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Environmental and health impacts of a policy to phase out nuclear power in Sweden

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HIGHLIGHTS

- The Swedish reactor fleet has a remaining potential production of up to 2100 TWh.
- Forced shut down would result in up to 2.1 Gt of additional CO_2 emissions
- 50,000–60,000 energy-related-deaths could be prevented by continued operation.
- A nuclear phase-out would mean a retrograde step for climate, health and economy.

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ABSTRACT

Nuclear power faces an uncertain future in Sweden. Major political parties, including the Green party of the coalition-government have recently strongly advocated for a policy to decommission the Swedish nuclear fleet prematurely. Here we examine the environmental, health and (to a lesser extent) economic impacts of implementing such a plan. The process has already been started through the early shutdown of the Barsebäck plant. We estimate that the political decision to shut down Barsebäck has resulted in ~2400 avoidable energy-production-related deaths and an increase in global CO_2 emissions of 95 million tonnes to date (October 2014). The Swedish reactor fleet as a whole has reached just past its halfway point of production, and has a remaining potential production of up to 2100 TWh. The reactors have the potential of preventing 1.9–2.1 gigatonnes of future CO_2-emissions if allowed to operate their full lifespans. The potential for future prevention of energy-related-deaths is 50,000–60,000. We estimate an 800 billion SEK (120 billion USD) lower-bound estimate for the lost tax revenue from an early phase-out policy. In sum, the evidence shows that implementing a 'nuclear-free' policy for Sweden (or countries in a similar situation) would constitute a highly retrograde step for climate, health and economic protection.

1. Introduction

Human industrial and agricultural activity is the principal cause of changes in the Earth's atmospheric composition of long-lived greenhouse gases, mainly carbon dioxide (CO_2), and will cause ongoing climate change over the 21st century and beyond (Hansen, 2013). More than 190 nations have agreed on the need to limit fossil-fuel emissions to mitigate anthropogenic climate change as formalized in the 1992 Framework Convention on Climate Change (UNFCC, 2014). However, the competing global demand for low-cost and reliable energy and electricity to fuel the rapid economic development of countries like China and India has led to a large recent expansion of energy production capacity based predominantly on fossil fuels. Because of this need for energy and economic growth in developing countries, coupled to the lack of progress on decarbonization in most developed nations, human-caused greenhouse-gas emissions continue to increase, even though the threat of climate change from the burning of fossil fuels is widely recognized (Boden and Andres, 2012).

Sweden (along with a few others nations such as France) stands out as an exception to this trend, having largely eliminated its dependence of fossil fuels for electricity production during the 1970s to 1990s via a large-scale deployment of nuclear energy (oil- and gas-based transport fuels remains a problem, hydropower was

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largely pre-existing before the nuclear phase). Despite this success, several Swedish political parties, most prominently represented in the current Swedish government by Green-party politician Ms. Åsa Romson (who holds the position of minister for the environment and climate) has promoted the urgent phase-out of the Swedish nuclear program. This is a primary objective of the Swedish Green party, with passive or active support from the Left and Center parties (with the position of the dominant Social Democrat party highly unclear). The Green-party, currently in a coalition government with the Social democrats, has promised that at least two reactors are to be shutdown prematurely in the next mandate period (2014–2018), with other reactors soon to follow. According to their announcements, this is to be accomplished by raising taxes on nuclear power production to the point where continued operation of the existing plants will become economically unviable (Dagens Nyheter, 2014).

What impact might this decision have—if carried to fruition—on Sweden's future environmental standing? To tackle this timely policy-relevant question, we first quantify the impact on global greenhouse gas emissions that the Swedish nuclear program has had to date, and then calculate what impact the proposed phase-out decisions will have future emissions. In addition, we use available mortality statistics for various electricity sources to estimate the impact on energy-related deaths. Our study is carried out in detail on a reactor-by-reactor basis and follows the general approach given in Kharecha and Hansen (2013). The hope is that by providing an objective assessment of the real-world impact of this announced policy, this study will help to better inform responsible politicians of the specific climate and health impacts of political decisions regarding the Swedish nuclear fleet.

