

Executive Summary

Projected Costs of Generating Electricity

2015 Edition

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INTERNATIONAL ENERGY AGENCY
NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Executive summary

Projected Costs of Generating Electricity – 2015 Edition is the eighth report in the series on the levelised costs of generating electricity. This report presents the results of work performed in 2014 and early 2015 to calculate the cost of generating electricity for both baseload electricity generated from fossil fuel thermal and nuclear power stations, and a range of renewable generation, including variable sources such as wind and solar. It is a forward-looking study, based on the expected cost of commissioning these plants in 2020.

The LCOE calculations are based on a levelised average lifetime cost approach, using the discounted cash flow (DCF) method. The calculations use a combination of generic, country-specific and technology-specific assumptions for the various technical and economic parameters, as agreed by the Expert Group on Projected Costs of Generating Electricity (EGC Expert Group). For the first time, the analysis was performed using three discount rates (3%, 7% and 10%).¹

Costs are calculated at the plant level (busbar), and therefore do not include transmission and distribution costs. Similarly, the LCOE calculation does not capture other systemic costs or externalities beyond CO₂ emissions.²

The analysis within this report is based on data for 181 plants in 22 countries (including 3 non-OECD countries³). This total includes 17 natural gas-fired generators (13 combined-cycle gas turbines [CCGTs] and 4 open-cycle gas turbines [OCGTs]), 14 coal plants,⁴ 11 nuclear power plants, 38 solar photovoltaic (PV) plants (12 residential scale, 14 commercial scale, and 12 large, ground-mounted) and 4 solar thermal (CSP) plants, 21 onshore wind plants, 12 offshore wind plants, 28 hydro plants, 6 geothermal, 11 biomass and biogas plants and 19 combined heat and power (CHP) plants of varying types. This data set contains a marked shift in favour of renewables compared to the prior reports, indicating an increased interest in low-carbon technologies on the part of the participating governments.

Part II of the study contains statistical analysis of the underlying data (including a focused analysis on the cost of renewables) and a sensitivity analysis. Part III contains discussions of “boundary issues” that do not necessarily enter into the calculation of LCOEs, but have an impact on decision making in the electricity sector. The chapter on financing focuses on issues affecting the cost of capital, a key topic given the trends noted above. The chapter on emerging generating technologies provides a glimpse of what the next study may include, as these emerging technologies are commercialised. The final two chapters present cost issues from a system perspective and cost metrics that may, in addition to LCOE, provide deeper insight into the true cost of technologies in liberalised markets with high penetrations of variable renewable power.

1. See Chapter 2 on “Methodology, conventions and key assumptions” for further details on questions of methodology and Chapter 8 on “Financing issues” for a discussion of discount rates. To aid in comparability with prior studies, results for a discount rate of 5% are presented in Chapter 5, “History of Projected Costs of Generating Electricity, 1981-2015”.

2. The report does not attempt to calculate the impact of CO₂ emissions or non-monetarised externalities associated with fossil-fired plants (e.g. in their fuel production) or with nuclear power plants (e.g. in their fuel cycles).

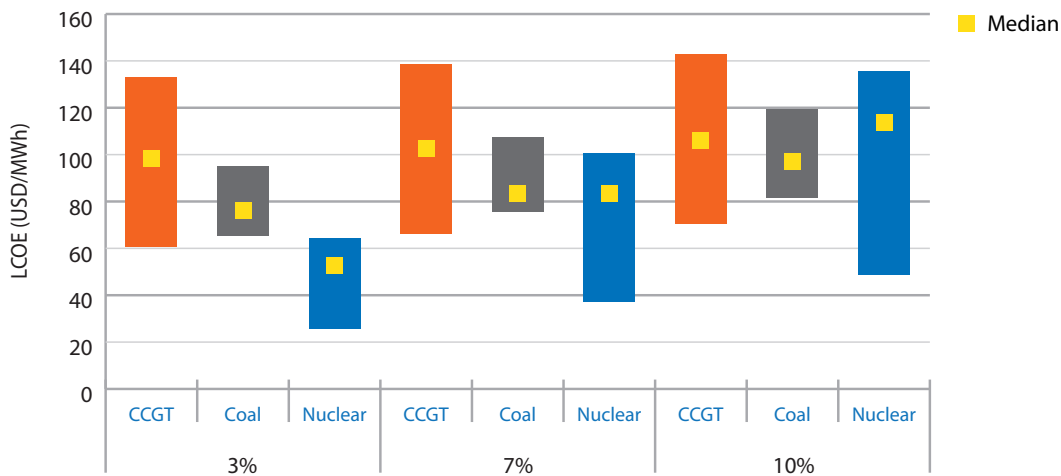
3. Brazil, China and South Africa.

