ECONOMIC VALUE OF NUCLEAR POWER IN FUTURE ENERGY SYSTEMS; REQUIRED SUBSIDY IN VARIOUS SCENARIOS REGARDING FUTURE RENEWABLE GENERATION AND ELECTRICITY DEMAND

Machiel Mulder, University of Groningen, E: machiel.mulder@rug.nl
Arjen Veenstra, University of Groningen, E: a.t.veenstra@rug.nl

Overview

In order to reduce the absolute levels of carbon emissions, the nature of energy systems has to change dramatically. This is the reason governments are promoting the development and use of renewable energy sources like solar PV, wind turbines, hydropower and biomass. Despite these policies, the growth in renewable energy will likely not be sufficient to reduce carbon emissions to the extent required to meet climate targets. Therefore, the attention is increasingly also going to another non-carbon energy source, which is nuclear power. The Dutch government, for instance, recently declared that it will enable the construction of two new nuclear power plants in the Netherlands. Nuclear power is, however, highly debated, because of its perceived safety, security and environmental risks. Next to that, it is debatable to what extent nuclear power fits within electricity markets which are characterised by high shares of intermittent generation. Because of the presence of these sources, more flexible sources are required which can help the electricity system to remain in balance all the time, but nuclear power is generally seen as a so-called base-load provider with high fixed costs. Therefore, it may economically not be efficient to have such a type of power plant in future electricity markets which are dominated by high shares of renewable generation. In order to shed more light on this topic, we explore the economics of an investment in a nuclear power plant of 1000 MW in the Dutch electricity market when there is already a large installed capacity of renewables.

Methods

The economic value of a nuclear power plant basically depends on four factors: a) the plant characteristics, including its construction costs and construction duration, lifetime, operational and maintenance costs, fuel costs, ramping constraints, costs of handling and storing waste, and decommissioning costs b) the degree of utilisation (which is called the capacity factor), c) the capture price (which is the average electricity price the plant actually receives), and d) the contribution to reducing carbon emissions. While the first factor can be seen as exogenous, the others are very much related to the characteristics and functioning of the electricity market.

In our paper, we analyse how both the utilisation of a new nuclear power plant and its capture price are related to the amount of renewable generation and the magnitude of the electricity demand (i.e. the degree of electrification in for instance industry and transport). In addition, we have analysed the impact on the reduction of carbon emissions by the electricity system. In order to assess these effects, we compare the results with similar increases in offshore wind, onshore wind and solar capacity, taking into account the differences in the respective capacity factors.

For our analysis, we use a partial hourly equilibrium model of an electricity market, with profit maximizing producers and utility maximizing consumers who both respond to market prices. This model is calibrated on the Dutch market situation in 2019 (in terms of prices and market size). We analyze the profitability of an investment in a 1000 MW nuclear power plant as well as investments in similar amounts of solar PV, onshore wind and offshore wine (controlling for differences in capacity factors).

The model analysis is done for a number of scenarios regarding the amount of already installed renewables (related to government objectives) and the increase in electricity demand (related to assumed increases in electrification and hydrogen production). As the installed capacities in these technologies are related to government objectives (and resulting support mechanisms), they can be treated exogenously. The installed capacity of gas-fired capacity, however, results from commercial investments, and, therefore, this has been treated endogenously in the model in order to mimic the long-term dynamics of electricity markets.

Results

From the model analysis, it becomes evident that the LCOE (Levelized Costs of Energy) of technologies are not constant, but that they very much depend on the market situation. In a scenario with a high amount of renewables and only a modest increase of demand, the utilisation of all technologies is reduced. This results from the fact that even low-marginal cost producers stop producing when the electricity prices become too low.

For a nuclear power plant, we find that the capacity factor is strongly reduced, from about 90 to about 60 percent, when the electricity market is characterised by a high share of renewable generation. This effect is partially mitigated when the demand for electricity has increased strongly. In relative terms, renewable technologies experience a similar decrease in capacity factors.

The capture price of the nuclear power plant, however, appears to be less sensitive to the amount of renewables in the system than the capture price for wind and solar. In a scenario with a high installed capacity of wind and solar generation, the capture price of a new nuclear power plant reduces from the current 40 to about 35 euro/MWh. The capture prices for wind and solar (including the prices for green certificates), however, decrease from about 50 to 10 euro/MWh when there exists already a high share of renewables in the market. The reason that the nuclear power plant experiences a much smaller reduction in its capture price is that it is able to benefit from high (scarcity) prices when solar PV and/or wind turbines are not able to produce because of weather circumstances.

Using external information on the construction, operating and decommissioning costs, duration and the lifetime, as well as the model results regarding utilisation rate and capture prices in various scenarios, we calculate the present value of an investment in a nuclear power plant. We compare this present value with the ones for similar investments in solar PV, onshore wind and offshore wind. It appears that, for all scenarios, all these technologies need external subsidies in order to fully recoup their fixed costs.

From these results follows that without any governmental support, commercial investors will likely not invest in a nuclear power plant as in all scenarios such an investment is loss making. For the current characteristics of the (Dutch) electricity market, we also find that a nuclear power plant needs more subsidy (in euro/MWh) than an onshore wind turbine, but less than an solar PV installation and an offshore wind park. In a scenario with a high share of renewables, however, also onshore wind turbines require more subsidies than a nuclear power plant, which is related to the strong decline in the capture price of renewable power plants.

As the promotion of renewable generation and possibly also nuclear power is related to climate policy objectives, we express the required subsidies per technology in terms of the realized reductions in carbon emissions (the so-called abatement expenditures measured in euro per ton of carbon emission reduction). This emission reduction results from the replacement of gas-fired power plants by one of the other techniques (nuclear, solar PV, onshore wind or offshore wind). It appears that in a scenario with a high amount of (already) installed renewables, the abatement expenditures (in euro/ton carbon) for nuclear are significantly lower than for wind and solar generation.

Conclusions

From our model analysis, we conclude that it is more efficient to install a nuclear power plant than renewable technologies to reduce carbon emissions. This holds in particular in scenarios where there is already a large installed capacity of renewables. We also conclude that nuclear power plants benefit more from higher gas or carbon prices than renewables. Because of their high availability factor, nuclear power plants are able to produce electricity when gas-fired power plants set the electricity price, and hence, they experience higher electricity prices when the costs of gas-fired power plants increase. This holds in particular for scenarios with already high amounts of renewables.

Although these economic insights coming from our model analysis are valuable elements in the societal debate on nuclear power, they are of course not sufficient. For the final societal decision whether or not to allow for an investment in nuclear power, also discussion is needed of (equally) relevant aspects, such as safety, security and environmental issues, and the societal acceptance.

References

Arjen Veenstra, Xinyu Li and Machiel Mulder (2022), Economic value of nuclear power in future energy systems. CEER Policy Paper 12.

Jenkins, J., Zhou, Z., Ponciroli, R., Vilim, R., Ganda, F., de Sisternes, F., and Botterud, A. (2018). The benefits of nuclear flexibility in power system operations with renewable energy. Applied Energy, (222):872–994.

Li, X. and Mulder, M. (2021). Value of power-to-gas as a flexibility option in integrated electricity and hydrogen markets. Applied Energy, 304/117863.

MIT (2018). The Future of Nuclear Energy in a Carbon-Constrained World; an interdisciplinary MIT study. Massachusetts Institute of Technology, MIT Energy Initiative.

OECD (2011). Technical and economic aspects of load following with nuclear power plants. OECD-NEA.