THE ECONOMICS OF NUCLEAR POWER

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Since the Chernobyl disaster nearly 20 years ago, nuclear power has been judged harshly. In today's changed policy context, Thibaut Rebet undertakes a re-evaluation. He analyses the costs and benefits in relation to available alternatives with a focus on application to European energy policy. In doing so, he makes many forceful and under-appreciated points in defence of nuclear power and provides evidence of environmental safety, reliability, economic efficiency, and strategic importance for Europe.

Introduction

The recent Kyoto agreement on global warming means that Western countries need to find new methods of producing electricity which will reduce carbon dioxide emissions. At the same time, electricity is an input into almost all industry and it is therefore obviously important to minimise the cost of such an important input. Hence, there is a trade-off between direct economic costs and externality costs (such as pollution). This new policy context poses the question: can we afford to ignore the potential of nuclear power any longer?

The nuclear industry has been vilified since Chernobyl and its image has never recovered. It is considered by critics to be a dangerous, expensive, and unsustainable source of energy that is worse than our current methods of producing electricity. However, the facts point in the opposite direction. With the rise of global warming and geopolitical problems in the Middle East, we need a new source of energy that is not dependent on fossil fuel. Many prominent public figures, including scientists from the Royal Society in London and the founder of Greenpeace, have backed the idea of expanding our use of nuclear power.

Is this feasible and should European countries follow the path recently taken by Finland by investing in nuclear power? To find out, this paper will analyse the three major pillars of any energy policy:

1. The need to minimise negative externalities
2. The need for economic efficiency
3. The need for a predictable, stable, and independent supply

We will then debate the merits and flaws of nuclear power vis à vis its main competitors: fossil fuels, wind, and solar power.[1] We will conclude on whether Europe should follow the French and Finn's example by building new nuclear reactors, or the Germans - who have decided to completely decommission all nuclear power plants in the years to come.

Externalities

One of the most important aspects of a national electricity policy is to choose an energy source that has the smallest amount of negative externalities, the most important of which is polluting the environment. Nuclear energy is considered by many to have a very negative environmental impact, but is this really the case? In fact, despite its bad image, nuclear energy is one of the cleanest methods of generating electricity and can be considered a green energy source. As can be seen from the table below, nuclear power doesn't contribute to global warming and doesn't emit sulphur dioxide or nitrogen oxides, two of the worse types of pollutants.

Table 1: Atmospheric pollution and solid waste from world energy use (Millions of tonnes, 2000)

	SULPHUR DIOXIDE	NITROGEN OXIDES	PARTICLES	CARBON MONIXIDE	CARBON DIOXIDE	SOLID WASTE
COAL	100	>20	500	3	9000	>300
GAS	<0.5	2	<0.5	5	4000	minor
OIL	40	10	2	200	9000	15
NUCLEAR	0	0	0	0	0	0.04
HYDRO	0	0	0	0	0	0

Source: Union of Concerned Scientists, 2004.

Apart from Hydropower, (which has reached its limit in terms of capacity) the only energies which can compete with nuclear power are renewable energies (Science et Vie 2003). Fossil fuels are an ecological catastrophe and it is estimated that they are involved implicitly in the premature deaths of about 100,000 people per year in the EU alone (Mittelstaedt 2004). Considering that a

[1] Hydroelectrical power isn't being considered as there are very few large rivers in Europe which haven't been dammed.

large portion of all atmospheric pollution comes from the burning of fossil fuels for electricity production (60% in the case of sulphur dioxide [EEA1997]), the use of an alternative technology could save the premature deaths of tens of thousands per year, producing a large welfare benefit for society.

Most importantly, nuclear energy doesn't add CO_2 to the atmosphere. Over the last 150 years, human activity has increased the level of CO_2 in the atmosphere by 40% (Wikipedia 2005). The goal of this paper is not to go into the effects of global warming,[2] but if CO_2 is continuously released into the environment, the global consensus seems to be that global temperatures will increase and the climatic effects of this could completely change the face of the planet. Below is a diagram demonstrating the amount of CO_2 released by various energy sources.

