit in the text, the table suggests that the variation in capital costs is due to variations in capacity, rather than, for example, technology or siting decisions.

Table 3. Indicative costs of electricity by renewable generation technology, 2000 (€)

	Indicative unit price of electricity at			
	8% discount rate (€/GWh)		15% discount rate (€/GWh)	
	Lower bound	Upper bound	Lower bound	Upper bound
Wind (onshore)	96,000	170,000	110,000	170,000
Landfill gas	52,000	61,000	61,000	70,000
Hydro	35,000	210,000	52,000	210,000
Waste				
Mass burn incineration	61,000	78,000	78,000	96,000
Refuse derived fuel	70,000	87,000	87,000	100,000
General industrial waste	52,000	70,000	70,000	87,000
Hospital	70,000	87,000	78,000	96,000
Tyres (small scale)	17,000	35,000	44,000	61,000
Poultry (small scale)	26,000	35,000	78,000	96,000
Biogas (sewage)	44,000	56,000	52,000	70,000
Biogas (farm slurry)	44,000	52,000	78,000	87,000
Arable coppice *	99,000	130,000	110,000	140,000

* Cost based on a specific example, although in practice a variation on these costs will occur.

Source: SWEB (1993).

Table 4. Costs used in the scenario modeling, average for the period 1980-2000 (rounded to 2 sf)

		Average consumption (KTOE/yr)	*Cost per TOE of fuel (€/KTOE)*	*Annual fuel cost (mill €/yr)*	*Average output (GWh/yr)*	*Average fuel cost per GWh (€/GWh)*	*With operating costs (F+O) (€/GWh)*	*With construction costs (F+O+C) (€/GWh)*
France	Coal	9,700	98,000	980,000,000	40,000	25,000	36,000	79,000
	Oil	2,500	200,000	570,000,000	12,000	46,000	52,000	69,000
	Gas	770	250,000	190,000,000	4,500	42,000	51,000	98,000
	Nuclear	75,000	34,000	2,600,000,000	290,000	9,000	19,000	42,000
	Renewables	6,400	-	-	68,000	-	9,900	130,000
Germany	Coal	80,000	200,000	16,000,000,000	310,000	52,000	77,000	170,000
	Oil	3,500	210,000	790,000,000	12,000	68,000	77,000	100,000
	Gas	11,000	220,000	2,400,000,000	42,000	57,000	69,000	130,000
	Nuclear	35,000	320,000	11,000,000,000	140,000	21,000	35,000	83,000
	Renewables	4,200	-	-	26,000	-	9,900	130,000
Italy	Coal	6,200	120,000	740,000,000	27,000	27,000	40,000	87,000
	Oil	21,000	210,000	4,100,000,000	100,000	42,000	47,000	63,000
	Gas	7,800	200,000	1,400,000,000	39,000	35,000	42,000	81,000
	Nuclear	500	320,000	160,000,000	1,900	21,000	35,000	83,000
	Renewables	6,600	-	-	46,000	-	9,900	130,000
Spain	Coal	13,000	110,000	1,300,000,000	57,000	23,000	34,000	75,000
	Oil	3,700	230,000	910,000,000	16,000	57,000	64,000	85,000
	Gas	910	260,000	210,000,000	5,600	38,000	46,000	88,000
	Nuclear	11,000	320,000	3,500,000,000	43,000	21,000	35,000	83,000
	Renewables	2,700	-	-	29,000	-	9,900	130,000

Sources: Nuclear and Renewables prices are derived from published total costs, and operating and fuel costs are worked from these. For other fuels, fuel costs were derived from IEA prices and quantities, and operating and construction costs worked from these.

Table 4 above shows the costs used in the construction of the model. Due to the limitations of the data, the cost for renewable electricity is the same in each country, and the cost for nuclear is the same for Germany, Italy and Spain. However, because the cost of coal, oil and gas-fired electricity varies, it still allows the model to have different outcomes for each country. It shows that costs in Germany are generally higher than the other countries, due in part to higher fuel costs, and in part to less efficient generation (as calculated by our model). This lack of efficiency may in part be due to problems caused by reunification, as two different generation policies merged to become one.

5. Results

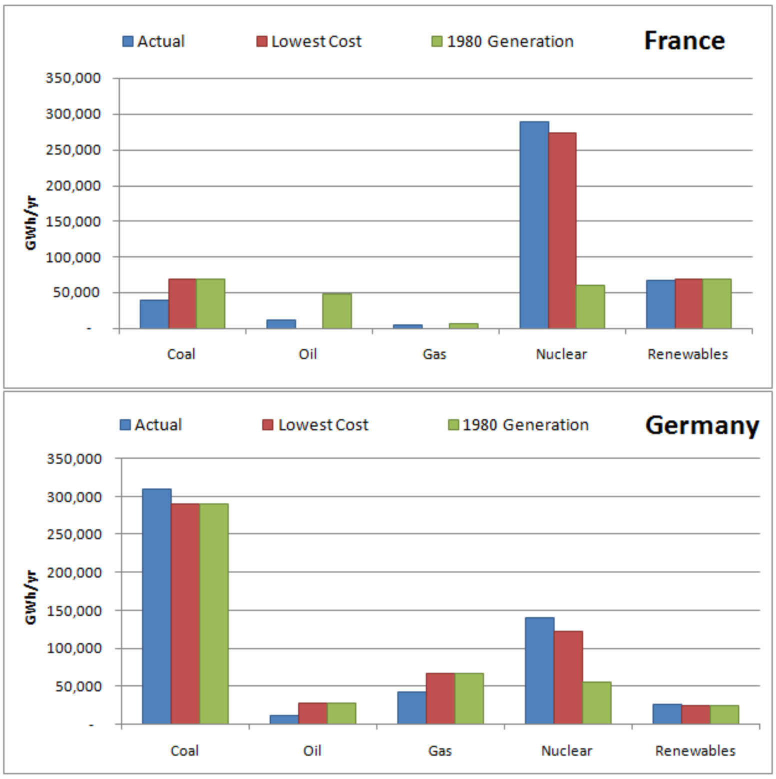
Table 5 shows the results of the model run. It shows the actual case versus the lowest-cost case costs in total and per gigawatt hour. The overall cost estimated is the difference between the two cases. Although it has the lowest costs for electricity, France has the lowest overall energy security cost at just 3% of the total electricity cost. Italy and Spain have the largest ES costs, at 11% and 10% respectively. The different scenarios, and the 1980 starting generation mixes, are shown in Figure 3.