4. Contrary to the 2010 study, plants with carbon capture and storage (CCS) were excluded from this analysis.

Results

Figure ES.1 shows the range of LCOE results for the three baseload technologies analysed in this report (natural gas-fired CCGTs, coal and nuclear). At a 3% discount rate, nuclear is the lowest cost option for all countries. However, consistent with the fact that nuclear technologies are capital intensive relative to natural gas or coal, the cost of nuclear rises relatively quickly as the discount rate is raised. As a result, at a 7% discount rate the median value of nuclear is close to the median value for coal, and at a 10% discount rate the median value for nuclear is higher than that of either CCGTs or coal. These results include a carbon cost of USD 30/tonne, as well as regional variations in assumed fuel costs.

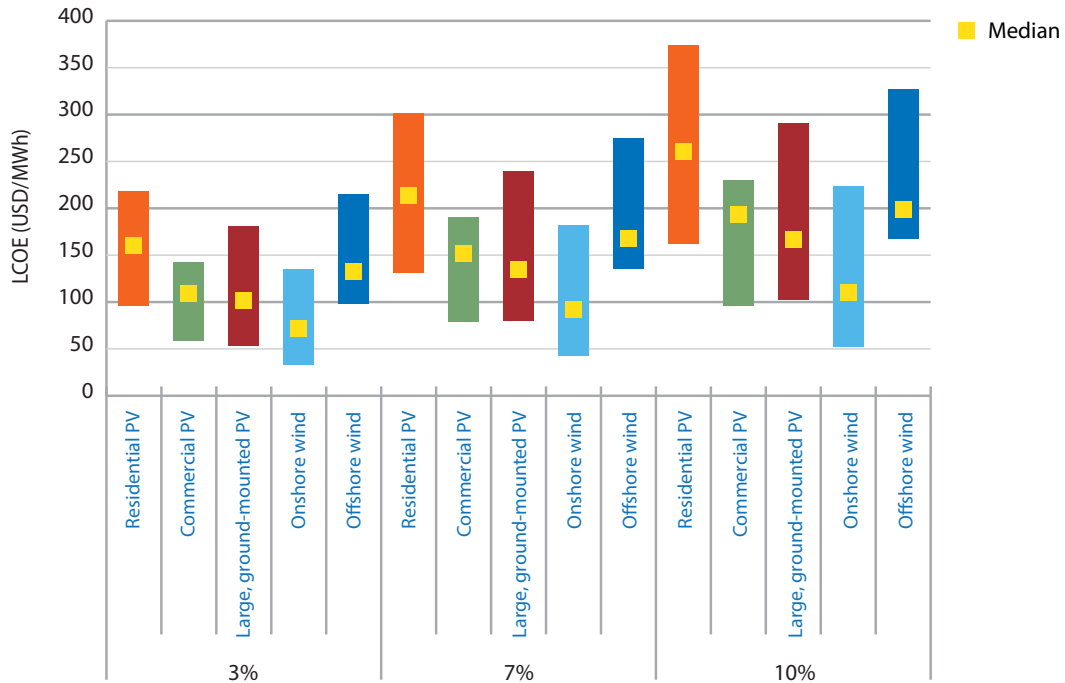
Figure ES.1: LCOE ranges for baseload technologies (at each discount rate)



The ranges presented include results from all countries analysed in this study, and therefore obscure regional variations. For a more granular analysis, see Chapter 3 on “Technology overview”.

