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External costs of nuclear: Greater or less than the alternatives?

Ari Rabl [a,b,*], Veronika A. Rabl [c]

[a] Ecole des Mines de Paris, France
[b] Consulting on Environmental Impacts, 6 av. Faidherbe, 91440 Bures sur Yvette, France
[c] Vision & Results, Alexandria, VA 22314, United States

HIGHLIGHTS

- ▸ The external costs of nuclear electricity are compared with the alternatives.
- ▸ Frequency and cost of nuclear accidents based on Chernobyl and Fukushima.
- ▸ Detailed comparison with wind as alternative with the lowest external costs.
- ▸ High external cost of wind because of natural gas backup (storage too limited).
- ▸ External costs of wind higher than nuclear but uncertainty ranges overlap.

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ABSTRACT

Since Fukushima many are calling for a shutdown of nuclear power plants. To see whether such a shutdown would reduce the risks for health and environment, the external costs of nuclear electricity are compared with alternatives that could replace it. The frequency of catastrophic nuclear accidents is based on the historical record, about one in 25 years for the plants built to date, an order of magnitude higher than the safety goals of the U.S. Nuclear Regulatory Commission. Impacts similar to Chernobyl and Fukushima are assumed to estimate the cost. A detailed comparison is presented with wind as alternative with the lowest external cost. The variability of wind necessitates augmentation by other sources, primarily fossil fuels, because storage at the required scale is in most regions too expensive. The external costs of natural gas combined cycle are taken as 0.6 €cent/kWh due to health effects of air pollution and 1.25 €cent/kWh due to greenhouse gases (at 25€/t_{CO_2eq}) for the central estimate, but a wide range of different parameters is also considered, both for nuclear and for the alternatives. Although the central estimate of external costs of the wind-based alternative is higher than that of nuclear, the uncertainty ranges overlap.

1. Introduction

In the wake of the accident at the Fukushima power plants there has been a very understandable worldwide reaction against nuclear power. Germany has decided to phase out all their nuclear plants, Japan wants to reduce its reliance on nuclear and has currently shut down almost all of its nuclear plants, and in France the Socialists have written into their platform that they intend to close one third of the nuclear plants in France. But what are the alternatives?

It would not be wise to retire nuclear plants precipitously, if the alternatives entail total (private+external) costs that are even higher. This paper compares the external costs[1] of nuclear with those of the alternatives, considering only the use of nuclear power in countries that have a well established culture of safety and adequate safeguards against proliferation (EU, US, Canada, Japan, South Korea and Taiwan).

The opposition to nuclear power stems mainly from three aspects of the technology, namely radioactive waste, the links to proliferation and terrorism, and the risk of catastrophic accidents. As far as normal operation is concerned, its external costs have been evaluated by several major assessments, in the EU (ExternE,

* Corresponding author. Tel.: +33 1 6928 0694.
E-mail addresses: ari.rabl@gmail.com (A. Rabl), VRabl@Vision-Results.com (V.A. Rabl).

[1] Here the term external cost is used for the entire damage cost due to pollutants or other burdens, even if some of this cost may already be internalized by regulations such as pollution taxes. This is in fact how the term has been used in most studies, in particular those of the ExternE series.

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1995), the US (ORNL/RFF, 1994) and Canada (Ontario Hydro, 1993), with the conclusion that they are small, certainly much smaller than those of the fossil fuels. This conclusion has been reconfirmed via a literature review by the U.S. National Academy of Sciences (NRC, 2010).

Traditionally, probabilistic safety assessments (PSA) have been carried out to estimate the likelihood of a catastrophic nuclear accident, i.e., one involving a core meltdown accompanied with a large release of radionuclides into the environment. The resulting impacts and costs are estimated by means of detailed models, based on the distributions of populations, agriculture etc.

Since Three Mile Island and Chernobyl the safety of reactors has been greatly improved, and yet Fukushima happened. Cochran and McKinzie (2011) offer an instructive review of reactor accidents and compare the actual frequency of core damage accidents with the safety goals of the U.S. Nuclear Regulatory Commission, namely that the frequency of a core damage should not exceed 10^{-4}/year and the frequency of a core damage with large release should not exceed 10^{-5}/year. These safety goals are based on a PSA approach. Worldwide, there have been 593 nuclear power reactors and the cumulative operation amounts about 14,400 reactor-years. There have been 23 core damage events and their frequency has been one in 14,400/23 = 626 reactor years; even excluding the nine least severe cases the core damage frequency is still 10^{-3}/year. The frequency of a large release has been one in 14,400/2 = 7200 reactor years. Both frequencies are an order of magnitude higher than what has been estimated by PSAs for the majority of plants that have been built until now. Can a PSA-based approach really foresee all the site-specific design weaknesses or operator errors that led to Chernobyl and Fukushima?

