Journal of Cleaner Production 205 (2018) 884–894

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Carbon emissions and costs associated with subsidizing New York nuclear instead of replacing it with renewables

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ARTICLE INFO

Article history:
Received 31 March 2018
Received in revised form
19 July 2018
Accepted 30 August 2018
Available online 7 September 2018

Keywords:
Energy systems decarbonization
Renewable energy
Nuclear power
New York
Scenarios

ABSTRACT

We compare the cost of maintaining a proposed subsidy for New York's three upstate nuclear power plants with the cost of replacing the plants with renewable technologies from 2016 to 2050. Keeping nuclear operating with subsidy until 2050 is the most expensive option, costing $32.4 billion (2014 USD) over that period in the base business as usual case. The least expensive option is to shut down nuclear today and replace it with onshore wind, saving $7.9 billion. All analyzed renewable scenarios lead to 20.1 to 27.4 Mt CO_2 greater life-cycle emission reductions. In addition, re-investing the cost savings of the renewable scenarios into additional onshore wind increase CO_2 savings up to 32.5 Mt.

1. Introduction

In 2015 the state of New York (NY) committed to ambitious climate mitigation goals, aiming to reduce greenhouse gas emission by 40% by 2030 compared with 1990 levels (New York State Energy Plan, (New York State, 2017)). To accomplish this, NY plans to transition from its current electricity generation portfolio—which heavily relies on natural gas-fired systems (41% of total annual power generation) and nuclear power plants (32%) (US Energy Information Administration, 2017a)—to higher shares of electricity from renewable energy (RE) systems. More specifically, by 2030 50% of power generation must come from RE sources (photovoltaic, wind, hydro, and biomass). This is in line with a general trend where states start to aim for more ambitious renewable goals, e.g. through renewable portfolio standards (RPS). The state of California, for example, targets a RE share of 50% by 2030 (and is proposing 100% by 2045), Vermont 50% by 2040, Oregon 75% by 2032, and Hawaii 100% by 2045 (US Energy Information Administration, 2017b).

1.1. Nuclear power - a low carbon alternative to renewables?

Nuclear energy is often seen as a fundamental or bridging technology for future low-carbon systems (International Energy Agency, 2015a; Echavarri, 2013). While it is true that electricity production from nuclear energy is characterized by very low CO_2 emissions during the operation phase of the plant, its full life-cycle CO_2 emissions, including all up- and downstream processes, are typically much more CO_2 intensive. Additionally, several drawbacks of the technology exist, such as operational risks including potential reactor accidents as happened in Chernobyl and Fukushima, concerns in weapon proliferation, waste issues, ecological hazards from byproducts of uranium mining, construction costs of new reactors, and a divided public acceptance (IPCC, 2015; Beckham and Mathai, 2013). The key practical challenge throughout the history of nuclear power development has been the high construction cost, which has been increasing steadily during the last few decades (Davis, 2012). While the operating costs of nuclear plants are relatively lower, the construction costs are currently so high that it becomes difficult to make an economic argument for nuclear even before incorporating all life-cycle costs and aforementioned

Abbreviations: BAU, Business as usual; CAPEX, Capital expenditure; CF, Capacity factor; HCLB, High costs low benefits; LCHB, Low costs high benefits; LCOE, Levelized Cost of Electricity; Nuc, Nuclear power plant; NY, State of New York; O&M, Operation and maintenance costs; OPEX, Operating expenditure; PV, Photovoltaic; RE, Renewable energy; RPS, Renewable portfolio standard; SCC, Social costs of carbon; ZEC, Zero Emission Credit.

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https://doi.org/10.1016/j.jclepro.2018.08.321
0959-6526/

external factors (Davis, 2012). Aside from having a very high capital expenditure cost (CAPEX), new nuclear plants are plagued by planning, permitting, and construction delays (Davis, 2012). In particular, the multi-year planning and construction phase bears the risk of technology lock-ins, where a change to more efficient technologies is almost impossible once investments are made (Beckham and Mathai, 2013). Other low-carbon technologies, including onshore wind and utility-scale solar photovoltaics, generally take much less time between planning and operation. Finally, nuclear power often is heavily subsidized, even to the extent that the overall subsidies actually exceed the value of the generated power (Koplow, 2011; Bradford, 2017).

Nevertheless, even after the severe impacts of the Fukushima accident, nuclear power generation is currently still the backbone of many energy systems, even though the worldwide annual electricity production of "modern" renewables (wind, photovoltaics) has exceeded that of nuclear power in recent years (and even surpasses electricity production from natural gas if hydropower > 50 MW is included) (Lovins et al., 2018). As of 2017, nuclear plants provided 10% (2,557 TWh) of the worldwide electricity generation (International Energy Agency, 2017), increasing its share by 3% compared with 2016. Still, worldwide additional nuclear capacity barely exceeded reductions due to shut-downs in 2017 (International Energy Agency, 2017).

