The cost of electricity: a poorly understood concept

Executive Summary

Calculating the cost of electricity, most of the time in $/KWh, is necessary but complex.
Many different methods of calculation can be used but they are always incomplete. We have studied 4 of them: LCOE, VALCOE, LFSCOE and the cost of electricity when limiting the emissions to 50 gCO2 per KWh.

We used 4 principal studies: The LCOE+ of the LAZARD bank; The VALCOE of the IEA; The LFSCOE of the Bank of America and the [50g/KWh for 2050] modelling of the NEA.

LCOE (Levelized Cost of Electricity) and its limits.

The LAZARD bank evaluates the cost of electricity by the Levelized cost of electricity (LCOE), which gives the cost of the produced electricity *at the exit of the plant*. It is the most used method due to its relative simplicity. The LAZARD study is much referenced by environmentalists, but it is not the only one, as the IEA also uses this approach. Their resulting costs are quite different, because they make other assumptions…

Even if the LAZARD experts consider that storage costs have to be added to the costs of Variable Renewable Energy (VRE), the LCOE is a limited method which doesn't consider the additional costs needed to deliver the produced electricity to the customers, like the cost of intermittency.

VALCOE (Value Adjusted LCOE), more precise but still limited.

To calculate to VALCOE, the IEA takes 3 different values into account: the energy value (market value of the produced electricity of a technology), the capacity value (ability of a technology to reliably meet demand, contributing to the adequacy of the system) and the flexibility value (non-energy ancillary services needed in power systems).

This leads to slightly more realistic costs but still doesn't consider enough global system costs and external costs to deliver the produced electricity to the customers.

LFSCOE (Levelized Full System Cost of Electricity) and its differences.

The Bank of America calculates the cost of electricity by using the LFSCOE method. This differs from the other methodologies as it calculates the cost of electricity in the (hypothetical) case that one single energy source delivers 100% of the electrical needs. By doing this, the BoA ends up by having the cost of energy as it is delivered instead of produced.

The cost of renewables is vastly superior even if the BoA reduces the scope to delivering only 95% of the needs. The effects of other percentages of the production delivered by one single source have not yet been calculated by the BoA. This was the specific purpose of the NEA modelling.

Modelling of the system cost for low-carbon electricity in 2050.

The OECD-NEA has issued a study of the total system costs cost of electricity in 2050, based on real weather data for a full year and the constraint that the whole production system could only emit 50g of CO2 per kWh.
This study concludes that going beyond around 30% of VRE is economically inefficient for a country in Europe such as France, even if the costs of renewables are assumed to be the lowest.

Conclusion.

Every cost calculation method has its pro's and con's and assuming that one method can understand and reflect everything is a wrong assumption. VRE may be low-cost in generating electricity, but they truly appear to be more expensive than any other technology when it comes to deliver dispatchable electricity to the customers.

We also learned, based on an extrapolation of the 4th study by the MIT, that the costs increase exponentially when going deeper in reducing carbon emissions and increasing VRE penetration, leading to the conclusion that reducing nuclear under 50% is economically inefficient, if decarbonisation remains a priority.

Synthesis of the 4 well-known studies to evaluate the cost of electricity per technology

An increase in electricity demand due to the development of A.I, reindustrialisation, data centre deployment & more leads to a growing need to understand and calculate the cost of electricity generation at system level, integrating all elements of the chain from the production to the consumer.

Continuous innovations in technology, financing and policy are needed to fully enable the Energy Transition, including an electricity mix that is diverse and advanced enough to meet the ongoing reshaping of our energy economy. It will also require continued maturation of specific technologies not included in the current analysis (carbon capture, use and sequestration ("CCUS"), long duration energy storage, new nuclear technologies (Generation IV and fusion), etc..).