Table 5. Results from the energy security cost model (rounded to 2 sf)

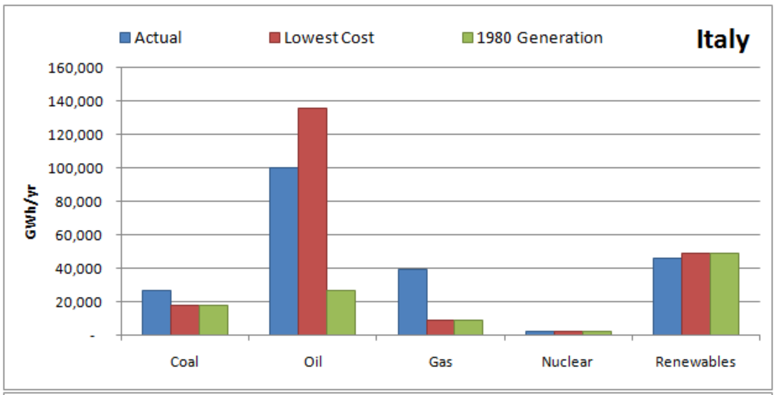
	Generation (GWh/yr)	*Actual case (2000 €/GWh)*	*Lowest cost case (2000€/ GWh)*	*Modelled ES cost (€/GWh)*
France	410,000	33,000	32,000	1,000
Germany	530,000	73,000	69,000	4,200
Italy	210,000	50,000	46,000	4,300
Spain	150,000	53,000	51,000	2,100

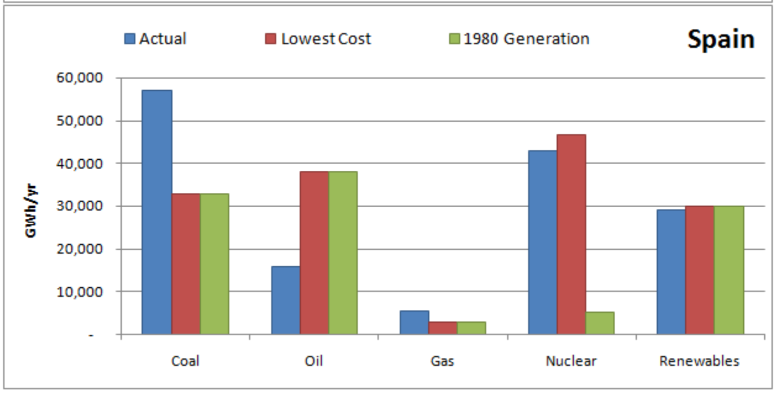
This suggests that the French policy of investing in a secure fuel also led to lower electricity costs. The largest Energy Security Premiums were for the Italian and Spanish policies, which in part were aimed at making oil and gas supplies more secure, whereas our model estimated the cheapest scenario was to use less gas and more oil.[2] The difference in renewables is due to changes from the 1980 level (which we modelled as cheapest in all countries) and the 1980-2000 average level.

Figure 3. A comparison of the estimated actual costs with the estimated lowest costs and the 1980 starting generation in France, Germany, Italy and Spain



[2] This of course is based on the 1980-2000 average, and the fall in the price of gas generation in the late 1990s is not significant in our non-dynamic model.





6. Discussion and further research

The model shows that there is a difference between the estimated lowest cost and estimated actual costs of generation for all the countries. The estimated cost premium was lowest for France in both absolute and relative terms and highest for Italy. Inasmuch as this model can yield firm conclusions, it suggests that policies such as France's, where a secure fuel is set as the cornerstone of electricity generation, have lower costs than policies such as Italy's, in which attempts were made to make existing fuels such as oil and gas more secure.

However, the results from this model are sensitive to the data used for costs. This is limited in three main ways:

1. The methodology for investment and operating costs is very simple, and is based on energy generation costs presented in the literature. A more transparent methodology, which would tie in better with the CASES project, would be to use the overnight investment cost methodology with the Average Annualised Generation Cost model, but this requires annual cost data which are unavailable.
2. Where cost data were unavailable, data from similar countries have been transferred. Ideally, more accurate data for each country would be used.
3. The costs and quantities used for the modelling were based on the 1980-2000 average. This leads to a static model which cannot account for changes in the price/costs of generation over time. A dynamic model, which allowed for changes in price over time, would be more realistic. This would require construction and operating cost data for the whole time period. It would also allow for the modelling of obsolescence/planned closure of plants over time which would place a greater emphasis on the construction costs and ensure that the model would be less reliant upon the capacity available in 1980.

However, despite these limitations, these results provide a valuable first indication of the importance of energy security in determining energy supply costs. Energy security is still an important policy concept. This model suggests that different energy security policies do have costs that impact on the price of electricity. With greater information about historical costs, these impacts could be understood more fully, enabling a more informed analysis of current energy security decisions.

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