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Renewable and nuclear electricity: Comparison of environmental impacts

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HIGHLIGHTS

- Given the acknowledged hazards of fossil fuels, it is important to compare the impacts of low-carbon alternatives.
- This report reviews published data to compare nuclear with hydro, wind, solar and biomass electricity production.
- Environmental impacts and risks to humans are compared.
- Specific impacts of wind turbines on bird populations are examined.
- Conclusions and recommendations for future energy choices are presented.

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ABSTRACT

Given the widely acknowledged negative impacts of fossil fuels, both on human health and on potential climate change, it is of interest to compare the impacts of low carbon alternative energy sources such as nuclear energy, hydropower, solar, wind and biomass. In this paper, we review the literature in order to summarise the impacts of the different technologies in terms of their materials and energy requirements, their emissions during operation, their health effects during operation, the accident risks, and the associated waste streams. We follow up these comparisons with some more anecdotal evidence on selected impacts that are either particularly topical or are important but less commonly addressed. These include impacts of wind turbines on persons and on bird life, the underestimated problems with biomass, and concerns about biodiversity reduction. Finally we address the public attitudes towards both renewable energy technologies and to nuclear power. The conclusion is drawn that energy policies of many countries are perhaps more strongly influenced by public and political perceptions of available technologies than they are by rational assessment of the actual benefits and drawbacks. Policy recommendations follow from this conclusion.

1. Introduction

There have been many studies on the environmental aspects of nuclear power generation and of renewable energy sources, for two particular reasons:

1) Nuclear energy production involves a series of processes from uranium mining through to final waste disposal, all of which are major engineering activities. These commonly require the production and assessment of an official Environmental Impact Assessment (EIA) before they can be licensed. Large scale use of renewables such as in wind farms or solar power plants also requires an EIA.
2) Nuclear energy production is a controversial subject in most countries, resulting in an active debate on the associated environmental issues, and on their impacts relative to alternative means of producing electricity. Increasing controversy also surrounds the environmental impacts of renewables as aggressive programmes to increase their market penetration have led to growing local opposition in some countries.

Most often in the current energy debate, the comparisons that have been made are between nuclear and fossil fuels or between renewables and fossil fuels. Given the widely acknowledged negative impacts of fossil fuels, both on human health and on potential climate change (Lynas, 2014), the more interesting comparison is between nuclear energy production and the use of other

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low carbon alternative energy sources such as hydropower, solar, wind and biomass.

Prior to examining the direct impacts, we briefly consider in Section 2 two fundamental concepts in energy economics which have direct implications on the exploitation of any energy source: power densities and Energy Return on Energy Invested (EROI). This is followed by sections examining the environmental impacts of nuclear and renewables in terms of a wide range of actual and potential impacts. There is a very extensive literature on these issues. The EU supported major studies in the NEEDS project which ended in 2009 but still has an online database (NEEDS, 2009). Scientists at the Laboratory for Energy Systems Analysis at the Paul Scherrer Institute have been a source of information and analyses for many years; a recent summary of their work is included in Hirschberg and Burgherr (2015). In the present paper, we reproduce from the available literature data to support the conclusions that we subsequently draw, fully recognizing that an in-depth comparison requires more extensive specification of the basic assumptions used in characterising the technologies to be compared. We begin by using the literature data to illustrate the impacts of the different technologies in terms of their materials and energy requirements, their emissions during operation, their health effects during operation, the accident risks, and the associated waste streams. The studies referenced provide important information for such comparisons, although challenges remain in gathering reliable data and in appropriate normalization of the impacts. We follow up these sections with some more anecdotal evidence on selected impacts that are either particularly topical or are important but less commonly addressed. These include impacts of wind turbines on persons and on bird life, the underestimated problems with biomass, and concerns about biodiversity reduction. Finally we address the public attitudes towards both renewable energy technologies and to nuclear power, before concluding with comments on the policy implications of the information presented.

