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Assessing the Renewable Electric Generation Projects with LCOE Methodology

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1. Introduction

The energy industry is a complex and highly competitive sector where companies grapple with diverse costs that yield a significant financial impact on performance and the ability to provide consistent and reliable energy to consumers. The costs range from fuel and labor to regulatory compliance and environmental remediation. Notably, in the transition to renewable energy, companies are now endorsing various costs associated with the energy transition. Understanding costs is a pivotal aspect of sustainable decision-making. There are many factors to consider, collectively shaping the feasibility, efficiency, and environmental impact of various energy sources and technologies. The main element to analyze is the Levelized Cost of Electricity (LCOE), a fundamental metric that goes beyond the upfront expenditure, encompassing the entire lifecycle of an energy source. It encapsulates the initial capital investment, operating and maintenance expenses, fuel costs, and even the duration of the asset's lifetime.

Several energy sources in Italy have been evaluated with LCOE-based methodology, and a comparison has been made between them; moreover, the impact of financial cost on LCOE has been analyzed. The LCOE calculation tries to determine an estimate of the effective price to which energy has to be sold in that specific market. In fact, the LCOE can also be considered the electrical price to have the NPV equal to zero.

For the government, the knowledge of LCOE is of great importance to determine a different set of incentivized tariffs for electrical production, also called feed-in tariff, to promote sustainable development of each renewable energy to offset the impact of CO_2 emission of fossil fuel electrical production. In Italy, they are referred to as the FER decree, which are prices set by the government comparing them to LCOE that allow the government to set prices above or at the same price of LCOE.

2. Energy Transition

The growth in renewable energy has been leading the transition to the green economy, eventually leading to net zero. In order to reach that goal, renewable companies are heavily invested in projects such as wind, solar, hydroelectric, geothermal, and nuclear power plants. These projects produce electricity without emitting greenhouse gasses. Further investments into renewables reduce reliance on fossil fuels, which cause most of the current greenhouse gasses. A complete shift in the job market will increase jobs as more renewable energy companies grow and need more workers than fossil fuels companies. Landowners of specific areas will benefit from leasing their territory by allowing companies to develop projects on their land. Energy mix is an essential benefit since it vastly increases energy security. Companies will help create a more resilient, efficient, and reliable energy system by having various renewable energy technologies. By investing in renewable energy, technologies will keep improving, leading to further cost reduction in power plants due to economies of scale. By making renewable technology more affordable and accessible to a broader range of consumers. Rising competition will help companies improve their technology to beat competitors in implementing the most advanced technology. Recent technology advancements include energy storage systems, smart grids, wind, and solar. Energy storage systems allow for energy storage when there is peak production and release in periods of low production. Energy can be stored with batteries, further increasing the development of battery technology to increase energy storage efficiency. Smart grids are another area of improvement by providing real-time consumption in households, allowing consumers to control the use of electricity in high peak demand. Wind turbines have also been improving in technology through advancements in the sharpness of the blade, the way systems are controlled, and raw materials. This allows for cost reduction and increased efficiency. Corporate social responsibility has risen among companies from pressure from investors and other companies setting renewable energy goals. Large companies commit to switching entirely to renewable energy, demonstrating their commitment to sustainability.

Enabling Sdgs through Inclusive, Just Energy Transitions, www.un.org/sites/un2.un.org/files/2021-twg_3-exesummarie-061721_0.pdf. Accessed 6 Sept. 2023.

Community projects are also a way for companies to further invest into renewable energy. This is through solar, wind, and geothermal projects, and the government may also provide additional incentives in order to implement them or develop research in certain areas.

2.1 Renewable Energy

The renewable energy market has seen strong growth in the past years from international efforts, such as the Paris Agreement, to reduce carbon emissions, allowing the opening of additional markets and fields for vast renewable development. The amount of renewable energy plant capacity installed worldwide is 2800GW in 2020. Due to market and cost structures, markets for individual economies have developed differently. The levelized cost of electricity generation has fallen below the cost of conventional fossil fuel generation. As the LCOE keeps decreasing it is expected that by 2025 onshore wind will have the lowest, on average, levelized cost of electricity generation. Five years ago, the median LCOE was at USD 150/MWh, which is now notably below USD 100/MWh. In order to follow the trajectory to achieving the goals set by the Paris Agreement, there would need to be a global reduction of 25%-30% in emissions. The United Nations general council has called all countries to cancel all plans to develop coal plans further. Market trends reflect that a transition from fossil fuels to clean energy is necessary and widely supported by shareholders, investors, and consumers. For example, BlackRock, the world's largest asset manager, is incorporating climate impacts into its government decisions. With extensive asset managers moving away from investing in fossil fuels, more companies are investing in renewable resources. Policies can be effective only with a holistic framework, where deployment policies that combine financial and fiscal incentives with market pull mechanisms and technology push mechanisms go in hand with enabling policies. Policies that support and enable renewable energy deployment and integration, as well as policies that ensure industrial and other economic capabilities are aligned with COVID-19 recovery, development, and climate priorities, as well as other environmental objectives.

"A Systemic Approach to the Energy Transition in Europe." Research and Innovation, research-and-innovation.ec.europa.eu/strategy/support-policy-making/scientific-support-eu-policies/group-chief-scientific-advisors/systemic-approach-energy-transition-europe_en. Accessed 6 Sept. 2023.

To support the green energy sector, industrial policies will be critical in supplying the productive structures. This happens particularly in developing countries where associated capabilities are scarce, and market pressures may impede optimal outcomes. Renewable energy, in this sense, provides favorable possibilities for localized inputs due to the relative ease of knowledge transfer and the labor intensity of its low and medium-skilled job sectors. The world now stands at a turning point, where most nations are striving to build resilient energy systems. Most of the new power plants that are being installed are from renewable energy sources further underpinning sustainable development. Nations are moving away from older energy systems and supply chains that now are no longer beneficial to the planet. Global energy supply dynamics are shifting, creating significant opportunities and challenges for all.

