Energy Policy 107 (2017) 138–150

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Driving forces and obstacles to nuclear cogeneration in Europe: Lessons learnt from Finland

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ARTICLE INFO

Keywords:
Nuclear
Cogeneration
District heating
Energy megaproject
Sustainability
Finland

ABSTRACT

Nuclear power plants generate electricity and a large amount of waste heat which is valuable for cogeneration. District heating (DH) is a suitable technology to decarbonize the European heat sector. By contrast with most of nuclear non-electric applications, nuclear district heating (NDH) has already been implemented in Europe, thus providing us with some valuable empirical insights. This paper investigates the forces and obstacles to nuclear cogeneration by looking at the Loviisa 3 NDH project in Finland. The key forces are energy efficiency, decarbonization of the heat sector, operational competitiveness of future nuclear technologies, and synergies with renewable energies. The key obstacles are split incentives, electricity prices volatility, inexpediency of business models and regulatory frameworks, electioneering of local authorities and pessimist expectations with regards to project financing. Policy makers should recognize nuclear plants alongside other utilities generating large amounts of wasted heat. International cooperation programs involving both nuclear and heat stakeholders should be encouraged. EU28 Member States wanting to promote nuclear cogeneration may consider providing support for the electricity generated by high-efficiency plants.

1. Introduction

The most common type of nuclear power plant (NPP) in operation (277 out of 438) or under construction (59 out of 70) (IAEA, 2015) is the Pressurized Water Reactor (PWR). The thermodynamic efficiency of a PWR is around 33%. Therefore, about two thirds of the heat generated by the nuclear fuel is wasted. Since the steam exiting the high-pressure turbine is superheated, it could be used for non-electric applications such as district heating, desalination of sea water, industrial process heating etc. (IAEA, 2003). Nuclear cogeneration plants (NCP) are defined as NPPs targeting a high thermal efficiency by generating both electricity and heat. It thus excludes hydrogen production from alkaline electrolysis. A PWR can be converted into an NCP without jeopardizing the reactor's safety (STUK, 2009: p. 6).

The thermal efficiency of NCP could reach up to 66% (ISNP, 2014), increasing the total energy output by at least 50% (IAEA (International Atomic Energy Agency), 2016a; Locatelli et al. (2015)) compared to a NPP of similar features generating only electricity. Operating a PWR as a NCP implies to reduce the electricity output of the reactor. Lost electricity production depends on the temperature and the amount of heat considered. Several studies pointed out that, for the temperature ranges useful to district heating networks (85–115 °C), NCP can be designed so that the amount of thermal energy (MW(th)) recovered is five to six times greater than the electricity losses (MW(e)) (IAEA, 2017, 2016a, 2003).

Among the nuclear non-electric applications, district heating (DH) and desalination benefit from the largest industrial experience worldwide (IAEA, 2003). In Europe (including Russia and Ukraine), nuclear district heating (NDH) is the most tried-and-tested technology, and it certainly has the highest potential in the short run. Lately, technico-economic studies have been led to explore regional opportunities for the deployment of large-scale NDH projects. In Finland, Fortum (the

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Abbreviations: NDH, Nuclear District Heating; NCP, Nuclear Cogeneration Plant

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http://dx.doi.org/10.1016/j.enpol.2017.04.025
Received 12 September 2016; Received in revised form 10 April 2017; Accepted 13 April 2017

second largest Nordic power company) offered to operate the planned Loviisa 3 NPP in a partial cogeneration mode (Fortum Power and Heat Oy, 2009: p. 26–28). In France, the possibility of transporting between 1500 MW(th) to 3000 MW(th) heat from the Nogent-Sur-Seine NPP to Paris over 110 km has been examined (Jasserand and Devezeaux, 2016; Safa, 2012). Similarly in Poland, an economic analysis was carried out for the Choczewo and Zarnowiec planned NPP (Jaskólski et al., 2014). The thermal output was about 250 MW(th) and the length of the main transport line varied between 22 km and 64 km depending on the town considered (Wejherowo, Reda, Rumia and Gdynia).

The implementation of such immense projects would imply an initial investment up to 1–2 billion euros alongside new agreements between utilities (Bergroth, 2010; Jasserand and Lavergne, 2016; Safa, 2012). For these reasons, they can be referred to as “megaprojects” in the sense of Sovacool and Cooper (2013). Similarly to other energy megaprojects, NDH would certainly attract a high level of public attention and political interest because of the substantial direct and indirect impacts on the community, environment, and budgets (Van de Graaf and Sovacool, 2014). If NCP is ever integrated into the EU's sustainable energy transition, there will be a number of obstacles to overcome as e.g. inexpediency of business models and regulatory frameworks or electioneering of local authorities. Prospective explorations are important to reduce the likelihood of future projects being overwhelmed by hidden costs and to limit delay in implementation. Given these considerations, this article sets out to answer and discuss the following questions:

i. What are the driving forces for the deployment of nuclear cogeneration in the EU28?
ii. What are the obstacles to the deployment of nuclear cogeneration in the EU28?
iii. What can be done to enhance the recognition of nuclear cogeneration and to prevent the failure of future similar megaprojects?

