Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

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

Sensitivity analysis and probabilistic assessment of seawater desalination costs fueled by nuclear and fossil fuel

K.C. Kavvadias, I. Khamis *

International Atomic Energy Agency (IAEA), Wagramer Strasse 5, PO Box 100, A-1400 Vienna, Austria

HIGHLIGHTS

- The paper demonstrated desalination costs under uncertainty conditions.
- Uncertainty for nuclear power prevails only during the construction period.
- Nuclear desalination proved to be cheaper and with less uncertainty.

ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form
16 October 2013
Accepted 21 January 2014

Keywords:
Water cost
DEEP
Nuclear desalination

ABSTRACT

The reliable supply of water and energy is an important prerequisite for sustainable development. Desalination is a feasible option that can solve the problem of water scarcity in some areas, but it is a very energy intensive technology. Moreover, the rising cost of fossil fuel, its uncertain availability and associated environmental concerns have led to a need for future desalination plants to use other energy sources, such as renewables and nuclear. Nuclear desalination has thus the potential to be an important option for safe, economic and reliable supply of large amounts of fresh water to meet the ever-increasing worldwide water demand. Different approaches to use nuclear power for seawater desalination have been considered including utilisation of the waste heat from nuclear reactors to further reduce the cost of nuclear desalination. Various options to implement nuclear desalination relay mainly on policy making based on socio-economic and environmental impacts of available technologies. This paper examines nuclear desalination costs and proposes a methodology for exploring interactions between critical parameters.

1. Introduction

The reliable supply of water and energy is an important prerequisite for sustainable development. Nuclear energy could contribute by filling the gap between demand and production. During the past few years, a large number of reactors have been planned in many developing countries owing to their increasing energy demands and their diminishing fossil sources. New constructions are also expected in the USA, Europe and Asia. The main features of nuclear energy are its mature technology, its nearly carbon-free electricity generation source, stable and low costs, even geopolitical distribution of uranium resources and its potential for storage of large quantities of fresh fuel, which allow considering it as a domestic source of energy. The existing NPPs have a steady return of investment for most utilities worldwide.

It is widely acknowledged that the sustainable development of any country is linked with increased electricity and water demand. The increasing demand for energy is being covered mainly by the establishment of new power plants and specifically fossil or nuclear power plants as they can provide electricity in large scale. According to IEA's main scenario it is expected that global demand will grow more than one-third over `the period to 2035 with China, India and Middle East accounting for 60% of this increase (International Energy Agency, 2012). On the other hand the coverage of water demand can be trivial due to the lack of available water resources. Fresh water demand is projected to increase by 55% globally between 2000 and 2050 with emphasis on the countries mentioned above. The increase in demand for electricity affects also the increase of water demand. 25% of global water demand is estimated to be used for electricity generation in 2050; a 140% increase compared to the levels of 2000 (OECD, 2012). It is projected that if no action is taken today, more than two thirds of the population will face water stress or scarcity of clean freshwater by 2025 (United Nations, 2012). The environmental concerns magnify these concerns. Rising fossil energy use

* Corresponding author. Tel.: +431 260 022 822/22815; fax: +431 260 029 598.
E-mail addresses: i.khamis@iaea.org, ibrahim.khamis@gmail.com (I. Khamis).

0301-4215/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2014.01.033

will lead to irreversible and potentially catastrophic climate and for every $1 of investment in cleaner technology that is avoided in the power sector before 2020, an additional $4.30 would need to be spent after 2020 to compensate for the increased emissions change (International Energy Agency, 2012).

The problem of water scarcity can be addressed with the use of desalination, which is considered to be a viable solution to cover potable and industrial water needs. This fact is proven by the almost exponential increase of cumulative contracted seawater desalination projects (Fig. 1) (Global Water Intelligence, 2012). However, desalination is an energy intensive process and requires stable supply of energy. Variations in the cost and availability of energy during its lifetime will affect the cost of desalinated water and increase the investment risk. For these reasons, it is very common to build desalination plants along with power plants in order to establish constant supply of energy while exploiting all the synergy benefits between the two plants. Moreover the colocation of the power plant, results not only to increase of the fresh water supply, but also to reduce the water demand for electricity production, which as mentioned before has a considerable share (25%) of the global water withdrawal. Part of the waste heat that is dissipated to the environment is used to fuel the desalination plant, lowering with that way the water withdrawal needs of the power plant.

Among others alternatives, nuclear energy is a good candidate for driving a desalination process. Steam readily available from the secondary coolant of the power plant is used as and stable supply of low cost energy. The viability and reliability of seawater desalination using nuclear energy has been demonstrated successfully with nearly 200 reactor-years of operating experience have been accumulated worldwide (International Atomic Energy Agency, 2000; Khamis, 2009). Of course, renewable energy could also be seen as a source of energy that meets the overall demand for energy. However, the use of renewable energy sources have to be evaluated carefully by policy making based on its nature (being an intermittent and requires wide areas in case of need for large power generation) which might be very suitable for some applications but not so for others.