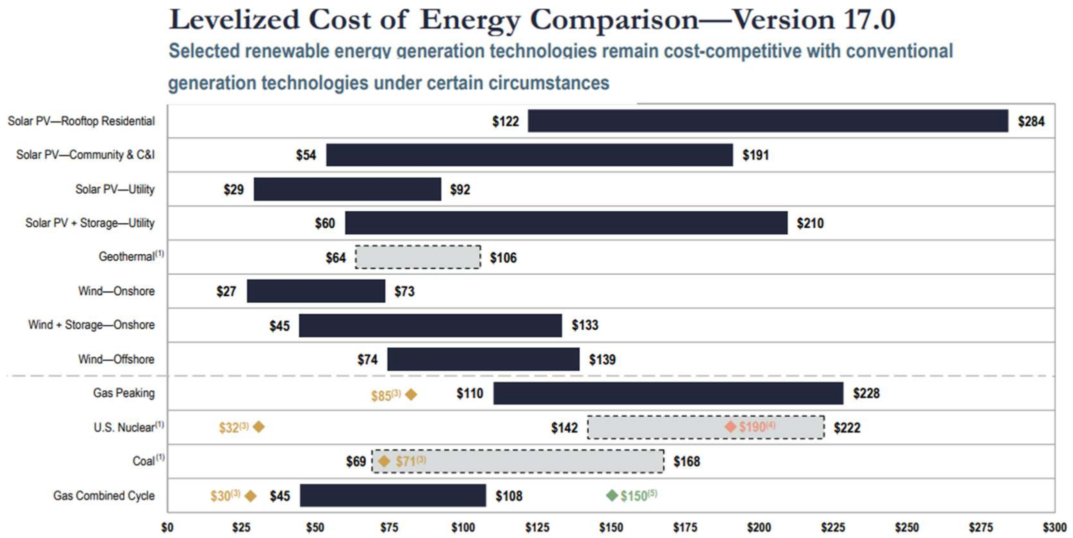
LCOE+ of LAZARD.

The first method used to calculate the cost of electricity is the Levelized cost of electricity (LCOE) explained in the LAZARD study named "LAZARD LCOE+". Lazard is a global financial advisory and asset management group. This group makes comparative LCOE analysis for various generation technologies on a $/MWh basis, including sensitivities for U.S. federal tax subsidies, fuel prices, carbon pricing and cost of capital.

Many assumptions are made in the study, here are some of them: Solar has a chosen capacity factor between 30 & 15%, wind 55 to 30% and nuclear between 92 & 89%; furthermore, storage O&M (Operation & Maintenance) is between 3.63$ & 8.18$/MWh when combined with renewables.

Lazard recognises that the displacement and composition of the new mix will be affected by many factors, including those outside of the scope of the LAZARD LCOE+: grid investment, economic policy, continued advancement of flexible load, locally sited generation and more. It also does not consider the side costs effects of the intermittent nature of selected renewables energy technologies, particularly the grid impacts of incremental renewable energy deployment. And it does not address potential social and environmental externalities. To make it simple the LCOE looks at the cost of electricity at the exit of the production installation without any consideration of the induced costs on the wider electricity system due to the specific nature of this installation (in particular the impact of intermittency).

Results:



Nuclear appear more costly than most renewables but even when the LCOE doesn't take many variables into account, residential solar is as much or more expensive than nuclear and community solar can be also equal in price to nuclear. Also, if we take storage into account (which is needed for most varying power generation) then solar can be as costly as nuclear even when produced as utility. Wind seems more competitive, but the storage is not taken into consideration for offshore wind which is already as costly as onshore wind + storage.

Lazard also shows that using existing nuclear generators is incredibly cost efficient but doesn't consider any additional investment cost for keeping nuclear generator working beyond the design lifetime in Long Term Operation.

Using a limited method like LCOE leads to the conclusion that renewables are on average better than nuclear except for private and some community solar generators and that maintaining existing nuclear plants in operation is incredibly cost effective. It also shows that the impact of indirect costs like grid adaptation or storage shouldn't be underestimated, the cost of solar utility + storage is at least twice the cost of solar utility.

Important to mention that the study is done for the US situation and does not therefore represent specific European or Belgian situations.

