Comparing the whole-system costs of baseload power from CSP and nuclear power plants under high renewables scenarios for the case of South Africa

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Overview

Nuclear power is a mature technology which, in 2011, delivered about 12% of total global electricity supply (IEA, 2013). It is advocated by many as a scalable and low-emissions power generation technology and thus potentially crucial to achieve deep reductions in greenhouse gas emissions (e.g., Brook & Bradshaw, 2014). But it is also a technology with low public acceptance, especially in the wake of the Fukushima disaster (Rudolf et al., 2014). In contrast to the long established nuclear sector, large-scale renewable energy has only recently been gaining traction, but is achieving high growth rates and — like nuclear — is generally seen as an essential part of any strategy to reach deep emissions reductions. We here compare CSP (concentrating solar power with thermal storage) and nuclear power as baseload electricity providers for the case of South Africa, which has an abundant solar resource, as well as one existing and further planned nuclear power plants. Both technologies are known to be baseload-capable and are considered scalable to provide large amounts of nearly emissions-free electricity. First, we compare the cost of baseload power from optimized CSP plant configurations with those of nuclear power plants under a range of input assumptions. Second, we simulate hypothetical nuclear and CSP plants deployed in a stylized version of the South African power system under scenarios with high shares of wind and PV capacity. This gives an estimate of the whole-systems cost of a substantial deployment of either nuclear or CSP power.

Methods

Investment and levelized power costs for nuclear plants are computed by assuming different values for capacity factors and by using a range of construction costs from both the literature and recent construction projects. Investment costs and levelized power costs of baseload-capable CSP plants are determined with the Calliope energy systems modeling framework (Pfenninger, 2014). A cost-minimizing linear optimization problem is used to design an optimal configuration of power plants for the given constraints. CSP power output is based on a central receiver plant model (Gauché et al., 2011) using hourly solar irradiance data from the SolarGIS database for the years 2008, 2009 and 2010 (GeoModel Solar, 2012). The model freely chooses the installed power block capacity, solar field size, receiver dimensions, and storage size for each possible site necessary to operate as a baseload provider on an hourly basis. 30 possible sites are spread through those areas of South Africa identified for CSP development, using land coverage data (JRC, 2010) to ensure they are in suitable areas. First, CSP plants given a flat (baseload) demand are simulated, and these results are compared with the estimated costs of new nuclear generation. In addition, various learning rate and global deployment scenarios are used to estimate likely technology cost trajectories through 2030. Following this assessment, a stylized power system model of South Africa is used to simulate some of the likely operational demands on power plants assuming different deployment scenarios with high shares of PV and wind. These, due to their variability, cause difficulties for the operation of a balanced power system if deployed at scale (Skea et al., 2008). For all these models, hourly data is used to capture hour-by-hour variability.

Results

The results suggest that CSP could enter a levelized electricity cost range similar to that of nuclear power in 2030 if it sees sufficient deployment to effect technological learning, and in some cases (at the higher end of the nuclear cost scale), it could already be competitive now. Furthermore, with the currently available CSP and nuclear technologies, CSP plants are a smaller investment with lower financial and environmental risk. Figure 1 shows some of these results. The "CSP dynamic baseload" scenario allows CSP plants to sell additional output beyond their guaranteed baseload supply on days with a good solar resource, thus lowering their levelized costs.

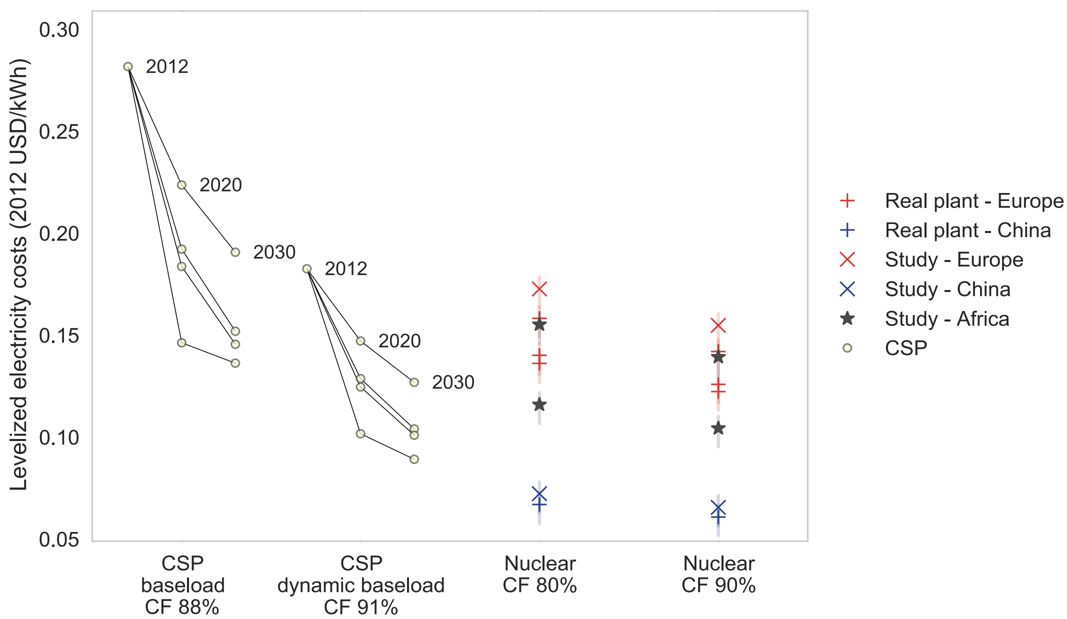

Figure 1: Levelized electricity costs for nuclear and CSP plants, under four different learning rate assumptions for CSP scenarios (CF = capacity factor). For nuclear, the shaded areas show sensitivity analyses for low/high fuel and O&M costs.

CSP plants have the additional benefit of flexibility in adjusting their output to match other variable generation sources, whereas the current generation of nuclear power plants is less able to do so.

Conclusions

While nuclear power is likely to remain an important low-emissions source of electricity for many parts of the world, these results suggest that South Africa (and possibly other countries with a substantial solar resource) could derive low-emissions baseload power from concentrating solar power plants instead.

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