For these reasons the present paper takes a different approach, which is based on the actual track record of nuclear power plants, in particular catastrophic accidents of which there have been two, Chernobyl and Fukushima. The frequency of such accidents is taken as one in every 25 years, the time between Chernobyl and Fukushima; that is also roughly the time from the first nuclear power plants until Chernobyl. This may well overstate the accident rate because after each large accident measures have been taken to improve the safety. For the central estimate impacts comparable to Chernobyl and Fukushima are assumed.

Of course, any assessment of the external costs of nuclear is controversial, in particular with regard to accidents, proliferation, terrorism and waste management. Subjective choices are inevitable and any specific assumption can and will be criticized. The present assessment is offered as a basis for discussion because it is better to base decisions on an explicit analysis rather than vague impressions. The calculations are simple and transparent, making it easy for the reader to modify the assumptions.

Many advocates of a nuclear shutdown propose renewables and load reduction through energy efficiency as clean and cost-effective substitutes. Among renewables the technologies with the greatest production potential are wind, solar, hydro and biomass. The issue to be addressed with wind and solar, quite apart from their cost, is the variability of wind or insolation, and the corresponding variability in the amount of electricity they supply. To achieve a reliable power supply, supplemental capacity must be available, especially if solar and wind provide a high fraction of the total electricity production. Of course, energy storage would be an attractive solution, but for most applications storage of the required magnitude and duration is still too expensive or the potential sites (for the most cost-effective option, pumped hydro) are too limited. Without sufficient storage the supplemental capacity requirement of wind and solar implies that part of the replaced electricity will come from natural gas, with the attendant costs for health and environment.

Section 2 discusses the external cost of nuclear power and presents an estimate of the cost of a nuclear accident. Section 3 examines the external costs of the principal non-nuclear technologies: coal, natural gas, wind, solar, hydropower, and energy efficiency, with special attention to the extent to which alternatives with the lowest external costs can serve as substitutes for the baseload power produced by nuclear. Section 4 discusses the results.

2. External costs of nuclear power

2.1. Normal operation

As mentioned in the Introduction, health impacts due to radiation from the normal operation of nuclear power plants are small compared to those of fossil power. For instance, ExternE (1995) found an external cost for nuclear of 0.0098 €cent/kWh at a discount rate of 3% and 0.25 €cent/kWh at a discount rate of 0%. The present paper uses the most recent estimate of the ExternE series by Markandya et al. (2010), which is 0.21 €cent/kWh at a discount rate of 5%. This cost is much higher than ExternE, 1995 at 5% discount rate because it is based on a more complete LCA inventory of upstream burdens, essentially all non-radiological. Lower and upper bounds are taken as 1/3 and 3 × this value, based on Spadaro and Rabl (2008).

2.2. Nuclear waste, proliferation and terrorism

Risks from storage of nuclear waste are extremely uncertain because they depend on the future management of the storage site. In the past the design goal of waste storage sites was to seal them when full, so one would never have to worry about them again. But detailed impact studies found that total safety could not be guaranteed for a sufficient duration. On the other hand, assessments of the impacts and damage costs that could result from a breach of confinement concluded that their contribution would be negligible, even compared to the low external cost of the normal operation of the nuclear fuel cycle (e.g., ExternE, 1995; ORNL/RFF, 1994). Such a result is plausible because the dispersion of pollutants in the ground is extremely slow and limited to the local range, unlike the dispersion of radionuclides emitted into the air or the ocean.

Risks from storage can be avoided almost entirely if the waste is stored in a retrievable manner and the site will be permanently maintained in safe condition. The means to do that are certainly available. In case of a leak, the waste can be taken out and repackaged. It can also be reprocessed and rendered less harmful once future technologies allow it. Many people argue that "we have no right to impose the burden of nuclear waste on future generations"; however, they should not overlook that the alternative implies fossil fuels, which impose the burden of greenhouse gases. Future generations can protect themselves from risks of our nuclear waste, but they cannot avoid the impacts of our greenhouse gases. The cost of permanently maintained storage sites is certainly not infinite, despite the practically infinite time horizon, because the appropriate discount rate is positive. Doing a cost–benefit analysis from the perspective of future generations (Rabl, 1996) shows that future generations would prefer us to use a discount rate equal to the long term average growth rate of real GDP per capita, for which historical data suggest a value of 1 to 2%. The reason is that future generations benefit from the growth stimulated by our economic activity. Even with such a low discount rate the total discounted cost of a permanently managed storage site is only 50 to 100 times the annual cost.