Economic analysis of OECD International Energy Agency (IEA-NEA):

The IEA (International Energy Agency) produces analyses on all energy sources and technologies, on global and regional markets, as well as specific country-level reports and studies on key technologies, minerals, and materials for the clean energy transition. Each five years the IEA produces a report comparing the LCOE of different ways to produce electricity: the Projected Costs of Generating Electricity PCGE studies (last one in 2020). This mean that most datas are more than 5 years old and that the data collected is limited by the participation and situations of different countries. For example, the investment cost or lifetime of nuclear in an Asian country is different than in a European one.

Here are some assumptions made in this study:

- The net capacity is used (generated capacity minus consumed capacity during operation of the generator).
- The common capacity of production of generators is set at 85% for dispatchable sources (nuclear, coal and CCGT), it is above average for coal and CCGT and under average for nuclear. This study also doesn't consider the economic advantage of multiple-unit plants (new build inside these plants can be 10 to 15% cheaper and easier to make approved). This can be considered if taken into account by the member country giving the data inputs of the Overnight Investment Costs values.
- For OCGTs (open cycle gas turbine), a capacity factor of 30% is assumed.
- Capacity factors vary significantly in different markets
- Each technology has an expected lifetime (60 years for nuclear and 25 years for renewables).
- The assumed load factor of solar is 18-20% & wind is 39-42%.
- Transmission and grid connection costs were disregarded, as the LCOE figures presented in the report exclusively consider plant-level production costs. This is an impactful choice.

Results

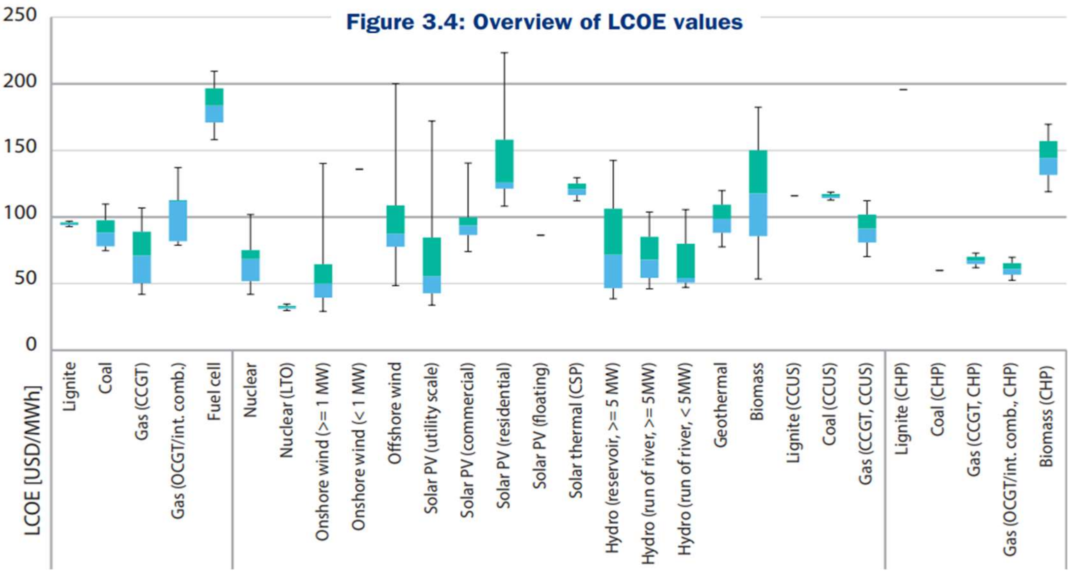


Figure 3.4: Overview of LCOE values

This study has similarities with Lazard, for example the LTO (long term operation: lifetime extension) is also the most economically practical but, differently from the Lazard LCOE, the LCOE value of nuclear is equal or better than the value of most renewables. And in this study an investment cost for the refurbishment allowing Long Term Operation (an additional 20-year operation) is included, making the calculation more accurate for existing nuclear plants beyond their design lifetime.

Thus, the LCOE is useful when comparing energy production technology of similar added benefice and usage but vary greatly between studies and fall short when we need to compare wildly different energy production methods which require different added costs at global electricity system level.