The growth of renewable energy over the past decade suggests that nations relying on fossil fuel revenue to drive their economies will be challenged by falling demand and increased pressure to decarbonize. Renewable power is now often the most economical option and with end-use sectors investing larger sums every year in decarbonization, the role of fossil fuels in global energy will start to dwindle. Many oil-rich nations are responding to this by looking to diversify their economies and further investing in clean energy sources. This provides an opportunity for all countries even if the migration away from fossil fuels can present challenges for some countries. The energy transition gives nations the opportunity to harness their native resources and move towards greater energy independence. It provides a chance for countries to establish new trade links through regional power collaboration. Flexible energy systems mean interconnected and integrated markets can respond quickly to shift supply to meet demand. Many developing countries will require international technical and financial support to implement the transition, and this will be more readily available as an increasing number of multilateral and bilateral development finance institutions have announced a halt to investments in coal.

“What Is Energy Transition?” *S&P Global Homepage*, www.spglobal.com/en/research-insights/articles/what-is-energytransition#:~:text=Energy%20transition%20refers%20to%20the,well%20as%20lithium%2Dion%20batteries.

Assessing the Economic Value of New Utility - Scale Electricity ..., www.eia.gov/renewable/workshop/gencosts/pdf/lace-lcoe_070213.pdf. Accessed 6 Sept. 2023.

The upcoming trends will depend heavily on decisions in a small number of economies. Cost-competitiveness and resilience will play a substantial role in determining which low-carbon alternative will prevail in different settings. Moreover, the main issues that nuclear power plants face are the time required for development meaning that it will be harder for them to play a significant role in the energy transition.

No single route exists to cleaner, fairer, and more sustainable energy systems. Each country must pursue its path, using data and evidence to make informed, long-term decisions while coordinating with each other. Countries must consider the direction of energy markets, investments, and technology, together with the changing needs of their citizens. They must embrace the principles of creating circular economies as a vital route to economic development and climate preservation. Resources should be focused where there are the most synergies with socio-economic and environmental policies, such as air quality, water, and waste policies. Institutions providing financial instruments such as climate and green financing and climate bonds should also avoid concentrating only on mature technologies and markets so that they can focus on getting other technologies and systems up to speed.

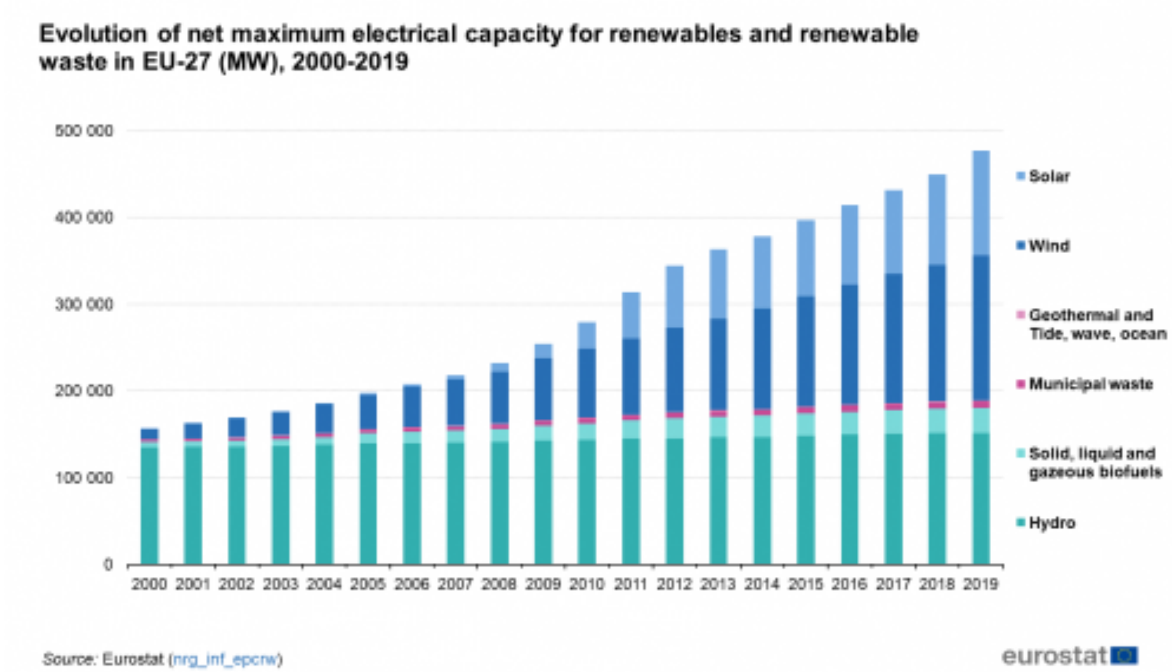
2.1.1 Energy Efficiency

According to the IEA, in order to meet the demand-side efficiency improvements goals set by the Paris Agreement, total emissions abatement should be around 40%, particularly in the near term. Demand-side abatement also offers economic, employment, and social benefits. However, the rate of improvement in energy intensity has declined for three years in a row. Moreover, aggressive efficiency strategies must be implemented in order to increase the share of renewables. At the time of its establishment, the sustainable development goal 7 target of doubling the annual improvement rate of energy efficiency was 2.6% per year. Recent studies by IRENA and the IEA use respectively 2.7% and 3.2% as average improvements from 2020 to 2050 in their scenarios for net zero. With these different estimates on the annual rate of improvements, there seems to be a convergence of views around a rate of 3% per annum.

Halm, Isabeau van. "Europe: Renewables in 2022 in Five Charts – and What to Expect in 2023." *Energy Monitor*, 27 Feb. 2023, www.energymonitor.ai/tech/renewables/europe-renewables-in-2022-in-five-charts-and-what-to-expect-in-2023/?cf-view.