The advantages of nuclear desalination are mentioned to be: energy security provided by nuclear energy, avoidance of fossil fuel price volatility, emission free energy, smaller energy penalty to the power production cycle etc. (Barak, 2009; Faibish and Konishi, 2003). Such advantages could well enhance the sustainability development in a country.

Currently, Japan operates desalination plants for make-up water at ten nuclear power plants. India and Pakistan have several demonstration projects in operation, and the Republic of Korea and the Russian Federation are working on design and demonstration projects. China is planning to commission over 100 reactors in the next 30 years, where a desalination plant will be built at least to cover the plant's needs. Other countries are studying the technical and economic viability of different processes and novel ways of coupling a desalination plant with a nuclear reactor.

However, even with the energy security of a co-located power plant, desalinated water costs are very uncertain because they are affected by many parameters that are site-specific but also depend on the overall economic environment: Capital costs, energy costs, fuel and infrastructure costs and labor, discount rate, energy policy instruments (taxes, carbon) etc. In volatile economic environment the accurate projection of all these economic figures is very difficult, and many studies are making arbitrary assumptions in order to estimate the cost. The lowest desalination prices reported were mentioned back in 2005 that fell into the range of 0.5–1$/m^3. However, during the last years, costs of contracted desalination projects have risen due to various reasons: rising energy costs, shortages of labor and raw material, risk premium for unknown markets, rising environmental concerns etc. (Global Water Intelligence, 2010).

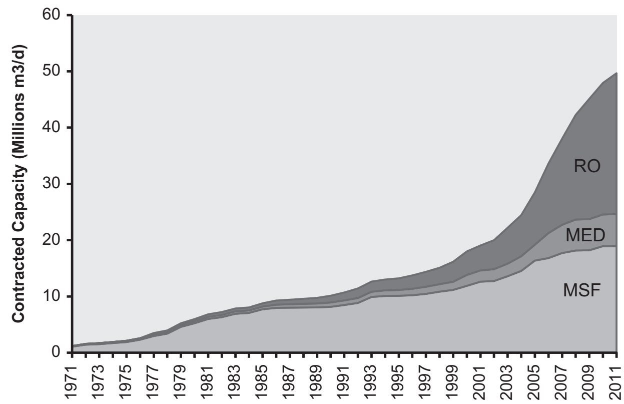

Fig. 1. Cumulative contracted seawater desalination plants for three different technologies.

Earlier studies have shown that while gas prices remain over $21/bbl ($150/toe) nuclear options lead to much lower power and desalination costs compared to those by gas fired plants (Nisan and Dardour, 2007; International Atomic Energy Agency, 2007; Mabrouk et al., 2010). Due to the rapid changes in global energy balances that are affecting all prices costs, data need to be updated to reflect latest changes in fuel and capital costs. Current geopolitical developments and the systematic risk of the fossil fuel prices have caused growing concerns over energy security. Moreover, the uncertainty of critical parameters is often neglected from these estimations and it is not reflected on the economic efficiency of the investment. Unexpected downtimes, delays in the construction, changes in energy pricing policy as well as economic environment instability variations, if not predicted, can lead to unpleasant results. Thus, the quantification of the risk taken should be justified as precisely as possible. One valuable tool for the quantification of uncertainty is Monte Carlo analysis. It has been used many times in recent literature to in order to quantify the uncertainty of cost in the energy sector. Feretic and Tomsic (2005) performed a probabilistic analysis of electrical energy costs comparing gas, coal and nuclear power plant as part of their national study. Locatelli and Mancini (2010) applied this analysis to investigate the effect of carbon tax and electricity energy prices on the economics of a nuclear, a coal and a combined cycle power plant. Vithayasrichareon and MacGill (2012) expanded this concept to quantify uncertainties in order to assess future electricity generation portfolio and policy decision. The above techniques can be successfully used to evaluate uncertainties related with dual purpose desalination plants.

The scope of this work is to identify the critical parameters that are affecting desalination costs perform sensitivity analysis among these parameters and quantify the uncertainty of the alternative dual purpose desalination plants. This method can be applied for various operational and regulatory parameters, and for different growth and volatility scenarios. After the identification of the deterministic relationship between the main cost parameters of different water desalination technologies, the uncertainty involved within these systems is examined. This methodology is based on Monte-Carlo simulation combined with the IAEA's Desalination Economic Evaluation (DEEP) model for the water cost estimation. This probabilistic estimation method is used to compare the expected value of water cost for different scenarios considering its uncertainty. With this method uncertain carbon and fossil-fuel prices or investment costs of any probability distributions can be formulated and used for the estimation of expected energy and water costs and their risk profiles. For a low discount rate nuclear

Please cite this article as: Kavvadias, K.C., Khamis, I., Sensitivity analysis and probabilistic assessment of seawater desalination costs fueled by nuclear and fossil fuel. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2014.01.033