Table 2: Grams of Carbon Dioxide equivalent per KWh of Energy produced

	INDIRECT FROM LIFE CYCLE	DIRECT EMISSIONS FROM BURNING
COAL	176 to 289	790 to 1017
GAS	77 to 113	362 to 575
HYDRO	4 to 236	None
SOLAR	100-280	None
WIND	10 to 48	None
NUCLEAR	9 to 21	None

Source: IAEA, 2000

Knowing that 60% of all CO_2 emissions in Europe come from electricity production, it can safely be assumed that it is a desirable public policy choice to use a source of energy that doesn't release large quantities of carbon dioxide into the atmosphere (Eurofer 2004). Renewable and nuclear power seem to be the only appropriate solutions if we want to respect the Kyoto protocol and try and avoid a continuing increase in global temperatures.

[2] For more details on global warming go to nrdc.com

Other Environmental Problems Linked to Nuclear Power

Radioactive Waste

One of the main worries people have about nuclear power is what to do with the radioactive waste that is generated by the reactors and secondly, what is the safety impact of storing this waste. However, even though no long-term solution has been found to eliminate the problem of waste management, the problem is much smaller than is commonly perceived. As can be seen below, the amount of deaths linked to radioactive waste over the long term are insignificant, especially when compared to the deaths caused by coal and solar power. The table below demonstrates this.

Table 3: Deaths per 1,000 MW plant per year of operation due to waste

NUCLEAR:	
-- HIGH-LEVEL WASTE	0.0001
-- LOW-LEVEL WASTE	0.0001
-- TOTAL	0.0002
COAL:	
-- AIR POLLUTION	25
-- RADON EMISSIONS	0.11
-- CANCER-CAUSING CHEMICALS	0.5
-- TOTAL	25.61
SOLAR PHOTOVOLTAICS:	
-- COAL FOR MATERIALS	0.8
-- CADMIUM SULFIDE (IF USED)	0.8
-- TOTAL	1.6

Source: Cohen, 1990.

One of the reasons for this low death rate is that the quantities of radioactive waste generated by a reactor are not large. In fact, the waste produced by a nuclear reactor is equivalent to the size of a coin per person, per year (Lauvergon 2003). It has even been calculated that "if the United States went completely nuclear for all its electric power for 10,000 years, the amount of land needed for waste disposal would be about what is needed for the coal ash that is currently generated every two weeks" (Cohen 1990).

Worldwide, 40,000 tonnes of waste are generated annually, 15,000 tonnes being spent fuel and the 25,000 remaining tonnes, low level radioactive materials such as protective clothing or shielding (Cohen 1990). The spent fuel used up in one year by the whole planet can be stored in an area measuring 10 X 20 X 10 meters and the low level waste in an area of 30 X 30 X 30 meters (Cohen 1990). These quantities are very small, especially when compared with the 30 billion tonnes of materials released worldwide into the atmosphere each year by the burning of fossil fuels (Cohen 1990). In terms of chronic low-level radiation emissions, burning coal emits more radiation in the fly ash, containing uranium and thorium, than is routinely emitted from an operating nuclear power plant for any given amount of energy (Cohen 1990).

However, there is no doubt that nuclear waste is still the Achilles' heel of nuclear power. As has been mentioned, there is no long-term solution to the problem yet. Fast-breed reactors which would divide the amount of waste created by 30 are one solution, but their cost has meant that no large scale programme has been undertaken for the moment (Science et Vie 2003). Fuel reprocessing is another path which has been taken by the French and British but again, economic factors aren't in favour of this option (Science et Vie 2003). This leaves the last option of burying the waste deep below ground as the Swedes and Americans have decided to do (Science et Vie 2003). It is far from ideal, but has been shown to be safe and cheap. Another advantage of this solution is that it allows us to recycle the waste in later years because only 1% to 3% of the energy of spent fuel has actually been used (World Nuclear Association 2004). In a couple of decades, it may well become economically viable to use this spent fuel to create new fast-breed reactors.

Reactor Safety

The reputation of nuclear power as an unsafe energy source is grossly unfair and due mainly to the Chernobyl catastrophe. However, once we look at the figures presented below, it is possible to see that of all major electricity sources, nuclear is by far the source with the lowest number of fatalities, with the possible exception of renewables (for which figures aren't available). Additionally, these figures don't take into account premature deaths caused by pollution. If included, this would place traditional energy sources even further behind nuclear power in terms of safety.