2.1.2 EU Energy Systems

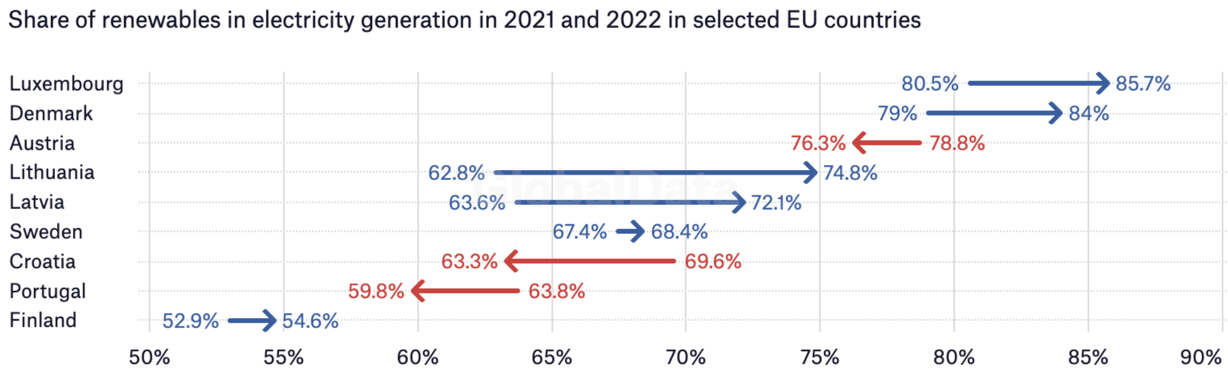
Image 1: Evolution of net maximum capacity for renewables and renewable waste in EU-27.



The European energy grid is rapidly moving towards greener solutions by increasing the net maximum electrical capacity year by year. The EU is working towards achieving the goal of net zero by 2050 and to reduce 55% of emissions by 2030. The share of renewable energy in the EU doubled from 2004 to 2019. Wind and hydropower are the greatest generators of electricity, while solar has been rapidly growing almost reaching the same level as hydro and wind production. Wind and solar energy alone represented more than 20% of the energy in the EU, overtaking gas.

"Statistics Explained." *Statistics Explained*, ec.europa.eu/eurostat/statistics-explained/index.php?title=Electrical_capacity_for_wind_and_solar_photovoltaic_power_-_statistics#Evolution_of_electricity_production_capacity_by_main_fuel_groups.

Image 2: Share of renewables in electricity generation in 2021 and 2022 in selected EU countries.



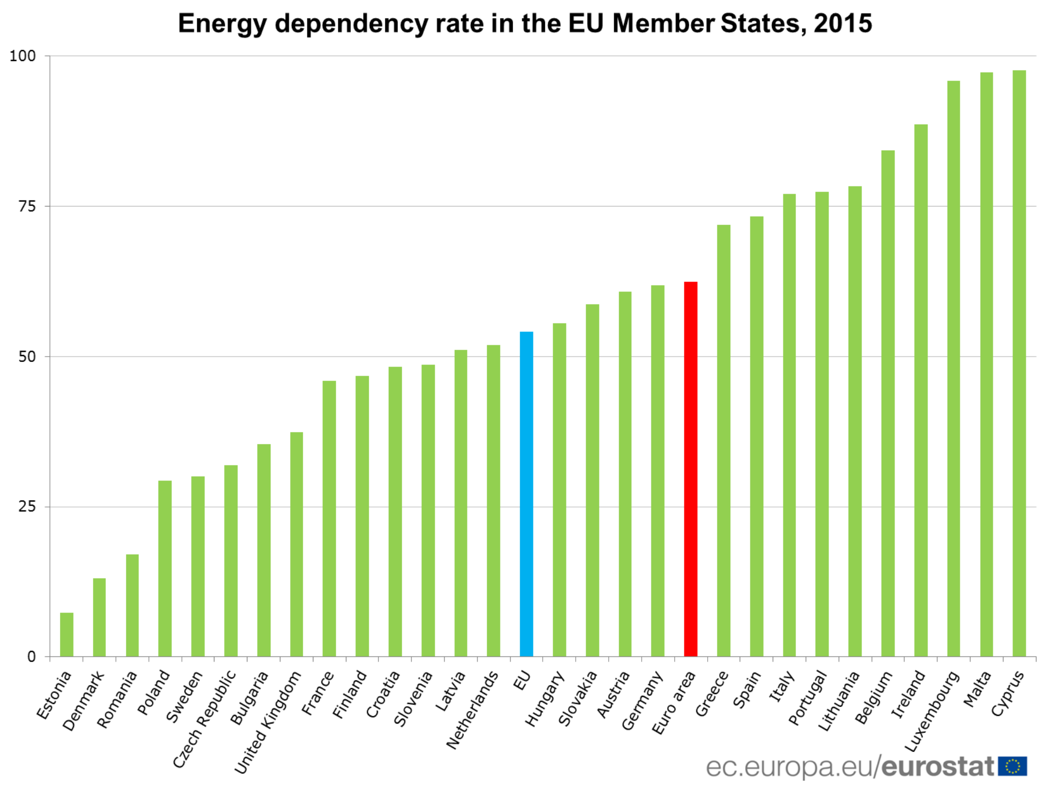
Nine of the EU countries are already past 50% of the total energy generated by renewable energy. Luxembourg had the most energy generated from renewable sources marking 85.7% of energy from renewables in 2022. Lithuania was the country with the highest increase in installation from 62.8% to 74.8%.

2.1.3 Energy Dependency in the EU

The European energy systems are very heterogeneous, and each member state has its own peculiarities, energy structure, and lock-ins. Past experiences in the member states show that those with good access to energy storage capacity have been able to effectively handle high shares of weather-dependent variable renewable electricity and thus pursue a faster track in decarbonizing their energy systems. In contrast, other countries need help to reach carbon targets. Two solutions could be to potentiate the power transmission capacity between EU countries and to integrate the electricity systems further, thereby achieving more flexibility to increase shares of intermittent and decentralized sources and mitigate variability problems. The other solution is that interconnection can also be the source of potential vulnerabilities as an example, similar adverse weather conditions could raise energy demand simultaneously in several neighboring zones, putting the overall supply under stress.