Commercial light-water reactor (LWR) technology was originally developed and deployed in Sweden to increase energy independence (primarily by reducing foreign oil imports) and to supply the increasing electricity and energy demand while protecting remaining major Swedish rivers from hydropower installations (Forsgren, 1994). The LWR program in Sweden started[1] with the grid-connection of the Oskarshamn-1 (O1) reactor in 1972, and by 1986 half of the electrical output of the country came from nuclear power plants. The active reactor fleet consists of 10 reactors with a combined capacity of 10 GWe at three nuclear power plants: Oskarshamn, Forsmark and Ringhals. In addition, the Barsebäck nuclear plant with two reactors (600 MWe each) has been shutdown prematurely due political decisions, but the reactor units at the plant have not yet been dismantled. The option of restarting the two reactors at the Barsebäck plant is considered in this study. The active nuclear fleet typically produces 60–70 TWh/y, making up 43–47% of the total electricity production of the country. The decommissioned Barsebäck units could potentially add an additional ~10 TWh/y.

The Swedish naming convention for reactors use the first letter of the plant name and a numeral corresponding to the chronological reactor start of construction; the reactors are abbreviated B1–B2, O1–O3, F1–F3 and R1–R4. The current reactor fleet and its age profile are summarized in Table 1. The naming convention used for different types of reactors in the study is taken directly from the IAEA PRIS database (International Atomic Energy Agency (IAEA), 2014). There is no specified constraint for the lifetime of specific reactors, in part because most of the systems and components can and have been replaced one or more times. Reactor operators apply for a renewed operational license from the Swedish Radiation Safety Authority every 10 years, and as long as it is granted they may continue to operate. An estimation of the probable lifetime, consistent with the statements of reactor owners and operators, have been made based on the reactor type with the following results:

- The first generation of BWRs (ABB-1): 50 years,
- The second generation (ABB-II) and smaller third-generation BWR units (ABB-III, BWR-2500): 60 years
- The larger third generation BWR units (ABB-III, BWR-3000): 60–80 years (60 years was used for all calculations)
- The Westinghouse PWRs: 60 years, except for R2 which has been designated for a 50-year lifespan (Radio, 2014)

Given Sweden's 10-year review approach to licensing, the decision to decommission (if not forced by political decisions) will likely not be based on any technological limits but rather on whether the economic analysis favor decommissioning and full reactor replacement over that of further upgrades to reactor components. Sweden has recently performed very extensive upgrade projects (some which are still on-ongoing) in several reactors that involve the replacement of turbines, valves, cables and control and safety equipment. Thus, rather than being up to 40 years old, much of the equipment in these plants is brand new. The only components that are typically not subject to upgrade analysis are the reactor pressure vessel and containment structure, which are seen as so expensive and difficult replace that a complete reactor replacement is preferable. One of the most age-critical component in the Swedish nuclear fleet is the pressure vessel of the O1 reactor, which is in good condition according to the reactor safety experts that periodically examine the vessel and has an estimated technical lifetime exceeding 60 years (Gärdinge, 2013).

Interesting to note is that while the age of reactors (measured not in the age or condition of components critical to safety, but as the time between the present and when the reactor was started) has received much attention in the media and political debate, no such attention has been paid to the, for the most part, significantly older hydropower installations that provide the other half of Swedish electricity.

2. Methods

2.1. CO_2 emissions impact of the Swedish nuclear program

To estimate the impact that nuclear power has had and will continue to have on electricity-generation-related CO_2 emissions, the emissions caused by nuclear power need to be compared to those from competing technologies. Reference values for the life-cycle emissions of nuclear and competing baseload electricity generation alternatives are given in Table 2. The life-cycle assessment (LCA) of emissions covers the areas of construction and dismantling of power plants, fuel production & transport, plant operations, and handling of residual products and waste. Three values have been added for nuclear due to the noticeable disparity of data. The most comprehensive LCA study specifically for the Swedish nuclear fleet are the periodic reports of the Swedish state-owned power producer Vattenfall, which produce LCA-emissions assessments based on the international ISO 14040 and ISO 14044 standards (Vattenfall, 2012). Notably, the largely theoretically derived values used by the Intergovernmental Panel on Climate Change (IPCC Working Group III—Mitigation of Climate Change, 2014) as well as from a comprehensive review study (Lenzen, 2008) for global nuclear are 2–10 times higher than those estimated specifically for Sweden by Vattenfall based on actual

[1] A very small (60 MWt, 12 MWe) dual-purpose (district heating and electricity) nuclear plant predates the O1 reactor and was connected to the grid in the Ågesta suburb of Stockholm in 1964. This reactor was the first part of the later abandoned “Swedish Line” program of natural-uranium fueled heavy-water-moderated reactors that were also meant to serve a role in the Swedish nuclear weapons program.