Table 4: Comparison of accident statistics in primary energy production. [3] **(Electricity generation accounts for about 40% of total primary energy)**

FUEL	IMMEDIATE FATALITIES (1970-92)	WHO?	DEATHS PER TWY* ELECTRICITY
COAL	6400	Workers	342
NATURAL GAS	1200	Workers & public	85
HYDRO	4000	Public	883
NUCLEAR	31	Workers	8

Source: Uranium Information Centre, 2003.

So far in over 7,000 plant years in the United States and a similar number in the EU, there has only been one meltdown. It is estimated that on average, one meltdown will occur for every 10,000 years of operation (Edwards 1996). The consequences of a meltdown are also minimal as power plants in the west have a solid containment structure in contrast to soviet reactors, which were designed with military purposes in mind (Frot 2000). It is hence estimated that a major catastrophe with up to 50,000 fatalities will only occur once every 100,000 meltdowns, or once in every 1 billion plant years (Edwards 1996). Considering that 100,000 people die annually because of fossil fuels in Europe, this figure is extremely small.

The extent of land contamination due to a worst-case scenario meltdown also needs to be taken into account. This is another area where the media and environmentalists have exaggerated the true consequences of a meltdown. It is considered that a worst case scenario would contaminate land over a radius of just 60 square miles and that of these 60 square miles, 90% could be easily treated leaving only 20 square miles affected (Cohen 1990). The worst possible accident would cause economic damage of $30 billion according to American researchers. However, the average meltdown would “only” cost $200 million (Cohen 1990). However, this figure is placed in better context when we consider that the annual

[3] “Basis: per million MWe operating for one year (i.e. about 3 times world nuclear power capacity), not including plant construction, based on historic data - which is unlikely to represent current safety levels in any of the industries concerned. The data in this column was published in 2001 but is consistent with that from 1996-7, where it is pointed out that the coal total would be about ten times greater if accidents with less than 5 fatalities were included” (UIC, 2003).

cost of property damage from coal burning alone is $1 billion per year in the US and probably similar in Europe (no figures available) (Cohen 1990).

Economic Efficiency

Table 5: External and direct costs of electricity generation in the EU (m /kWh)

EXTERNAL COST [4]							
	COAL	OIL	GAS	NUCLEAR	BIOMASS	SOLAR	WIND (NOT COUNTING BACKUP) [5]
AUSTRIA			11 to 26		24-25		
BELGIUM	37-150		11 to 22	4-4.7	28-29		
GERMANY	30-55	51-78	12 to 23	4-4.7	28-29	1.4-3.3	0.5-0.6
DENMARK	35-65		15 to 20		12 to 14		0.9-1.6
SPAIN	48-77		11 to 22		29-52		1.8-1.9
FINLAND	20-44				8 to 11		
FRANCE	69-99	84-109	24 to 35	2.5	6 to 7		
GREECE	46-84	26-48	7 to 13		1 to 8		2.4-2.6
IRELAND	59-84						
ITALY		34-56	15 to 27				
NETHERLANDS	28-42		5 to 19	7.4	4 to 5		
NORWAY			8 to 19		2.4		0.5-2.5
PORTUGAL	42-67		8 to 21		14 to 18		
SWEDEN	18-42				2.7-3		
UK	42-67	29-47	11 to 22	2.4-2.7	5.3-5.7		1.3-1.5
DIRECT COST	32-50	49-52	26-35	34-59	34-43	512-853	67-72

Source: European Commission, 2000

[4] EXTERNAL COSTS: radioactive waste disposal, future financial liabilities arising from decommissioning and dismantling of nuclear facilities, health and environmental impacts of radioactivity releases in routine operation, and effects of severe accidents.

[5] WIND: as explained further on, due to the fact that wind cannot be controlled, backup energy sources are needed for operation when enough wind isn't blowing.

As can be seen in the above diagram, in terms of direct cost, nuclear power is beaten by gas, biomass, and coal. However, when external costs are taken into account, there is on balance only one winner. A further consideration in reading the above study is that it was undertaken 4 years ago when gas and oil prices were much lower than they are today. Hence, it is probable that today, in direct costs, nuclear power is even cheaper relative to gas and oil.