VALCOE of OECD International Energy Agency (IEA-NEA):

The VALCOE captures the value of three system services: energy value, flexibility value and capacity value by technology. The sum of the differences between these technology-specific value streams and the system average values form the basis of the "value-adjustments" to move from the LCOE to the VALCOE.

- Energy value is the market value of the produced electricity of a technology that varies by region and penetration of variable renewables (penetration = % of renewables).
- Capacity value reflects the ability of a technology to reliably meet demand, contributing to the adequacy of the system.
- Flexibility values encompass non-energy ancillary services needed in power systems, such as primary and secondary reserves, frequency regulation and synchronous inertia.

The variations depend on when the electricity is generated: Nuclear has minimal value adjustments due to values close to the system average (produce constantly), renewables are less competitive (produce all at the same time = lower prices) & gas are more competitive (produce during heavy demand = high prices).

But VALCOE is not the only alternative to LCOE!

Levelized Full System Costs of Electricity of Rice University-Bank of America:

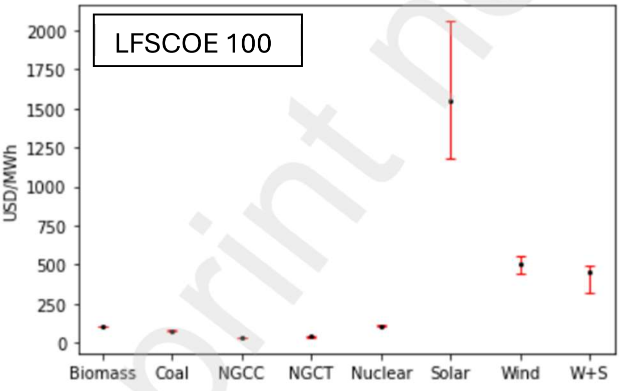
The Bank of America Corporation is an American multinational investment bank and financial services holding and Rice University is a well ranked university in Texas.

They refer to another method of evaluation: the Levelized Full System Costs of Electricity (LFSCOE), a novel cost evaluation metric that compares the costs of serving the entire market using just one source plus storage. LFSCOE condense the cost for each technology into one figure per market. The paper calculates LFSCOE for several technologies using data from two different markets (Texas & Germany). It then discusses some refinements, including the LFSCOE-95 metric that require each technology to supply only 95% of total demand.

Intermittency of generation makes the cost comparison between different generation technologies much more difficult. While being a good measure to evaluate the cost to generate electricity, the most popular cost measure, the LCOE, fails to include the costs associated with meeting the demand and providing usable electricity. On the other hand, the System Levelized Costs of Electricity include the cost of integration and balancing, but do not seem to be simple enough to make it to a broader audience. Therefore, BoA introduced the LFSCOE: taking all system costs into account to get one final figure, which makes it easier to understand, even if the assumption to rely on only one single mode of production for the entire demand is unrealistic.

We choose Germany over Texas due to its proximity to Belgium and thus results closers to the Belgian reality.

Result



We can observe that the costs of renewables are far above those of nuclear. This indicates that despite the potential lower plant level cost of production for solar or wind (in particular if equipment is coming from low revenue countries in Asia) the cost of storing and delivering this cheap energy appears to be prohibitive.

The LFSCOE-95 are only slightly lower than the LFSCOE for dispatchable technologies, but they are about **50% lower** for intermittent sources, which challenges the economic feasibility of 100% intermittent renewable targets. This is due to the residual demand curve (the demand not met by others productors) for the generator being flattened by the free generation, which increases the average capacity factor (this also led to reduced variability between years).

We regret the lack of other percentage like 80 or 70% that could be far more realistic and more interesting on the short term. LFSCOE introduced in this paper condense the cost of providing electricity to one number per market and technology. With LFSCOE being much higher than the LCOE for wind and solar, it becomes clear that LCOE are far from being an accurate measure to include the cost of intermittency.