Dave Jones, Head of Data Insights, et al. "European Electricity Review 2023." *Ember*, 1 Mar. 2023, ember-climate.org/insights/research/european-electricity-review-2023/.

Image 3: Energy dependency rate in the EU Member States, 2015



Investments for the stability of the electricity grid and additional cross-border electricity transmission are needed to be able to integrate electricity from different renewable sources at different scales. Investment in additional cross-border electricity transmission networks will reduce the need for national and regional infrastructures for managing peaks in electricity production and use. This will complement strategies and incentives to avoid demand peaks. The need for short-term investments should be balanced with the long-term requirements of the industrial investment cycle. It should further connect remote regions and strengthen possibilities for existing cross-border interconnections, electricity highways, and pipelines for gases from renewable sources. Making carbon pricing a central driving force of the energy transition gives a clear sense of direction. Firm long-term commitments provide security for short-term investment decisions that will enable the energy transition in the long term.

"More than Half the Energy the EU Uses Comes from Imports." *More than Half the Energy the EU Uses Comes from Imports - Products Eurostat News - Eurostat*, ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20170220-1. Accessed 6 Sept. 2023.

2.1.4 Carbon Pricing

Carbon pricing, as a crucial element of a combination of policy measures, would reduce overall emissions, and it would become the prime objective. Market prices would reveal the cost of avoiding emissions for different actors and in different sectors. Carbon pricing would lead to additional public revenue, means to prevent carbon leakage and preserve the principle of technology neutrality. Carbon pricing should cover the entire life-cycle of products, from the mining of rare metals and iron needed, production of steel and plastic materials, batteries, putting the product together, to final dealing with waste. The EU would be in an excellent position to incentivize other economies and act as a driver of coordinated action. In this sense, where developed countries should pursue stricter targets than less developed ones in the Paris Agreement, the EU should insist on reciprocal commitments by other countries and, in particular, be wary of unilaterally over-achieving these targets, as research suggests that such a strategy would be ineffective. With rising interests and developments in reducing emissions, it is an opportunity to form alliances. This would lead in the long term to a uniform carbon price at a global scale.

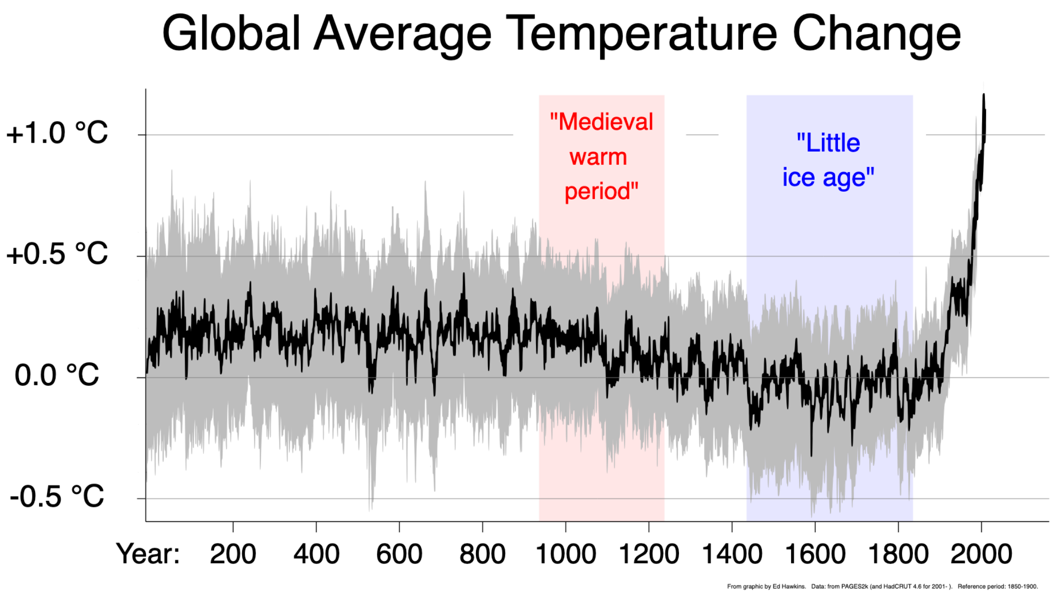
Image 4: EU Carbon Permits (EUR)

Permit prices in the European Union's carbon market fell to €88 a ton, the lowest level in four weeks, as investors predict lower demand for permits due to the manufacturing sector's weakness. The latest S&P PMI revealed yet another severe deterioration in the health of the Eurozone manufacturing economy. The performance of the manufacturing sector differed throughout the eurozone members evaluated by the study. Greece and Ireland were the only two nations to improve since July, but the four major economies, Germany, France, Italy, and Spain, all remained in contraction area.

"Eu Carbon PERMITS2023 Data - 2005-2022 Historical - 2024 Forecast - Price - Quote." *EU Carbon Permits - 2023 Data - 2005-2022 Historical - 2024 Forecast - Price - Quote*, tradingeconomics.com/commodity/carbon. Accessed 6 Sept. 2023.
"What Is Carbon Pricing?" *What Is Carbon Pricing? | Carbon Pricing Dashboard*, carbonpricingdashboard.worldbank.org/what-carbon-pricing#:~:text=Carbon%20pricing%20is%20an%20instrument,to%20their%20sources%20through%20a. Accessed 6 Sept. 2023.

2.2 Global Warming and Climate Change

Image 5: Global Average Temperature Change



The intricate interplay between climate change and the energy transition is central to comprehending the multifaced dynamics shaping sustainable energy trajectories. Energy transition plays a crucial role in mitigating the far-reaching impacts of climate change and fostering a paradigm shift towards more environmentally responsible energy systems. The ever-growing concentration of greenhouses gasses are at the center of climate change, which are mainly from fossil fuel combustion. From the graph shown above, it can be clearly seen that the temperature is rising rapidly, and the global average temperature has risen above 1 degree Celsius. The main contributor to greenhouse gas emissions would be the energy sector. This includes electricity generation, industrial processes, and transportation, emerges to be a significant contributor to greenhouse gas emissions.