It should also be taken into consideration that nuclear energy offers greater price stability than its rivals. The main cost of a nuclear plant is the initial capital cost (UIC 2004). Other sources rely much more on the cost of the fuel used to operate the turbines. In today's world of fossil fuel price instability, nuclear power gives economies what they crave most, certainty.

Nevertheless, there is one major problem. The building of a nuclear power plant requires a massive capital injection. This is then compensated by very low running costs, meaning that over the life-time of a plant, the electricity produced is quite cheap. But private firms might not be willing or able to support the large amounts of capital needed, knowing that they will not get a return for 5 to 6 years and that profitability starts only after 20 or 25 years (UIC 2004). This means that for nuclear power to survive, it needs to be sponsored by the state. In today's liberalised electricity market, this poses a problematic policy conflict.

The need for energy independence and sustainability of supply

It is critical for an economy to have a sustainable and predictable flow of electricity. Energy is a crucial input into almost every industry, without it modern economies simply crash. The wisdom of having a sustainable electricity supply is evident in California, where electricity shortages in 2003 caused $45 billion in higher electricity costs and lost business due to blackouts and a slowdown in economic growth over two years (Economist 2003). It is inconceivable for an economy to function without a sustainable electricity supply. Securing supply should thus be a central objective of any energy policy and all threats to the security of a stable electricity supply need to be minimized. The three key elements in doing this are: devloping energy independence, reliability, and long-term sustainability.

Energy Independence

Firstly, Europe needs to maximise energy independence. Europe is no different to California in that it has an energy-intensive economy and limited natural resources with which to generate electricity. The costs of producing electricity using our limited resources are well above world prices (IAEA 2000).

Hence, Europe is dependent on such regions as the Middle East for its oil supplies and Russia for its gas supplies. This is far from ideal for Europe as both these regions can be highly unstable (and as recent events have shown). The lack of control of our energy supply means that we are strategically vulnerable to external shocks: for example the 1970s oil crisis which caused massive increases in the cost of oil and brought the global economy into recession.

The fact that Europe cannot be guaranteed a natural, safe energy supply has a major impact on energy policy. There are large costs associated with energy independence but the net benefit can be massive. Energy independence needs to be considered as an insurance policy and the extra cost linked to energy independence can be considered as an insurance premium on protecting the economy from external shocks. Like insurance, the net benefit may never materialise but the policy is sensible because the potential risks of energy dependence are simply too great.

A trade-off exists between the risks of energy dependence and economic efficiency. Therefore Europe must not choose supply sources simply according to efficiency criteria but also needs to consider which sources minimise dependence on countries outside our sphere of control. The current situation in the oil market, where the price of a barrel of oil has increased from $15 to $50 in less than five years, is a perfect example of why this policy needs to be taken seriously (Economist 2005). It is clear that oil and gas cannot provide this stability. The only energy sources that can are nuclear, renewable, and to a lesser extent, coal power.

Reliability

Secondly, Europe needs to choose sources that are capable of matching current electricity supply with fluctuating demand. This is to say, we need a base of power which can be relied upon at all times to generate electricity to meet demand and this is not the case with all sources. Here nuclear energy needs to be compared to its competitors.

FOSSIL FUELS: This source of energy has become the most common in the world due to the fact that fossil fuel burning plants can be used 90% of the time during each year (Science et Vie 2003). Also, these sorts of plants can be turned on or off instantly, meaning that electricity companies can quickly match supply and demand. This is especially important in the electricity market as electricity cannot be stored cheaply (with the exception of hydroelectrical power, which can be stored using dams), meaning that excess generation is simply wasted. For these reasons, fossil fuels will have a share of the energy market in Europe for a good number of years to come.