LCOE and its variants may be useful for a particular producer, but they are not the proper way to evaluate the costs of delivering this electricity to the final consumers. Therefore, one needs to properly integrate the system costs beyond the plant-level costs.

Beyond LCOE-Integrating system costs by OECD-NEA.

NEA (Nuclear Energy Agency) is an intergovernmental agency that facilitates co-operation among countries with advanced nuclear technology infrastructures to seek excellence in nuclear safety, technology, science, environment and law. Many costs exists when it comes to energy, but a large amount are ignored, here are some important ones:

- Profile cost: Increase in the generation cost of the electricity system due the variability of VRE (Variable Renewable Energy) output.
- Connection cost: Costs of connecting a power plant to the nearest connecting point of the transmission grid (very variable)
- Grid cost: Building of new infrastructures (grid extension) & increasing the capacity of existing infrastructure (grid reinforcement).
- Balancing cost: Increasing requirements to ensure the system stability due to the uncertainty in the power generation.

The study tries to take the four costs and more into consideration and uses an imaginary (but realistic) situation composed of two area, one using France data (including weather data for a given full year) and the other being the average of neighbouring countries including Belgium and Germany. The interconnection capacity is 7.2 GW and beside hydroelectricity all generators are considered as new ones or with no prior existence (may disadvantage nuclear due to the inability of LTO).

From this, many scenarios were created:

- 6 scenarios: Base case [1] without VRE + five cases where the fraction of VRE is imposed to the model 10; 30; 50 & 75% Renewables (VRE) [2 to 5] + one case where the model is free to run to define the most economic situation – it is called the Low cost VRE (since very low costs for VRE equipment was considered in this case)) [6]
- 2 sensibility scenarios: No interconnection [7] + Same as [7] but without flexible hydroelectric [8]

Due to resource limitations, this modelling effort did not focus on the technical feasibility of power systems with high shares of VRE. It's also limited to a year and an imaginary (but created using real data) country.

VRE's production.

It is important to understand that the production of renewable energy infrastructure is coupled, they produce (or not) at the same time. This leads to hours where the value of electricity is near or equal to zero and hours of extremely high prices. This effect is part of the "cannibalisation" effect where VRE's compete with each others and reduce their own production value.

Pricing issues

The VREs bring new costs that are not always internalized and thus not considered during economical studies which negatively change the interest in those studies and the ability of decision makers to understand the situation.

The development of VRE's (and its high variability) has short- and long-term impact on the grid and the electricity market.

Short term

- Reduction of the level of wholesale electricity market prices when VRE are generating (merit order effect).
- Reduction of the load factor of existing generators (compression effect).

Long term

Creation of a new residual load curve (mainly affect baseload plants):

- Low VRE: demand = production so flattening of the curve (impact peak & middle generators).
- High VRE: demand ≠ production so steeper curve.

Flexibility options

The flexibility of a system is an important subject who can be improved in many ways:

Power plants are currently the major sources of energy flexibility, but this may change with the increasing penetration of VRE's.

Storage can be used as a tool to increase flexibility, but it will require heavy investment and adaptation of the grid.

Network development or in other word the development of the capacity to transport electricity is also an option.

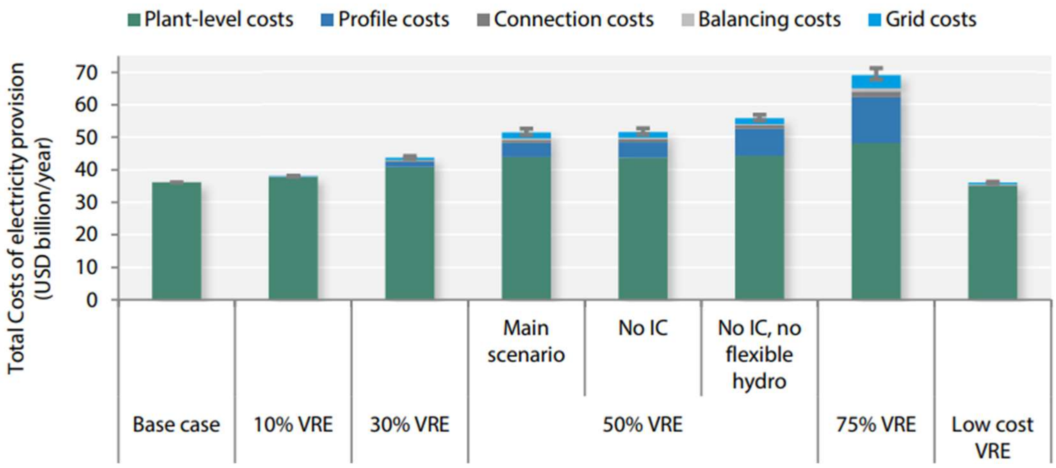
Operational flexibility of VRE’s is the curtailment and control of energy generators.

