How Wind Stacks up to Coal and Nuclear: A Comparison of Life-Cycle Assessments for Coal, Nuclear, and Wind Generation by Vattenfall AB Generation Nordic

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INTRODUCTION

Life-cycle Assessment (LCA), as defined by the Environmental Protection Agency, is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- compiling an inventory of relevant energy and material inputs and environmental releases; and
- evaluating the potential environmental impacts associated with identified inputs and releases

DESCRIPTION OF THIS STUDY

This study compares a series of studies published by a Vattenfall AB Nordic, a European energy company that generates electricity using nuclear, wind, and coal technologies [1-3]. The Vattenfall studies were carried out applying the Environmental Product Declaration (EPD®) system based on ISO 14025, Type III Environmental Declarations.

Generation Nordic owns and operates 7 nuclear reactors, 5 fossil fuel base-load plants, more than 500 wind turbines, and over 100 hydropower plants.

Total installed wind power for Generation Nordic across Denmark, Finland, and Sweden is 369 MW, and avg annual electricity generation is 0.89 TWh. Individual turbines have capacities of 0.2-2 MW and are on or offshore. The study assumes a 20-year lifetime and an average capacity factor of 30% for wind turbines.

The nuclear analysis is based on the Ringals plant which has one BWR and 3 PWR reactors, and a total installed capacity of 3,670 MWe, producing an annual average of 26.4 TWh (82% capacity). The study assumes a 50-year lifetime for the nuclear plant.

The 5 coal fuel base-load plants are all combined heat and power units, ranging from 250-388 MWe per plant when producing only electricity. The lifetime varies per unit and ranges from 27 to 44 years.

RESULTS

Material and Energy Resources

Table I lists the material and energy resource inputs for each energy source for the Vattenfall studies. Fig. 1 shows the ratio of material inputs for wind to that required for coal or nuclear.

The difference in steel requirements (approximated with iron in ore) is notable. The wind plant is estimated to require 27 times from steel that required for nuclear. The difference can be roughly broken down into three factors of three:

- 3:1 ratio for amount of materials to build equivalent nameplate capacity (~270:90 tonnes steel per MWe);
- 3:1 ratio for capacity factor (~30%:90%); and
- 3:1 ratio for plant lifetime (~20:60 years).

Table I. Resource inputs in g/kWh [1-3]

	Wind	Coal	Nuclear*
Materials			
Rock, gravel, sand	16	2.8	5
Iron in ore	5.10	2.00	0.19
Energy Resources			
Coal	2.6	280	0.23
Crude oil	0.84	12	0.36
Natural gas	0.5	7	0.15
Uranium	~0	~0	0.02

*Raw data multiplied by 0.76 to convert to 60 year lifetime at 90% capacity factor as opposed to 50 year lifetime at 82%

As shown, wind is estimated to require almost 6 times the amount of concrete for equivalent energy output from nuclear and 2.5 times that required for coal generation. In terms of energy resources, the magnitude of coal used as fuel in coal-fired generation in comparison to uranium (0.02 g/kWh) as fuel in nuclear generation is noteworthy.

Air Emissions including Greenhouse Gases (GHG)

Fig. 1 to Fig. 3 show the emissions for the energy types by phase of the lifecycle. Nearly 90% of the impacts for wind plants can be attributed to the construction of the wind tower (including the manufacturing and transportation of the required steel, concrete and other material). For nuclear plants, the dominating impact is from the extraction of uranium from mines, except for ozone depleting emissions, where enrichment dominates. Overall, upstream processes contribute 50-90% for nuclear depending on the emission category. For coal, the operation of the unit produces 95% of greenhouse gases while the upstream activities associated with mining and transportation of coal produce most of the ozone depleting substances.

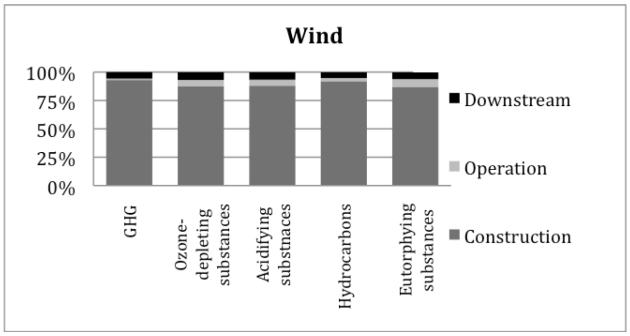

Fig. 1. Wind Emissions by Life-cycle Phase

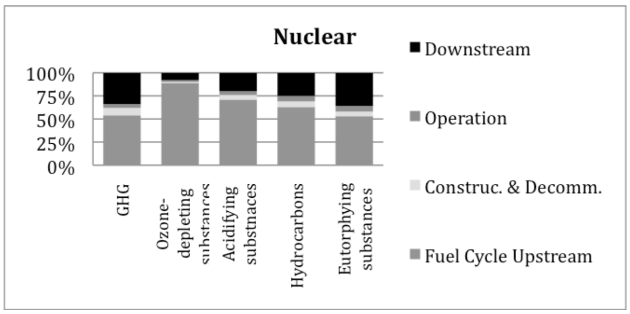

Fig. 2. Nuclear Emissions by Life-cycle Phase

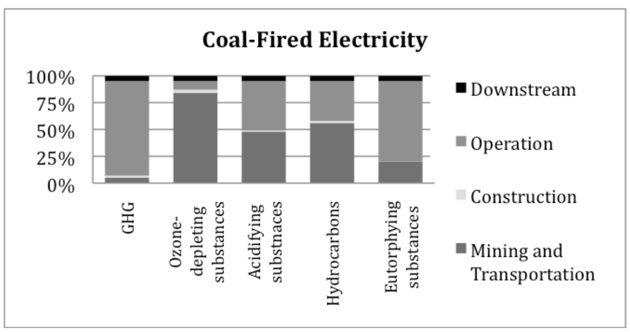

Fig. 3. Coal Emissions by Life-cycle Phase

While Fig 1-3 are meant to illustrate the dominating phase of the lifecycle, Table II shows the actual value of GHG emissions for each energy type. Coal results in a much greater amount of GHG emissions than either nuclear or wind. For additional comparison, Table II also shows how the Vattenfall results for CO_2-eq compare to the range of results in various US studies. The overall CO_2-eq for the Vattenfall nuclear plant is much less than that of the U.S. studies because enrichment is assumed using gaseous diffusion technology for the U.S. studies, which requires 40 times more energy than centrifuge technology, assumed in the Vattenfall scenario. Also, the electricity used for enriching in the Vattenfall study is almost entirely non-fossil, (47% from hydropower, and 42% nuclear[ii]). This compares to an electricity distribution in the U.S., which is heavily reliant on fossil fuels (45% coal, 24% gas, 20% nuclear, 10% renewable according to EIA in 2010).

Table II. Comparison of Greenhouse Gases

GHG (g CO2-eq/ kWh)	Wind	Coal	Nuclear
Vattenfall Nordic [1-3]	14	774	4
US [4-5]	~18	~1000	16 - 66

Since 1994, about 50% of U.S. enriched uranium has been provided through down blending Russian weapons-grade uranium and the U.S. plans to import enriched uranium from Russia when the program ends in 2013. These programs, as well as future U.S. projects to build greater centrifuge enrichment capacity, will most likely serve to lower the energy requirements for enrichment in the US.

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[i] This summary paper was prepared, in part, by an employee or employees of the U.S. Nuclear Regulatory Commission on his or her own time apart from his or her regular duties. NRC has neither approved nor disapproved its technical content.

[ii] WNA, http://world-nuclear.org/info/inf42.html