Figure ES.2 shows the LCOE ranges for various renewable technologies – namely, the three categories of solar PV in the study (residential, commercial and large, ground-mounted) and the two categories of wind (onshore and offshore). It is immediately apparent that the ranges in costs are significantly larger than for baseload technologies. It is also notable that the costs across technologies are relatively in line with one another. While at the high end, the LCOE for renewable technologies remains well above those of baseload technologies, at the low-end costs are in line with – or even below – baseload technologies. Solar PV in particular has seen significant declines in cost since the previous study, though onshore wind remains the lowest cost renewable technology. The median values for these technologies are, for the most part, closer to the low end of the range, a reflection of the fact that this chart obscures significant regional variations in costs (in particular for solar PV). This is not surprising, because the cost of renewable technologies is determined in large part by local resource availability, which can vary significantly among countries or even within countries.

Figure ES.2: LCOE ranges for solar PV and wind technologies (at each discount rate)



The ranges presented include results from all countries analysed in this study, and therefore obscure regional variations. For a more granular analysis, see Chapter 3 on “Technology overview”. Based on IEA analysis and commentary from the EGC Expert Group, an alternative measure to median value was also included in this study, namely the generation weighted average cost. For more on that topic, see Chapter 6 on “Statistical analysis of key technologies”.

To better interpret the results, it is important to bear in mind several relevant issues. First, as already noted, there is significant variation among countries both in terms of the technologies presented and the reported costs. While the IEA and NEA Secretariats, with the support of the EGC Expert Group, have worked to make the data as comparable as possible (by using consistent assumptions when possible, and by verifying the underlying data both with the participating countries as well as with other reliable sources), variations in cost are to be expected even in the case of technologies that are considered standardised. Local cost conditions are highly dependent on, for example, resource availability, labour costs and local regulations.

Further, even with highly accurate cost data, some assumptions will also have a degree of uncertainty. Future fuel costs, for example, may be significantly different from the costs assumed in this report. In fact, as the report was being finalised, commodity prices such as oil and natural gas declined significantly. These uncertainties cannot fully be captured in the core analysis of the report, though they are addressed to some extent in Chapter 7 on the “Sensitivity analysis”. With that in mind, the results of the *Projected Costs of Generating Electricity* study (“EGC study”) can be reviewed in more detail.

Baseload technologies

Overnight costs for **natural gas-fired CCGTs** in OECD countries range from USD 845/kWe (Korea) to USD 1 289/kWe (New Zealand). In LCOE terms, costs at a 3% discount rate range from a low of USD 61/MWh in the United States to USD 133/MWh in Japan. The United States has the lowest cost CCGT in LCOE terms, despite having a relatively high capital cost, which demonstrates the significant impact that variations in fuel price can have on the final cost. At a 7% discount rate, LCOEs range from USD 66/MWh (United States) to USD 138/MWh (Japan), and at a 10% discount rate they range from USD 71/MWh (United States) to USD 143/MWh (Japan).

Overnight costs for **coal plants** in OECD countries range from a low of USD 1 218/kWe in Korea to a high of USD 3 067/kWe in Portugal. In OECD countries, LCOEs at a 3% discount rate range from a low of USD 66/MWh in Germany to a high of USD 95/MWh in Japan. At a 7% discount rate, LCOEs range from USD 76/MWh (Germany) to USD 107/MWh (Japan), and at a 10% discount rate they range from USD 83/MWh (Germany) to USD 119/MWh (Japan).

The range of overnight costs for **nuclear technologies** in OECD countries is large, from a low of USD 2 021/kWe in Korea to a high of USD 6 215/kWe in Hungary. LCOEs at a 3% discount rate range from USD 29/MWh in Korea to USD 64/MWh in the United Kingdom, USD 40/MWh (Korea) to USD 101/MWh (United Kingdom) at a 7% discount rate and USD 51/MWh (Korea) to USD 136/MWh (United Kingdom) at 10%.