The most transparent approach to comparing all such environmental impacts from various electricity production methods is within a Life Cycle Analysis (LCA) in which all impacts, including costs, are assessed and summed throughout all stages. These types of analyses were extensively studied within the ExternE Project of the EU which ran through to 2005. The website established for this project remains updated to include references and results for subsequent work up to the present. (ExternE, 2015). This includes links to the above-mentioned NEEDS project which extends the nuclear power plant studies to include estimates for newer reactor technologies that may be implemented up to 2050.

Many of the figures given in the texts below for nuclear power and for renewable technologies are based on LCA analyses, often making use of the Ecoinvent database produced in Switzerland (Ecoinvent, 2014). A large database was also assembled for the recent IPCC report on climate change (IPCC, 2014) and results from this comprehensive document are also included below.

2. Power densities and energy returns

In addition to comparing the detailed environmental impacts or the costs of alternative energy supply systems, it is instructive to consider some of their more intrinsic attributes that can directly influence impacts and costs. These attributes are related to the specific energy content of the different sources. Interesting measures that can be used to aid comparisons between energy sources are the energy density, the power density and the energy return on energy invested; these provide additional insight into the advantages and disadvantages of various energy sources. Energy density is simplest; it is the amount of energy per unit weight or per unit volume and can be used to compare fuels. Fuels based on nuclear reactions are vastly more concentrated than chemically based fuels. For example, typical energy densities in kWh/kg of coal, lead- acid batteries and uranium 235 are respectively 8, 40 and 24,000,000 million. The difference is impressive, but the technology and the energy input needed to extract the energy is, of course, also very different, as is pointed out below.

Power density is a more complex measure that is extensively used in the work of Vaclav Smil who uses the definition of W/m^2 of horizontal area of land or water surface. Renewable forms of energy have lower power densities than nuclear (or the fossil fuels) (Smil, 2015; Cruz and Taylor, 2012; Jefferson, 2013). This places renewable energy at a disadvantage in principle, although in practice much depends on locational factors – local mean wind speeds for wind power; levels of direct and indirect insolation for solar PV and solar "farms", for instance. Some examples of power density are given below (Smil, 2010):

- Nuclear up to 4000 W/m^2
- Solar photovoltaic 4–10 W/m^2
- Wind 0.5–1.5 W/m^2
- Biomass 0.5–0.6 W/m^2

For comparing electricity generating systems which require energy input for construction and operation of facilities, it is also instructive to calculate the energy balance. The EROI (energy return on investment) is the ratio of energy generated over the facility lifetime relative to the embodied energy. The concept of EROI has had relevance ever since the earliest humanoid hunters and gatherers existed, and has been evident throughout the Industrial Age and since (Jefferson, 2015). Renewable energy forms – with the possible exception of hydro – in general have lower EROIs than nuclear power (and the fossil fuels – although these are in general decline) (Hall et al., 2014; Jefferson, 2013, 2015). Fig. 1 below, produced by Conca (2015) based on earlier data, gives one example of a comparison of EROI for a variety of energy technologies. Although there are uncertainties about the precise EROIs to be attached to each of the energy forms, the underlying picture is clear.

3. Resource requirements

3.1. Materials

The principal materials concerns with wind and solar energy technologies relate to the use of “rare earth” materials.

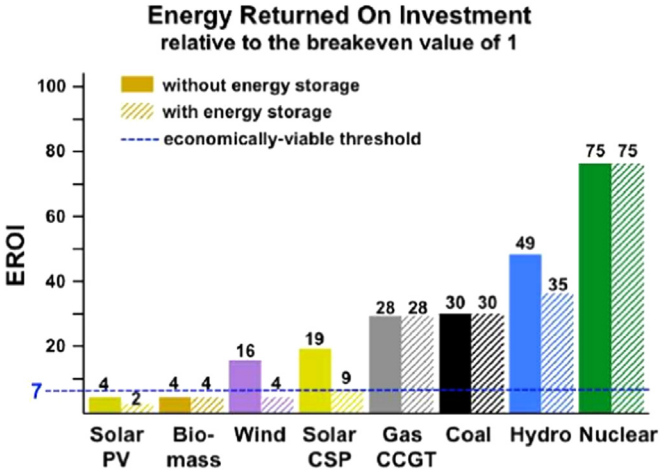

Fig. 1. Energy return on investment (from Conca, 2015).

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