LOGISTICS OF DISMANTLING NUCLEAR POWER PLANTS – A MODEL-BASED ANALYSIS OF LOW- AND INTERMEDIATE-LEVEL WASTE MANAGEMENT IN GERMANY

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Overview

Dismantling and decommissioning of nuclear power plants constitutes a significant industry with a volume of 1€ billon per reactor (Meyer 2012). This process requires high-tech and cost-intensive equipment, generates significant amounts of material with low- and intermediate level radioactivity (additional to the high-level radioactive spent fuel), and is highly regulated. It comes with high potentials for economies of scale and a need for integrated planning to tackle the complex task of investment in equipment and operation of a logistial network under uncertainty (List et al. 2006). Currently there is a global fleet of 435 nuclear power stations with an average age of 29 years, and with 58 power stations that are older than 40 years (Schneider et al. 2015). With tight safety requirements, negative learning rates and the unresolved issue of nuclear waste disposal, nuclear energy has always been a highly disputed technology (Lévêque 2014). The Fukushima Daiichi accident in 2011 has reinforced the phase-out policies in various countries, most prominently in Germany, which opted for a complete nuclear phase-out by 2022. This rapid and ex-ante uncoordinated shut-down of 17 nuclear power stations signficantly complicates the individual dismantling process and requires a close coordination.

Figure 1: Site with significant nuclear material production and/or storage in Germany. Source: (Albrecht et al. 2016)

The framework developed in this paper provides a comprehensive tool to assess the level of low- and intermediate-level nuclear waste resulting from the individual phases of dismantling and decomission and the required machinery to perform the different tasks in each of the phases. These levels provide input to a logistical program that solves the task of scheduling transports between the site of the power plant and the central and final storage sites, taking into account variable storage costs, costs of storage expansion, and restrictions on annual throughput capacities at various critical points.

The paper is organised as follows: After the introduction the second section gives a brief overview about the technical setting followed by a section that describes the regulatory settings. The fourth section presents the modeling framework. A detailed discription of input data is given in section five. Section six presents the resulting cost-minimizing stocks and transport volumes, gives various scenarios driven by regulatory assumptions, and compares these to a robust stochastic solution. of the model. The final section provides conclusions.

Methods

The multi-objective problem of hazardous waste location and routing has been studied before in various frameworks (see e.g. Samanlioglu 2013; Ghiani et al. 2014). Hawickhorst (1997) and Hwang et al (2003) present optimization tools for the management of radioactive wastes from the operation of nuclear power plants. In a reverse logistics approach that considers both the nuclear power generation and the corresponding induced waste reverse logistics, Sheu (2008) address the effcient and cost-minizing organization of nuclear waste disposal during operation, while taking into account operational risks. Laraia (2012) provides an overview of planning, execution and international experience with nuclear decommissioning, while Sorenson (2015) gives an assessment of the requirements for safe and secure transport and storage of radioactive materials. Building on existing literature, the modeling framework presented in this paper is able to calculate the cost-minizing decision on the respective decommisioning option (direct decommisioning, or long-term entombment) for each of the 17 German reactors. The decomissioning process is broken down into the five typical phases, where for each phase requirements of machinery and respective investments, space and personel, and levels of accumulated low- and intermediate waste are tracked. The waste can either be conditioned and reduced in volume on-site in a conditioning facility, stored on-site but unconditioned, or transported to central or final storage sites. The model dataset includes information on existing storage and conditioning capacities by site and on respective expansion potentials. By empolying a stochastic approach the model can account for regulatory and technological uncertainty with respect to timing and duration of the decomissioning phases and provides robust solutions.

Results

Model results are driven by assumptions on capacity restrictions, in particular for annual storage capacity at the final storage, but also by cost of decommissioning, investment and variable costs for conditioning, storage and transport. In a simplified and deterministic version of the model Zoder et al. (2015) examine different scenarios of annual storage capacity for the final stroage in “Schacht Konrad” and a delay of its construction. Results show that if the completion of “Schacht Konrad” is delayed, required interim storage capacity doubles and total system costs increase by 50%. To arrive at a solution where all reactors are directly dismantled and do not go for entombment, additional annual storage capacity and a timely construction of “Schacht Konrad” are required, otherwise seven reactor are entombed to pospone waste accumulation and reduce residual waste levels.

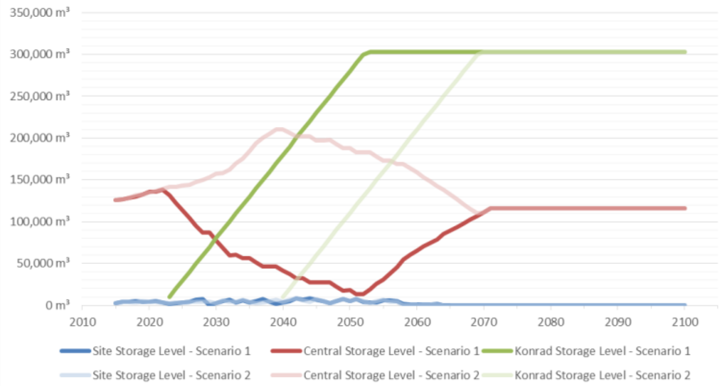

Figure 2: Storage levels of on-site storage, central, and final storage for Scenario 1 (BAU) and Scenario 2 (delayed complition of “Schacht Konrad”) from 2015 to 2100. Source: (Zoder et al. 2015).

Conclusions

The modeling framework presented in this paper explicitily models the logistical problem of dismantling and decommissioning of nuclear power plants in Germany. The results can be used as a current bechmark solution to assess what development in the dismantling industry needs to be incentivized or regulated and how current regulation needs to be adapted to minimize societal and environmental costs and risks. If the decommissioning process is successfully organized and implemented in Germany, it can serve as a role model for the nuclear phase-out in other countries.

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