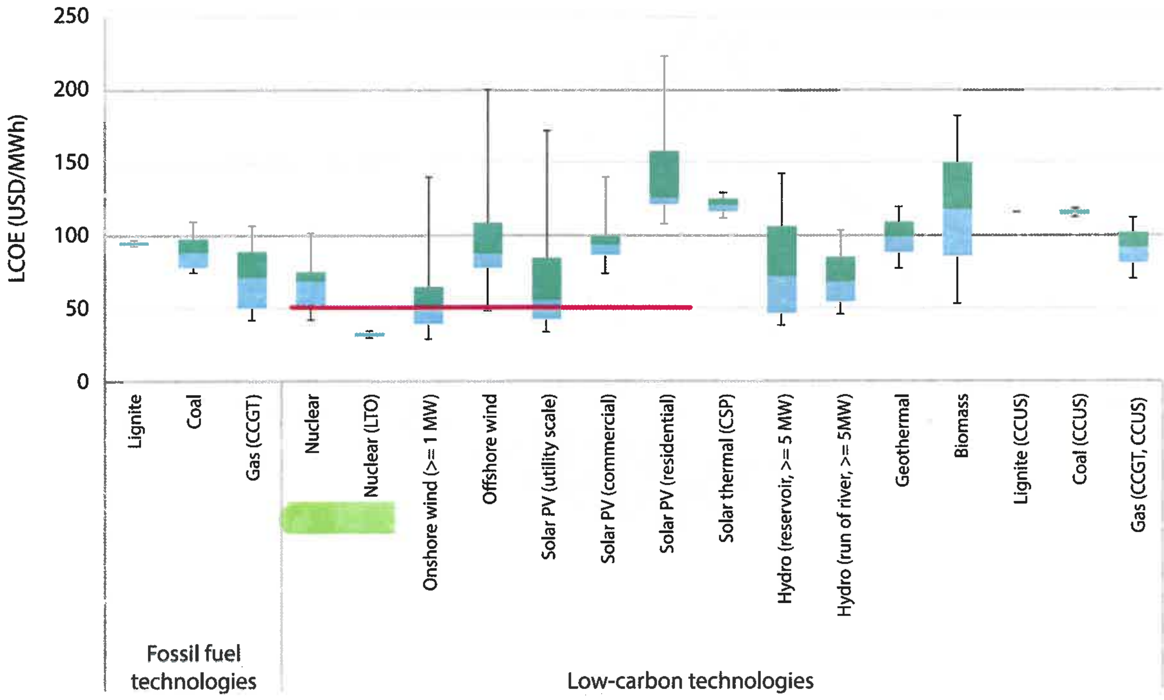
To be clear: while all technologies impose some system costs, variable, intermittent, and uncertain sources of power generation impose far greater grid-level system costs, which is why it is so important to take a systems level perspective when comparing costs of variable renewables with nuclear, baseload hydro, and fossil generation.

Figure 19. **Levelised cost of electricity (LCOE) for different sources of electricity**