1.2. Literature review

There are various studies that analyze the role of nuclear power as an alternative or complementary technology to renewables. Typically, these studies either focus on techno-economic aspects of nuclear-renewable hybrid solutions (Ruth et al., 2016; Suman, 2018), which combine nuclear reactors with RE systems and industrial processes in order to compensate for shortcomings in each technology, or on region-specific case studies, which analyze the role of nuclear power in decarbonization scenarios (Beckham and Mathai, 2013; Park et al., 2016; Dong et al., 2017, 2018; Strategen Consulting, 2017; Caldwell et al., 2016). We summarize and assess some of the recent literature on such case studies.

Park et al. (2016) study whether nuclear power is cost-effective relative to RE systems in Korea. The authors quantify the willingness to pay of private customers to replace nuclear and fossil power with renewables. This metric is also compared with the actual costs of building and operating renewable systems. While the study of Park et al. (2016) has much value, the analysis uses high cost data for renewables and low cost data for nuclear power from 2014 relative to, for example, Lazard (2014). In addition, the authors do not differentiate between different renewable technologies—such as residential and utility-scale Photovoltaic (PV) or wind power systems—but instead aggregate all renewable technologies and assign one cost per unit of electricity produced. When compared with more recent levelized costs of electricity (LCOE) data (e.g., Lazard (2017)) RE systems are less expensive relative to nuclear power than shown by Park et al. (2016).

Studies of China and India that analyze CO_2 mitigation strategies as well as the efficient use of energy (Tollefson, 2018) acknowledge the importance of RE compared with nuclear power as an alternative. Dong et al. (2018), (Dong et al., 2017), for example, highlight the importance of RE systems for CO_2 mitigation in China. The authors emphasize that, while nuclear can help to reduce CO_2 emissions, its potential contribution is significantly smaller than of RE systems. Moreover, the study concludes that RE systems will become gradually more important over time. Similarly, Beckham (Beckham and Mathai, 2013) argues that nuclear power cannot fulfill the promise of an unlimited energy resource in India and points out that it is impossible to incorporate all ancillary and social costs over the whole life-cycle of a nuclear power plant. Costs are therefore distorted and under-estimated. As the current electricity generation share of nuclear power in India is only around 2%, and the technology is typically associated with large opportunity costs that arise from the time lag between planning and operation of a nuclear plant relative to RE systems (Jacobson et al., 2017), Beckham (Beckham and Mathai, 2013) advises against the expansion of nuclear power in India.

Despite these findings, global installations of new nuclear plants are usually delayed or slowed down (International Energy Agency, 2015b). In addition, the Fukushima accident initialized the phase out of nuclear in some countries, such as Belgium, Germany, and Switzerland. Mathai (2013) describes the policy reactions to Fukushima as a "a pause, nod, shrug policy".

1.3. Nuclear power in New York

NY operates four nuclear power plants at the moment. Recently, the state proposed to subsidize the three upstate nuclear plants Fitzpatrick, Nine Mile Point Unit 1, and Ginna through Zero Emissions Credits (ZEC) to keep them operating rather than investing into new RE capacities (New York State, 2016). This approach was assumed to save costs while relying on a low carbon technology, very much in line with the idea that existing nuclear power as a bridge technology to low carbon scenarios (International Energy Agency, 2015a; Echavarri, 2013). Whether this is the case has already been investigated in several studies for other power plants and sites, e.g. for Diablo Canyon (Caldwell et al., 2016)—the last nuclear plant in California operated by Pacific Gas & Electric—and Indian Point north of New York City (Strategen Consulting, 2017). The former study concludes that replacing the twin reactors of Diablo Canyon with renewables and energy efficiency measures can save up to $5 billion, compared with extending the life-time. The latter finds that $315 million over five years can be saved if Indian Point is replaced with a combination of wind and solar power, electricity storage, and increased energy efficiency.

We evaluate the NY proposal by comparing the nuclear subsidy scenario with several alternative renewable scenarios with regard to cost and life-cycle CO_2 emissions.

The remainder of this paper is structured as follows. Section 2 describes the methodology and the analyzed scenarios. Section 3 presents the results in terms of mitigation costs and CO_2 emissions savings, including a sensitivity analysis of the main drivers. Section 4 summarizes conclusions.

2. Methodology and data

We compare costs based on fixed annuities of the investments and operating expenditures (OPEX). The latter are comprised of fuel costs and variable operating and maintenance (O&M) costs. Fixed O&M costs are included as a share of the CAPEX. All cost assumptions are time-dependent and can change over the observation period (e.g. due to learning effects or resource scarcity that increase fuel prices). Throughout the scenarios, a discount rate of 4.5% and an amortization period of 20 years are assumed. Sensitivity tests are run to test the effects of 3% and 6% discount rates.

Emissions are considered per kWh of produced electricity (kWh_{el}), including emissions that occur over the complete life-cycle of a technology (*cradle to grave*). We use the following values (based on Sovacool (2008), Lenzen (2008) and updated values from Jacobson (2009); nuclear: 66 g-CO_2/kWh_{el}, onshore wind: 10 g-CO_2/kWh_{el}, PV (no difference between utility-scale and rooftop): 30 g-CO_2/kWh_{el}.

The summed installed capacity of Fitzpatrick, Nine Mile Point Unit 1, and Ginna is 2.1 GW (US Energy Information Administration,