To that purpose, we led a case study based on the Loviisa 3 NDH project in Finland. Our analysis suggests that NDH megaprojects will always involve trade-offs and invariably will create winners and losers.

The paper is organized as follows: Section 2 is an extensive background Section that introduces NDH to literature on energy policy. It includes a discussion on the driving forces to nuclear cogeneration in the EU28 (2.1), an overview of NDH experiences (2.2), a description of the singular Loviisa 3 NDH project (2.3) as well as the conceptual framework which supported our analysis (2.4). Section 3 describes the methods followed to conduct the case study. Section 4 details the experience and lessons learnt from the Loviisa 3 NDH megaproject. Actions designed to improve the recognition of nuclear cogeneration are also discussed. Finally, our conclusions are drawn in the fourth and last section.

2. Background

2.1. Driving forces to the deployment of nuclear cogeneration with PWR

In the past, long-distance, large-scale NDH have been disregarded because of high losses and inefficiency, considering that the NPP is generally located far away from urban crowed areas. Nonetheless, the extension of DH over the last decades has led to improvements in low-temperature heat distribution, and there is potential to further reduce heat losses (Li and Wang, 2014). This opens new opportunities for energy projects involving the transport of heat over long distances (Ma et al., 2009), such as nuclear cogeneration.

Cogeneration goals are in line with the EU plans for a low-carbon society (EC, 2012a), particularly energy efficiency (EC, 2009, 2012b). The European heat sector accounts for about one third of the carbon emissions in the EU28 (EC, 2016). Although the heating sector is moving towards low-carbon energy, 75% of the heat still comes from fossil fuels (nearly half from gas; IEA, 2015). According to the recent Heat Roadmap Europe, DH is one of the main technologies to deploy if we intend to decarbonize the heat sector and should be increased from the today's level of about 10% of the residential and heat consumption up to at least 50% by 2050 (STRATEGO, 2015a). Application of the Directive 2012/27/EU require the industries and power plants producing large quantities of excess heat to consider connection with DH networks through cost-benefit analysis (EC, 2012b: article 14). However, most EU member states chose to exempt their nuclear plants from analyses. And yet, similarly to excess heat recovered from industrial processes, the carbon emissions avoided by the use of NCP are equivalent to the carbon dioxide emitted by the heat sources that the nuclear heat would effectively replace. Besides, the use of nuclear heat would reduce the energy dependence from imported fossil-fuels.

The directives and programs mentioned above are general and nuclear energy is not specifically mentioned. Nuclear technologies are, however, identified in the EUROPAIRS (2009) project under the European Union's 7th Framework Program (FP7) for European cogeneration markets (Angulo et al., 2012). The sustainable nuclear energy technology platform (SNETP) in collaboration with the EC conducted the ARCHER (2015) project and the Nuclear Cogeneration Industrial Initiative (NC2I, 2015a), which fall in line with the European Union's strategic energy technology plan (EC (European Commission), 2015a). More recently, the Nuclear Energy Agency's working group focusing on the role and economics of nuclear cogeneration in a low-carbon energy future has been targeting the development of a generic method to assess the economic and environmental potential of nuclear cogeneration (NEA, 2015). The shared goal of these programs is to prepare the future nuclear cogeneration technologies and markets. On one hand, future reactors will generate higher-temperature heat, thus widening the range of market applications (Locatelli, 2013; NC2I, 2015b; Ruth et al., 2014). On the other hand, small modular reactors (SMR) are increasingly regarded by policy makers and stakeholders as a viable option to decarbonize both electricity and heat sectors (Carlsson et al., 2012). As for example, the Energy Technology Institute of the United Kingdom recommends to investigate further the potential of small and modular reactors to provide low carbon district heating (Middleton, 2015). A review of potential SMR technologies for cogeneration is presented in Locatelli et al. (2017), while a focus on desalination (one of the most attractive option) is presented in Locatelli et al. (2015). Compared to large nuclear reactors, SMR may be advantageous to address cogeneration markets; and this because:

- SMR may be easier to deploy close to urban areas thanks to high safety standards, thus limiting the major cost of building a heat transport pipeline (Kessides, 2012; Locatelli et al., 2014; Sainati et al., 2015).

- SMR may be faster to deploy (shorter time period from planning to operational phases). This could facilitate the development of suitable business models for those industrial clusters which aim to build and amortize a NCP and industrial plant factories during the same period of time (Greene et al., 2009). If SMR are largely deployed in the future, they could benefit from positive learning by doing effects (Boarin et al., 2012). Hence, in the mid-term, policy makers and stakeholders may expect SMR to be built in a shorter time period than larger reactors.

Overall, it seems reasonable to say that the optimal size of NCP should be determined on a case by case basis. Questions which may help making a choice are e.g. ‘What is the size of the heat demand?’; ‘Is the building of SMR instead of larger reactors likely to allow the sitting of nuclear units closer to consumption sites?; ‘Can we expect a shorter deployment time if building several SMR?”.

Another driver identified resides in the potential synergies which could be generated by the joint use of NCP and renewable energies.