Demand-side response is the ability of the users to change and adapt their consumption.

Result

Figure 74. **Total electricity generation costs in function of the share of VRE**

(USD billion per year, common emission target of 50 gCO_2 per kWh)

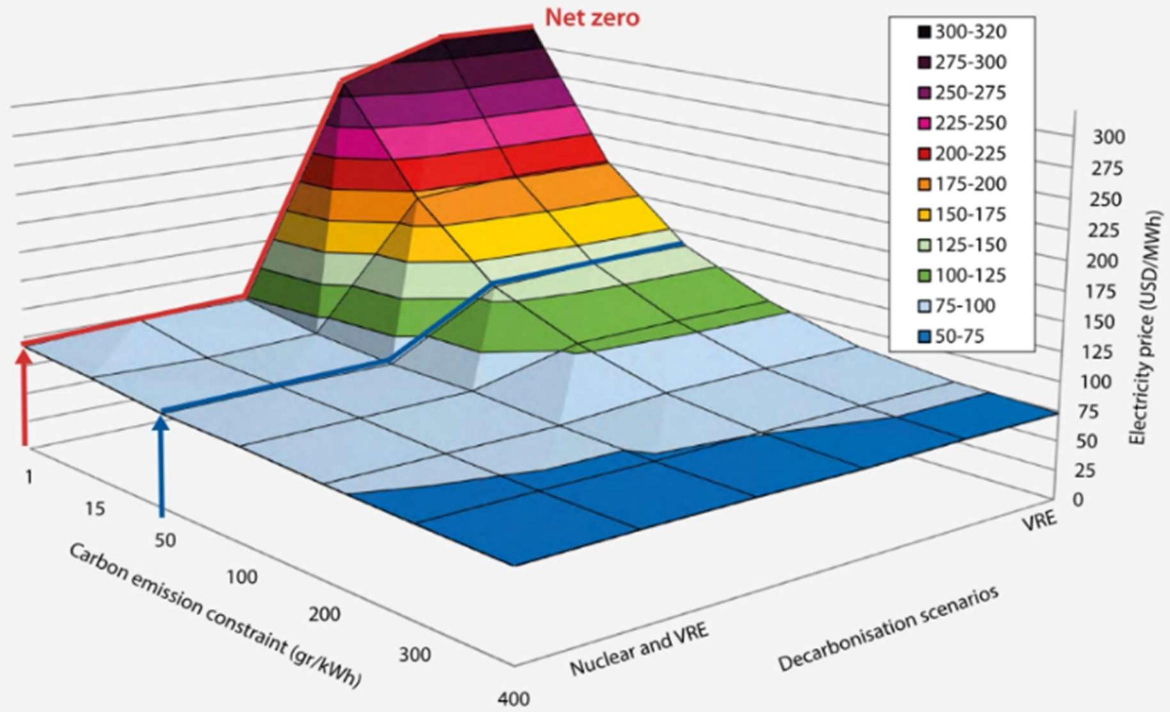


Out of all Scenarios the one that seems to combine cost efficiency and usage of renewables is the 30% renewables one. Any more than that and the economic interest sharply decline. This is interesting because the Low-cost model where the % of renewables weren’t set also reached around 30% showcasing than even with reduction in price the best economical choice remain the same.