Solar PV and wind technologies

Solar PV technologies are divided into three categories: residential, commercial, and large, ground-mounted. Overnight costs for residential PV range from USD 1 867/kWe in Portugal to USD 3 366/kWe in France.⁵ LCOEs at a 3% discount rate range from USD 96/MWh in Portugal to USD 218/MWh in Japan. At a 7% discount rate, LCOEs range from USD 132/MWh in Portugal to USD 293/MWh in France. At a 10% discount rate, they range from USD 162/MWh to USD 374/MWh, in Portugal for both cases.

For commercial PV, overnight costs range from USD 1 029/kWe in Austria to USD 1 977/kWe in Denmark. LCOEs range from USD 69/MWh in Austria to USD 142/MWh in Belgium at a 3% discount rate, USD 98/MWh (Austria) to USD 190/MWh (Belgium) at a 7% discount rate and USD 121/MWh (Portugal) to USD 230/MWh (Belgium) at a 10% discount rate.

Overnight costs for large, ground-mounted PV range from USD 1 200/kWe in Germany to USD 2 563/kWe in Japan. LCOEs at a 3% discount rate range from USD 54/MWh in the United States to USD 181/MWh in Japan, USD 80/MWh (United States) to USD 239/MWh (Japan) at a 7% discount rate and USD 103/MWh (United States) to USD 290/MWh (Japan) at a 10% discount rate.

Onshore wind plant overnight costs range from USD 1 571/kWe in the United States to USD 2 999/kWe in Japan. At a 3% discount rate, LCOEs range from USD 33/MWh in the United States to USD 135/MWh in Japan, USD 43/MWh (United States) to USD 182/MWh (Japan) at a 7% discount rate and USD 52/MWh (United States) to USD 223/MWh at a 10% rate (Japan).

Finally, overnight costs for **offshore wind plants** range from USD 3 703/kWe in the United Kingdom to USD 5 933/kWe in Germany. LCOEs at a 3% discount rate range from USD 98/MWh in Denmark to USD 214/MWh in Korea; at a 7% discount rate, they range from USD 136/MWh (Denmark) to USD 275/MWh (Korea); and at a 10% discount rate, they range from USD 167/MWh (United States) to USD 327/MWh (Korea).

Results from non-OECD countries

The study also includes data from three non-OECD countries: Brazil (hydro only), the People's Republic of China and South Africa. In the particular case of China, data was derived from a combination of publicly available sources and survey data – in particular, the IEA Photovoltaic Power Systems Programme (PVPS) survey. They cannot, therefore, be considered official data from China for the *Projected Costs of Generating Electricity* study. Nevertheless, it is important to consider the possible costs of generation in China as part of this study.

The estimated overnight cost for a CCGT in China (the only non-OECD data point in the sample) is USD 627/kWe, while the LCOE is USD 90/MWh, USD 93/MWh and USD 95/MWh at 3%, 7%, and 10% discount rates respectively. For coal, cost estimates are included for China, with an overnight cost of USD 813/kWe, and South Africa, with an overnight cost of USD 2 222/kWe. The LCOEs for China are USD 74/MWh at a 3% discount rate, USD 78/MWh at a 7% discount rate and USD 82/MWh at a

5. Costs in France, for residential rooftop, include additional costs specific to roof-integrated solar systems.

10% discount rate. For South Africa, the range is larger: USD 65/MWh at 3%, USD 82/MWh at 7% and USD 100/MWh at 10%. The report includes two nuclear data points for China, with overnight costs of USD 1 807/kWe and USD 2 615/kWe; LCOEs are USD 26/MWh and USD 31/MWh at a 3% discount rate, USD 37/MWh and USD 48/MWh at 7% and USD 49/MWh and USD 64/MWh at 10%.