"Global Temperature Record." *Wikipedia*, Wikimedia Foundation, 16 Aug. 2023, en.wikipedia.org/wiki/Global_temperature_record.

"Global Surface Temperature." *NASA*, NASA, 26 July 2023, climate.nasa.gov/vital-signs/global-temperature/.

Afterall, it can be seen that the energy transition emerges as a fundamental mechanism to counteract climate change, moving away from fossil fuels and leading towards cleaner renewable energy sources. The main focus of the energy transition's role in climate change mitigation is its potential to recalibrate the composition of energy sources. Through solar, wind, nuclear, hydro, and geothermal renewable energy technologies, the world is able to shift away from fossil fuels. This pivotal characteristic fundamentally alters the carbon footprint of energy generation and consumption, thus constituting a pivotal tool to combat climate change at its roots. Ingrained within the energy transition is a fundamental emphasis on energy efficiency measures, casting a direct impact on energy consumption patterns and, subsequently, emissions and encompassing an array of strategies, from innovative building designs to optimized industrial processes, energy efficiency champions a reduction in overall energy demand, ultimately curbing the reliance on fossil fuels for energy generation.

2.2.1 Government Policy

Policy and regulation play another pivotal role in controlling climate change and the energy transition. Governments across the globe are enacting climate policies and setting ambitious emission reduction targets, often accompanied by incentives and subsidies that catalyze the adoption of renewable energy sources. Therefore, through the policy landscape, the shift toward clean energy can be significantly accelerated by galvanizing economic growth and innovation. This shows that energy transition is a thrust for technological innovation, propelling advancements in renewable energy efficiency, energy storage capabilities, and grid integration strategies. These innovations serve as crucial enablers, circumventing challenges posed by the intermittent nature of renewable energy sources and bolstering the overall stability and reliability of the transition process. Harmonizing climate change mitigation with the energy transition introduces the just transition principle. Embedded with the domains of climate change and the energy transition is a clarion call for international collaboration. As the impacts of climate change transcend geographical boundaries, concerted global efforts become imperative. Countries around the world are imposing restrictions to limit their greenhouse gasses and push their transition to net zero. For example, all vehicles sold in Norway starting in 2025 will have to be electric or hydrogen powered. The European Union set to ban gas and diesel cars by 2035, and other countries such as Canada, the UK, and even some states in the U.S. such as California, Massachusetts, and New York. With governments pushing for newer power plants to be from renewable resources and limiting the use of gas cars, the shift will be inevitable. As the power grid shifts to greener alternatives fueling electric cars becomes greener and greener. International cooperation materialized in the form of emission reduction accords, knowledge exchange platforms, and coordinated investments in sustainable energy infrastructure, driving the energy transition towards a shared and sustainable future. The LCOE is widely used by the government to incentivize the development of renewable energy. The government is able to set competitive prices for companies by referring to the LCOE. The FER decree in Italy does exactly so. The basic tariff is determined on the basis of the power plant, always on systems with a useful life of approximately 20 years.

Table 1: Incentivized energy prices per Technology

Fonte rinnovabile	Tipologia	Potenza	VITA UTILE degli IMPIANTI	TARIFFA
		kW	anni	€/MWh
Eolica	On-shore	1<P≤100	20	150
		100<P<1000	20	90
		P≥1000	20	70
Idraulica	ad acqua fluente (compresi gli impianti in acquedotto)	1<P≤400	20	155
		400<P<1000	25	110
		P≥1000	30	80
	a bacino o a serbatoio	1<P<1000	25	90
		P≥1000	30	80
Gas residuati dai processi di depurazione		1<P≤100	20	110
		100<P<1000	20	100
		P≥1000	20	80
Solare fotovoltaico		20<P≤100	20	105
		100<P<1000	20	90
		P≥1000	20	70

From the graph above, it can be seen the various incentivized tariffs set by the government based on a specific technology. In this case, using the LCOE as a reference would help an investor understand if the investment would be profitable or not.

Ministero Dello Sviluppo Economico , www.gse.it/normativa_site/GSE%20Documenti%20normativa/ITALIA_DM_MISE__04_07_2019.pdf . Accessed 6 Sept. 2023.

"Il Decreto Fonti Energetiche Rinnovabili: Myenergy." *Webtek.It*, Webtek s.p.a., 9 June 2020, www.myenergy.it/blog/rinnovabile/cose-il-decreto-fer.

3. Levelized Cost of Electricity (LCOE)

The levelized cost of energy (LCOE), often known as the levelized cost of electricity, is an indicator used to examine and compare various energy production systems. The LCOE of an energy-generating asset is defined as the average total cost of construction and operation of the asset per unit of total electricity generated over an anticipated lifetime.

Alternatively, the levelized cost of energy may be defined as the average minimum price at which the electricity generated by the asset must be sold in order to balance the entire production costs during its lifetime. Calculating the LCOE is similar to determining a project's Net Present Value. The LCOE, like the NPV, may be used to assess if a project is a reasonable undertaking.

The levelized cost of energy is a critical factor in deciding whether or not to proceed with a project. The LCOE will assess if a project will be profitable or break even. If not, the company will end the construction of the power-generating facility and seek an alternative. Using the LCOE to evaluate a project is one of the first essential stages in examining such projects.

The LCOE is also an essential figure for financial analysts to use when comparing various energy-producing technologies such as wind, solar, geothermal, and nuclear power sources. It enables these comparisons despite uneven life durations, varying capital expenditures, project sizes, and the varying risks associated with each project. This is because the LCOE indicates the cost of energy generated per unit, and the risk of each project is a result of the individual discount rate utilized for each power-generating equipment.

Iea. "Projected Costs of Generating Electricity 2020 – Analysis." *IEA*, www.iea.org/reports/projected-costs-of-generating-electricity-2020. Accessed 6 Sept. 2023.