Conclusion

We can observe from the previous studies that increasing the penetration of renewables beyond 30% or reducing nuclear under 50% seems incompatible with the decarbonisation at reasonable cost. Here is a 3-axis graphic created by the MIT that explains the effect of exponentially increasing costs based on the decarbonisation and % of renewable energy.

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



Source: Based on Sepulveda (2016).

We also learned that the cost of electricity depends on the assumptions made at the beginning of the study. This is shown in the comparative table. Where the costs of nuclear is lower and the cost of renewables higher the best we take system cost into consideration. Thus, if we were to trust only the LCOE renewables are far better than they are, this could lead to misinformed decisions.

ENERGY	LCOE (Lazard	LCOE (IEA)	VALCOE	LFSCOE 100%	LFSCOE 95%
Solar rooftop residential	122 284	130 158	130 158	1185 2058	849
Solar Community & C&J	54 191	-	-		
Solar Utility	29 92	45 74	55 84		
Solar Storage + Utility	60 210	-	-		
Geothermal	64 106	92 105	92 105	-	-
Wind Onshore	27 73	40 60	45 65	438 552	279
Wind Onshore + Storage	45 133	-	-		
Wind Offshore	74 139	74 110	79 115		
Gas (peaking)	110 228	-	-	-	-
Nucclear	142 222	51 59	49 64	101 113	90
Gas combined cycle	45 108	50 90	20 70	34 36	31
Coal	69 168	85 99	65 79	76 82	67
Nuclear in place	31 33	40 40	35 45	-	-

We choose for the IEA LCOE to only take the datas between the first and last quartiles to have more telling results.

LCOE's are useful for individual producers but are far less precise for larger studies.

It is also interesting to compare the cost obtain for the continuation (LTO) of the nuclear already in place with the LTO of the "NEA REPORT LTO 2021". They are very similar in their range which reinforce the argument that conserving and improving current nuclear reactor is a good choice.

Table 6.1: LTO LCOE values for LWRs as a function of the LTO period, discount rate, overnight costs and the capacity factor

Overnight LTO investment costs (USD/kWe)	LWR LTO LCOE (USD/MWh)					
	LTO period = 10 years			LTO period = 20 years		
	Discount rate			Discount rate		
	3%	7%	10%	3%	7%	10%
	Capacity factor = 85%					
450	29.4	31.2	32.6	26.4	28.6	29.7
700	33.4	36.1	38.3	28.7	31.4	33.8
950	37.4	41.1	44.1	31.0	34.7	38.0
	Capacity factor = 75%					
450	31.9	33.9	35.5	28.4	30.5	32.2
700	36.5	39.5	42.0	31.0	34.2	36.9
950	41.0	45.1	48.5	33.6	37.9	41.6
Min	29.4			26.4		
Max	48.5			41.6		

Note: These values have been computed assuming a refurbishment period of two years, fixed O&M costs of USD 85/kWe, variable O&M costs of USD 1.5/kWe, front-end fuel costs of USD 7/MWh and back-end fuel costs of USD 2.33/MWh, consistent with the values for new build projects considered in IEA/NEA (2020). The overnight LTO investment cost includes other plant enhancements beyond LTO and 5% of contingencies. Decommissioning costs are not included as they have largely depreciated during the initial design lifetime.

Those results are interesting and need to be considered when setting the electricity price, for example a CFD (Contract for Difference), which is a negotiated price, like the one being debated for France need to be realistic and adapted to be efficient, which is difficult because they are mostly based on LCOE studies who are limited in their considerations.

An example of CFD is the UK one which put the energy price ate GBP 92.50 per MWh (121 $/MWh at the actual conversion rate). This price lies between the LCOE evaluations of IEA and Lazard.

No method is perfect, but many can be more useful and complete than LCOE to judge the economical prospect of a generator.

There exists other consideration that cannot be represented with a cost, like for example the security and reduced incertitude of nuclear energy compared to renewables. This is an appreciated benefits in Finland for example.