For solar PV, China has the lowest cost commercial PV plant in the database, with an overnight cost of USD 728/kWe; LCOEs are USD 59/MWh, USD 78/MWh and USD 96/MWh at 3%, 7% and 10% discount rates respectively. The overnight cost for the large, ground-mounted PV plant is USD 937/kWe; the LCOEs are USD 55/MWh, USD 73/MWh and USD 88/MWh at 3%, 7% and 10% discount rates. Finally, for onshore wind, overnight costs for the two estimates from China are USD 1 200/kWe and USD 1 400/kWe. While in South Africa, the single onshore wind plant in the database is USD 2 756/kWe; LCOEs are USD 77/MWh, USD 102/MWh and USD 123/MWh at 3%, 7% and 10% respectively.

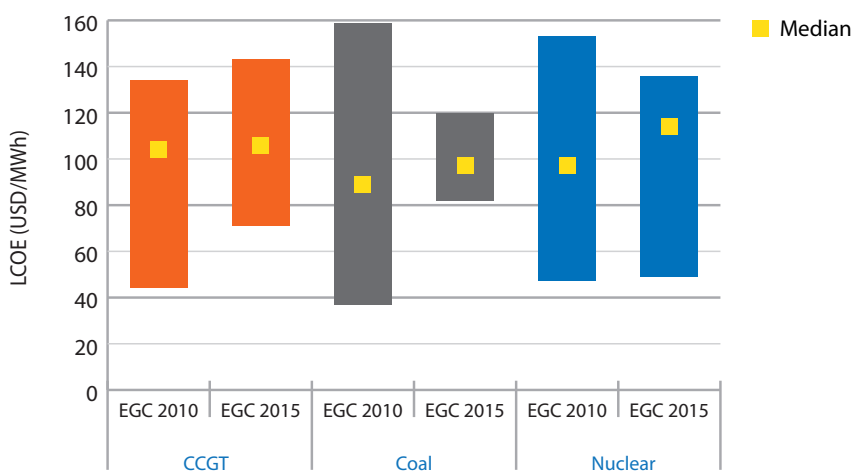
Details on other technologies included in the report, such as OCGTs, solar thermal, hydro, biomass/biogas and CHPs can be found in Chapters 3 and 4.

Comparison with EGC 2010

While changes in assumptions and differences both in terms of size and composition of the underlying dataset make cross-study comparisons difficult, it is nevertheless useful to examine, at a high-level, how cost estimates have changed over time.⁶ Figure ES.3 compares the range of LCOE results for baseload technologies in the most recent 2010 edition of *Projected Costs of Generating Electricity* (EGC 2010) and in the current study.

The EGC 2010 results show a wider range of LCOEs, in particular for coal-fired generation. This is in part due to the fact that EGC 2010 contained a greater number of data points for each technology than there are in EGC 2015,⁷ but also because of changes in fuel price and other underlying assumptions. While the range of LCOE values is smaller in EGC 2015, it is notable that the median value for each technology is higher than in EGC 2010. While the median value is an imprecise measurement for comparing costs between technology categories and across countries, the fact that the median value is higher in each case does suggest the possibility of increasing costs for each of these technologies on an LCOE basis.

Figure ES.3: EGC 2010 and EGC 2015 LCOE ranges for baseload technologies
(at 10% discount rate)



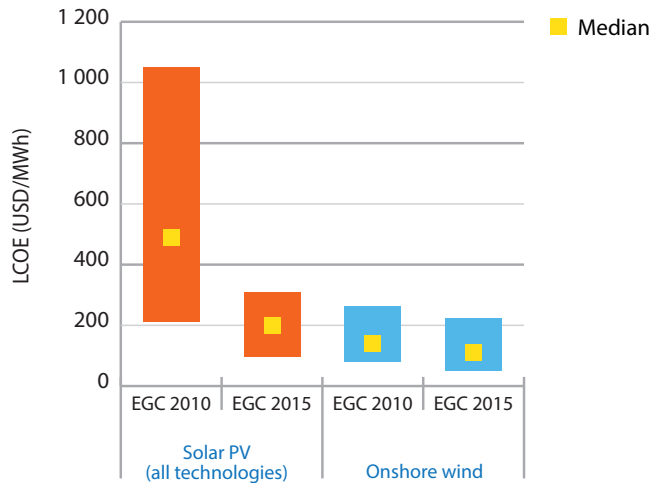
EGC 2010 results have been converted to USD 2013 values for comparison.