3.1 Mathematical Formula

To further analyze LCOE, it is vital to visualize its mathematical meaning. The value of LCOE is calculated as the relation between the sum of the discounted costs and the sum of the discounted production. Therefore, LCOE is a stream of equal payments, normalized over expected energy production, that would allow the recovery of all costs, including financing and assumed return on investment, over a predetermined financial life. LCOE can be divided into three different cost components:

- The initial investment cost that includes all the expenditures sustained during the construction period until the constructed plant starts production; these costs are indicated as Capital Expenditure (Capex).
- The operations and maintenance cost (O&M) sustained every year for the functioning and maintenance of the plant, such as human labor, raw materials, change of parts, and accessories costs. These costs will be divided into variable and fixed costs (Opex)
- The costs that are referenced to the substitution and the upgrading or renewing of essential components of the plant are higher than usual costs. These costs are not sustained yearly and, therefore, can be considered investment costs carried out later.

The initial investment cost is realized in the present. Therefore, it does not have to be discounted, and it coincides with calculating the value of the LCOE in full. However, the variable costs and financing costs are sustained in the future and, therefore, must be discounted.

Regarding production, it is also realized in the future and must be discounted. It should be reiterated that directly discounting production which is necessary in this case is no different from discounting the revenues deriving from production.

The calculation of the LCOE can be summed up in the following formula:

$$\frac{\text{discounted capital costs} + \Sigma\ \text{O\&M annual cost discounted} + \Sigma\ \text{fuel annual cost discounted}}{\Sigma\ \text{annual expected generation hours discounted}}$$

The indicated formula can be described as the simplified form of the LCOE value. If applied, it brings to the construction of a simple financial plan. Some estimates try to obtain more precise results concerning the specific context in which the plant operated and bring to the construction of more complex financial plans. For example, in the base formula, the tax factors are not considered but are an essential cost for a business. A complete financial plan should determine annual profits according to current tax regulations and then calculate taxes. Therefore, defining the tax depreciation rates of the investments made would be crucial.

A more evolved setting in calculating the value of the LCOE tries to determine an estimate of the effective price to which energy has to be sold in that specific market. In contrast, the base set represents more of an estimate of the pure unitary cost of the technology.

Even if less precise, the base set has the advantage of being universal. It is easier to compare it between technologies and different countries, mainly because it considers only the main variables and the most common. In this case, the base formula will be utilized for calculations, not only because of the advantage that was just mentioned but in order to simplify the scheme.

The LCOE methodology allows for all costs engaged in the production of energy to be aggregated, giving a range of results or a range of results that will work as a proxy for the technology. Since the result is always in the same unit, the method allows for cross-technology comparisons, giving an estimate of which technologies are cheaper despite their differences in dispatch ability. For example, This standard method is used to establish price-based support instruments such as feed-in tariffs, premiums, green certificates, and contracts for difference.

"Levelized Cost of Energy (LCOE)." *Corporate Finance Institute*, 10 May 2023, corporatefinanceinstitute.com/resources/valuation/levelized-cost-of-energy-lcoe/.

Iea. "Levelised Cost of Electricity Calculator – Data Tools." *IEA*, www.iea.org/data-and-statistics/data-tools/levelised-cost-of-electricity-calculator.

3.1.1 Limitations

However, this methodology has some limitations. It does not consider the level of competition, the essential financial indicators for investment decisions, or the streams of the systems. Furthermore, comparing technologies must be carefully made. The LCOE methodology does not take into account indicators based on the dispatchability and reliability of the technology. This means that it cannot represent the hourly market conditions, which are strongly influenced by meteorological conditions for intermittent renewables, fuel availability for thermal systems, peak demand, and other factors. After considering all these factors, the results are easier to interpret and understand.

3.1.2 LCOE Data

Beyond referring to the base formula, the proposed calculation scheme is essential and straightforward in the structure to be used as a model for possible modifications and integrations. Instead of referring to invented data, it is preferred to analyze data of a specific technology in a way to have a concrete example of the LCOE. In this case, this refers to a large-scale photovoltaic plant destined for only a single energy production without self-consumption.

To have a view of the costs that are related to each technology, we can consider the EIA study 2022 “Electricity Market Module,” in particular the following table 2:

Methodology Supplement- U.S. Energy Information Administration (EIA), www.eia.gov/renewable/workshop/gencosts/pdf/methodology_supplement.pdf.

Levelized Costs of New Generation Resources in the Annual Energy ..., www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

Levelized Cost of Electricity and Levelized Avoided Cost of Electricity ..., www.eia.gov/renewable/workshop/gencosts/pdf/methodology_supplement.pdf. Accessed 6 Sept. 2023.

Table 2: Cost and performance Characteristics of new central station electricity generating technologies.

Table 3. Cost and performance characteristics of new central station electricity generating technologies