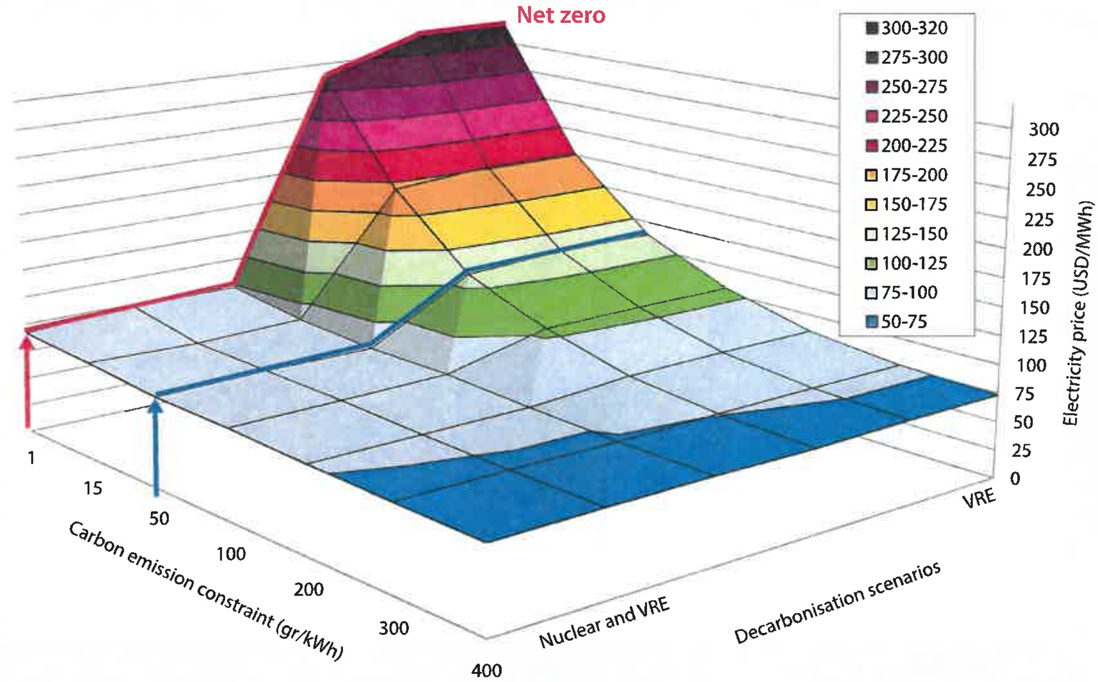
Source: IEA/NEA (2020).

The first step for cost comparisons remains LCOE analysis. Presented in Figure 19, an analysis of system costs from more than 20 IEA and NEA member countries concluded that the lowest cost option for generating electricity is long-term operation of nuclear power plants (IEA/NEA, 2020). Equally notable was the finding about the range of costs for solar and wind generation, which depend heavily on regional endowments and conditions. These results can be reproduced, and tested with different input parameters, with the IEA-NEA online LCOE calculator at: www.oecd-nea.org/lcoe.

LCOE analysis, considering technologies one by one, only tells part of the story though. It is crucial also to assess the interaction of different technologies in a mix of generating sources with different shares in the electricity supply. In order to analyse this, a recent NEA study compared a range of scenarios, starting with a base case with 0% variable renewables, then considering mixes with increasing shares of variable renewables, up to 75% variable renewables in the mix.

Figure 20 shows the break-down of system costs as the share of variable renewables grows from 10% to 75% of the mix, including profile costs (to compensate for variability and intermittency), connection, distribution, and transmission costs, and balancing costs (to compensate for uncertainty). A key finding is that profile costs (to compensate for variability and intermittency) are the dominant driver of increasing total costs as the share of variable renewables grows.

Figure 21. **Total costs for different mixes of electricity (driving to net-zero emissions)**



Source: Based on Sepulveda (2016).

System costs are also a function of overall carbon constraints. Figure 21 shows the total costs (the sum of plant-level and grid-level system costs) as a function of carbon constraints (on the horizontal axis pointing left) and share of variable renewables (on the horizontal axis pointing right). The previous 2-dimensional graph (shown in Figure 20 above) illustrated how total costs increased significantly in scenarios with high shares of variable renewables. On the three-dimensional graph (shown in Figure 21), this is represented by the blue line, which cuts the three-dimensional image at a carbon constraint of 50 grams per kilowatt hour.

The 3-dimensional graph shows the effects on total costs as carbon emissions are increasingly constrained. The red line shows what happens to total costs when carbon constraints reach net-zero emissions. The relationship between the share of variable renewables and systems costs, driven by profile costs to compensate for variability, is even more pronounced when carbon constraints become more stringent.

The policy implications of these systems costs findings are significant. It may be possible to reduce emissions to meet 2030 targets by growing the share of variable renewables in the mix. However, the costs of reaching net zero with high shares of variable renewables are likely prohibitive. *Why?* In part, because initially, as variable renewables are introduced, they can be backed up with a low cost option, which in the absence of a serious carbon constraint is likely to be natural gas. But eventually, in a carbon constrained world, the options for backing up variable renewables become increasingly expensive. Dispatchable hydro power and nuclear energy are the only economic options while batteries remain prohibitively expensive for anything other than very short-term storage.