6. For a more detailed examination of the history of the Projected Costs of Generating Electricity study, see Chapter 5.

7. EGC 2010 contained 23 CCGTs (without CCS), 31 coal-fired plants (without CCS), and 20 nuclear power plants, compared to 13 CCGTs, 14 coal-fired plants and 11 nuclear plants in EGC 2015.

For renewable technologies (specifically, solar PV and onshore wind), the change relative to EGC 2010 is in the opposite direction. This can be seen most clearly in the LCOE values for solar PV, where, despite a larger number of data points in EGC 2015,⁸ there are both a smaller range of LCOE values and a very significant decline in costs. Onshore wind LCOEs are also noticeably lower in EGC 2015, though the difference is much less pronounced.⁹

Figure ES.4: EGC 2010 and EGC 2015 LCOE ranges for solar and wind technologies
(at 10% discount rate)



EGC 2010 results have been converted to USD 2013 values for comparison.

Conclusions

This eighth edition of *Projected Costs of Generating Electricity* focuses on the cost of generation for a limited set of countries, and even within these countries only for a subset of technologies. Caution must therefore be taken when attempting to derive broad lessons from the analysis. Nevertheless, some conclusions can be drawn.

First, the vast majority of the technologies included in this study are low- or zero-carbon sources, suggesting a clear shift in the interest of participating countries away from fossil-based technologies, at least as compared to the 2010 study.

Second, while the 2010 study noted a significant increase in the cost of baseload technologies, the data in this report suggest that any such cost inflation has been arrested. This is particularly notable in the case of nuclear technologies, which have costs that are roughly on a par with those reported in the prior study, thus undermining the growing narrative that nuclear costs continue to increase globally.

Finally, this report clearly demonstrates that the cost of renewable technologies – in particular solar photovoltaic – have declined significantly over the past five years, and that these technologies are no longer cost outliers.

Despite the general relevance of these conclusions, the cost drivers of the different generating technologies nonetheless remain both market- and technology-specific. As such, there is no single technology that can be said to be the cheapest under all circumstances. As this edition of the study makes clear, system costs, market structure, policy environment and resource endowment all continue to play an important role in determining the final levelised cost of any given investment.

8. EGC 2010 contained 17 solar PV technologies, compared to 38 in EGC 2015.

9. The median value presented in these figures may not fully represent renewable energy costs, as it gives equal weight to markets or data points which may be less relevant globally. For a more detailed discussion on the cost of renewable energy – and, in particular an alternative measurement to the median value – see Section 6.1 of the full report.

Projected Costs of Generating Electricity

This joint report by the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) is the eighth in a series of studies on electricity generating costs. As policy makers work to ensure that the power supply is reliable, secure and affordable, while making it increasingly clean and sustainable in the context of the debate on climate change, it is becoming more crucial that they understand what determines the relative cost of electricity generation using fossil fuel, nuclear or renewable sources of energy. A wide range of fuels and technologies are presented in the report, including natural gas, coal, nuclear, hydro, solar, onshore and offshore wind, biomass and biogas, geothermal, and combined heat and power, drawing on a database from surveys of investment and operating costs that include a larger number of countries than previous editions.

The analysis of more than 180 plants, based on data covering 22 countries, reveals several key trends, pointing, for example, to a significant decline in recent years in the cost of renewable generation. The report also reveals that nuclear energy costs remain in line with the cost of other baseload technologies, particularly in markets that value decarbonisation. Overall, cost drivers of the different generating technologies remain both market-specific and technology-specific.

Readers will find a wealth of details and analysis, supported by over 200 figures and tables, underlining this report's value as a tool for decision makers and researchers concerned with energy policies, climate change and the evolution of power sectors around the world.