Technology	First available year[a]	Size (MW)	Lead time (years)	Base overnight cost[2b] (2021$/kW)	Techno-logical optimism factor[c]	Total overnight cost[d,e] (2021$/kW)	Variable O&M[f] (2021 $/MWh)	Fixed O&M (2021$/ kW-y)	Heat rate[g] (Btu/kWh)
Ultra-supercritical coal (USC)	2025	650	4	$4,074	1.00	$4,074	$4.71	$42.49	8,638
USC with 30% carbon capture and sequestration (CCS)	2025	650	4	$5,045	1.01	$5,096	$7.41	$56.84	9,751
USC with 90% CCS	2025	650	4	$6,495	1.02	$6,625	$11.49	$62.34	12,507
Combined-cycle—single-shaft	2024	418	3	$1,201	1.00	$1,201	$2.67	$14.76	6,431
Combined-cycle—multi-shaft	2024	1,083	3	$1,062	1.00	$1,062	$1.96	$12.77	6,370
Combined-cycle with 90% CCS	2024	377	3	$2,736	1.04	$2,845	$6.11	$28.89	7,124
Internal combustion engine	2023	21	2	$2,018	1.00	$2,018	$5.96	$36.81	8,295
Combustion turbine—aeroderivative[h]	2023	105	2	$1,294	1.00	$1,294	$4.92	$17.06	9,124
Combustion turbine—industrial frame	2023	237	2	$785	1.00	$785	$4.71	$7.33	9,905
Fuel cells	2024	10	3	$6,639	1.09	$7,224	$0.62	$32.23	6,469
Nuclear—light water reactor	2027	2,156	6	$6,695	1.05	$7,030	$2.48	$127.35	10,443
Nuclear—small modular reactor	2028	600	6	$6,861	1.10	$7,547	$3.14	$99.46	10,443
Distributed generation—base	2024	2	3	$1,731	1.00	$1,731	$9.01	$20.27	8,923
Distributed generation—peak	2023	1	2	$2,079	1.00	$2,079	$9.01	$20.27	9,907
Battery storage	2022	50	1	$1,316	1.00	$1,316	$0.00	$25.96	NA
Biomass	2025	50	4	$4,524	1.00	$4,525	$5.06	$131.62	13,500
Geothermal[i, j]	2025	50	4	$3,076	1.00	$3,076	$1.21	$143.22	8,813
Conventional hydropower[j]	2025	100	4	$3,083	1.00	$3,083	$1.46	$43.78	NA
Wind[e]	2024	200	3	$1,718	1.00	$1,718	$0.00	$27.57	NA
Wind offshore[i]	2025	400	4	$4,833	1.25	$6,041	$0.00	$115.16	NA
Solar thermal[i]	2024	115	3	$7,895	1.00	$7,895	$0.00	$89.39	NA
Solar photovoltaic (PV) with tracking[e, i, k]	2023	150	2	$1,327	1.00	$1,327	$0.00	$15.97	NA
Solar PV with storage[i, k]	2023	150	2	$1,748	1.00	$1,748	$0.00	$33.67	NA

Cost and Performance Characteristics of New Generating Technologies ..., www.eia.gov/outlooks/aeo/assumptions/pdf/table_8.2.pdf.

"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *EIA*, www.eia.gov/outlooks/aeo/electricity_generation.php.

3.2 Discount Rates

The first initial data is the real interest rate awaited on the activity. When describing large plants, there is never a single investor due to the extensive fund requirements, or the single investor requires a debt. Therefore, it is important to refer to the debt of capital, i.e., loans granted by third parties which mainly come from banks. The rates banks request on loans are always lower than the expected rates of return on equity capital, given that creditors are better protected than those who invest in company capital since if things go badly, they are the first to be repaid.

In the entrepreneurial sphere, therefore, there are two reference target rates: one on equity capital, an expression of the returns expected by the shareholders-shareholders, and the other on debt capital, an expression of the returns expected by the creditor banks, where the former is higher than the second.

Starting from this assumption, in calculating the LCOE value, it is widespread to determine a single reference rate as the weighted average of the two rates just mentioned, commonly called Weighted Average Costs of Capital (WACC).

The entity of the WACC, and therefore the two rates from which it is composed, has a direct correlation with the perception of the investment risk: the higher the risk, the higher the rate of return, and the lower the risk, the lower the rate of return. Other than the generic risk associated with the activity itself, which can vary based explicitly on the market where the company operates, even at a geographical level, there is a risk related to the specific technology. For example, the scarce diffusion of a specific technology is considered an incremental risk factor compared to an already established technology. The dangerousness of the technology used can also be relevant to the risk that in the event of an accident, the functionality of the plant will be compromised. For the possible possibility of having to compensate for damages to these parties, an emblematic case is nuclear energy.

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monday.com, All of us at. "The Complete Guide to Strategy Portfolio Management." *Monday.Com Blog*, 24 Aug. 2023, monday.com/blog/project-management/strategy-portfolio-management/.

Furthermore, the technologies that require the construction of unique power plants of large dimensions for optimization reasons, a strategy used in business called economies of scale. They also require the primary lenders to invest higher sums on individual projects, concentrating the risk and increasing the required returns. From what has been previously said, the reference rate for calculating the value of LCOE can vary according to the technology and the considered market. A typical example of such an approach can be observed in the study performed by the Fraunhofer Institute for Solar Energy Systems, released in June 2021, on the LCOE calculation of various production technologies, mainly on the German market. The following nominal and real WACC rates are indicated among the input data used:

Table 3: Rates based on Technology

	Wind onshore	Wind offshore	Biogas	Solid biomass	Lignite	Hard coal	CCGT
Lifetime in years	25	25	25	25	40	30	30
Share of debt	80%	70%	80%	80%	60%	60%	60%
Share of equity	20%	30%	20%	20%	40%	40%	40%
Interest rate on debt	3.5%	5.0%	3.5%	3.5%	5.0%	5.0%	5.0%
Return on equity	7.0%	10.0%	8.0%	8.0%	11.0%	11.0%	10.0%
WACC nominal	4.20%	6.50%	4.40%	4.40%	7.40%	7.40%	7.00%
WACC real	2.96%	5.24%	3.20%	3.20%	6.20%	6.20%	5.80%
OPEX fix [EUR/kW]	20	70	4% of CAPEX	4% of CAPEX	32	22	20
OPEX var [EUR/kWh]	0.008	0.008	0.004	0.004	0.0045	0.004	0.003
Annual degradation	0	0	0	0	0	0	0