WIND POWER: Reliability is a major problem associated with wind power. Wind turbines in fact only produce electricity 20%-30% of the time (Country Guardian 2004). This is because wind is unpredictable and a certain wind speed is needed to get mills turning. This wind speed may not always be maintained and picks up quite often at night, when electricity demand is at its lowest. A study done by an organisation called Country Guardian gives empirical results demonstrating these problems (2000). They can be observed in Northern Denmark where 21% of electricity is generated using wind power. The windmills often don't produce enough electricity and the shortfall has to be imported from Sweden. These problems mean that wind power needs to have backup electricity-generating units to produce up to 80% of the average electricity generated by windmills. The only realistic backup energies for countries which don't have large hydroelectric resources is fossil fuels, as it is necessary for the units to be put into operation very quickly to avoid an interruption in supply.

SOLAR ENERGY: As can be imagined, the problems linked to solar energy are similar to those faced by wind energy.

NUCLEAR POWER: This source of energy has a load factor of 80% and future reactors will be able to produce electricity 90% of the time (Science et Vie 2003). This is second only to fossil fuels. However, nuclear power does face a problem. It takes 24 hours to get a plant up and running (Science et Vie 2003). This means that nuclear plants cannot easily adjust to fluctuating demand. This is why nuclear plants tend to be turned on constantly except during maintenance when other sources, usually fossil fuels, tend to be used to adjust for demand.

Long Term Sustainability

We need to take the long-term future and sustainability into account. Many electricity sources rely on natural resources that will be used up in the not too distant future, or which will otherwise become prohibitively expensive. It is senseless having an energy policy that encourages a particular source of energy if in 20-30 years the policy is going to lead to a dead end; the main reason for this is economic.

FOSSIL FUELS: Current world reserves of coal outstrip demand by a ratio of 200:1. Hence, in the medium run there isn't a great deal to worry about when it comes to coal resources. The situation for oil gas is less encouraging. According to BP, there are 67 years worth of proven gas reserves left and 41 years of oil (2004). However, these numbers need to be taken with a grain of salt as they only count "proven reserves." Actual reserves are probably significantly higher.

WIND AND SOLAR ENERGY: These resources are renewable and supply is unlimited.

NUCLEAR POWER: There are about 4 million tonnes of conventional uranium resources currently available. Current consumption is about 75,000 tonnes per annum meaning that we have conventional reserves that will last us 30 years at the current rate. There are other reserves of up to 10 million tonnes that aren't currently viable but would be if the price of uranium doubled. This would allow 200 years of use at current levels. Unconventional sources of uranium such as seawater could provide enough uranium to produce the electricity supplies of the world for 7 million years at a cost of 2 to 6 times the current cost of uranium. As uranium represents only about 2% of the generating costs of nuclear power, even seawater uranium is feasible (Uranium Information Centre 2003). Hence, nuclear power is not limited by resource constraints.

Conclusion

The conclusion seems evident. No energy is perfect and the best solution is to spread electricity production between various sources.

Fossil fuels have shown themselves to be environmentally catastrophic but due to their direct price advantage and convenience, they will be around for a while, especially gas, which surely has a role to play due to its cheap price and the fact that fossil fuel plants are very quick in responding to demand.

Power generation using natural renewable energy sources, such as solar and wind power, does not emit CO_2 and is therefore viewed as an effective means of mitigating climate change. However, these natural energy sources also present problems including the large amount of land needed, intermittent supply, and high price. Continuing investment in this resource will help reduce costs and renewable resources need to be an integral part of Europe's electricity production. Nevertheless, for the time being, renewables simply aren't up to scratch to produce large amounts of electricity efficiently.

This leaves us with nuclear power, which seems to be the best source available. Nuclear power does have its problems, but it is the cheapest source and still does not pollute the environment. Additionally, using nuclear power would help us achieve a stable supply and some sort of energy independence vis à vis the Middle East and Russia. It is the conclusion of this paper that nuclear energy does have a future and that European countries should follow the path of France, Finland, and Lithuania by fully embracing nuclear power.

Table 6: Advantages and disadvantages of nuclear power

	ADVANTAGES	DISADVANTAGES
NUCLEAR POWER	• Cheapest solution when direct and external costs are taken into account • Most concentrated source of energy generation • Waste is more compact than any other source • Causes the least direct deaths per TWh • No atmospheric pollution, saving thousands of lives per year • Would help reduce political dependence on Middle East and Russia	• Requires larger capital cost; means private companies might shy away • Requires a resolution of the long-term, high level waste storage issue in most countries • Needs to improve public image problem

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