"Dati Fraunhofer"

https://grafici.altervista.org/wp-content/uploads/Dati-Fraunhofer-01.png

Table 4: Cost of electricity

	PV rooftop small (≤ 30 kWp)	PV rooftop large (> 30 kWp)	PV utility-scale (> 1 MWp)	PV rooftop small incl. battery (≤ 30 kWp, 1:1)	PV rooftop large incl. battery (> 30 kWp, 2:1)	PV utility-scale incl. battery (> 1 MWp, 3:2)
Lifetime in years	30	30	30	15	15	15
Share of debt	80%	80%	80%	80%	80%	80%
Share of equity	20%	20%	20%	20%	20%	20%
Interest rate on debt	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Return on equity	5.0%	6.5%	6.5%	5.0%	6.5%	6.5%
WACC nominal	3.40%	3.70%	3.70%	3.40%	3.70%	3.70%
WACC real	2.20%	2.50%	2.50%	2.20%	2.50%	2.50%
OPEX fix [EUR/kW]	26	21.5	13.3	0	6.0-10.0*	6.7-9.3*
OPEX var [EUR/kWh]	0	0	0	0	0	0
Annual degradation	0.5%	0.25%	0.25%	0	0	0
Battery replacement costs	-	-	-	40-50% of initial investment	35% of initial investment	30% of initial investment
Efficiency	-	-	-	90%	90%	90%
Annual charge cycles	-	-	-	200	100-300**	100-300**

As can be seen from this chart, for a technology such as solar energy, simple and quick to install, modular, not very problematic to operate, and now widely tested, the real rate of return considered is about 2.5%, much lower than that of thermal technologies fossil fuels which are around 6% and even lower than renewable technologies that are still not established such as marine wind power.

The estimated inflation rate, in this case, is 1.2%, the difference between the nominal and real rates.

At this point, determining which rates of return to use for calculations depends on the type of information you want to obtain. If the objective is to provide a LCOE value that is as realistic as possible for that specific technology and market, the 2.5% indicated in the table for solar energy should be chosen; however, if the goal is to make a comparison between multiple technologies focused on the cost structure ignoring the risk and financing aspects, then a higher rate should be chosen which is more or less intermediate between the various technologies.

"Cost of electricity" - https://www.ise.fraunhofer.de/en/publications/studies/cost-of-electricity.html

Another reference can also be the LCOE estimates calculated by the U.S. Energy Information Administration, the government body of the United States, which, precisely by making a comparison as close as possible, uses the same real rate of return for all technologies. In this case, the interest rate is 6.2%.

Even in other cases, generally, for equal comparisons, the rates that are used are similarly higher than those that would be used in a real context for photovoltaics. In this case, therefore, for the demonstration of the calculations, the real rate of return that was used is 6%. The real rate is the only variable that is needed in this case since all cost and production values considered are subject to inflation; if they are not, the nominal rate should be used. However, in the diagram, it is advisable to indicate all three rates involved: nominal, real, and inflation interest rates, calculating the real rate starting from the nominal one.

3.4 Inflation

Currently, the inflation rate is high, at around 7% to 8%. This is why, in this case, for simplicity, the current inflation rate to be considered will be an average inflation rate over the entire reference period. It is not easy to estimate since these are generally long periods. However, in this case, it is assumed that the rate will slowly decrease and that the average inflation rate will be around 4%. It is always better for these estimates to be oriented toward the near future rather than the more distant one because, in an actualization plan, the distant future affects the calculation less. Thus, with an inflation rate of 4% and a real rate of return of 6% as a target, the nominal rate to be included in the framework will be around 10%.

3.5 Nominal Interest Rate

The formula to use is the one presented below.

Team, The Investopedia. "Real Interest Rate: Definition, Formula, and Example." *Investopedia*, Investopedia, www.investopedia.com/terms/r/realinterestrate.asp.

Real interest rate = $\frac{(nominal\ interest\ rate - inflation\ rate)}{(1+inflation\ rate)}$

To accurately obtain a real rate of 6%, instead of making manual attempts on the nominal rate to be included in the scheme, it can be calculated using the inverse formula:

Nominal interest rate = real interest rate * (1 + inflation rate) + inflation rate

= 0.06 * (1 + 0.04) + 0.04 = 0.1024 → 10.24%

In the calculations chart, the data is then inserted for reference:

Rates		
Nominal Interest	Inflation	Real interest
10.24%	4.00%	6.00%

3.6 Lifetime of the Plant

Regarding the duration of the investment, the operational life cycle of the plant is usually considered, but a shorter reference period can also be considered. In fact, in this type of evaluation, it is more convenient to use a period of 30 years since over very long periods, the discounting process tends to reduce the values involved, making them insignificant. This means that over long periods of time, the LCOE values tend to almost stabilize, making further calculations useless. Furthermore, making investment plans far into the future is always tricky because the uncertainty about the data to be estimated increases over time.

In any way the reference period is 30 years in this case, but the scheme can be extended up to 60 years to demonstrate what has been said above. Since it is a photovoltaic system, this approach is still plausible given that production trends are to decline over time due to the degradation of the panels but never cases entirely due to the breakage of critical parts and thanks to its modular nature.

4. LCOE Numerical Analysis

4.1 Solar Power Plant

At this point, it is necessary to establish how much is the initial investment cost for the production plant. We can rely on the National Survey Reports carried out under the Photovoltaic Power Systems Program managed by the IEA for solar energy. The latest report from 2020 is available for Italy. It can be noted that the "turnkey" cost, which also includes taxes of large-scale photovoltaic plant with a power greater than 20 MW, is 500 to 700 euros per kW:

Table 5: Turnkey PV system prices of different typical PV systems

Table 9: Turnkey PV system prices of different typical PV systems (1)

Category/Size	Typical applications and brief details	Current prices [€/W]
Residential BAPV 5-10 kW	Grid-connected, roof-mounted, distributed PV systems installed to produce electricity to grid-connected households. Typically roof-mounted systems on villas and single-family homes.	1,20 – 1,60
Small commercial BAPV 10-100 kW	Grid-connected, roof-mounted, distributed PV systems installed to produce electricity to grid-connected commercial buildings, such as public buildings, multi-family houses, agriculture barns, grocery stores etc.	1,15 - 1,25
Large commercial BAPV 100-250 kW	Grid-connected, roof-mounted, distributed PV systems installed to produce electricity to grid-connected large commercial buildings, such as public buildings, multi-family houses, agriculture barns, grocery stores etc.	0,95 - 1,15
Industrial BAPV >250 kW	Grid-connected, roof-mounted, distributed PV systems installed to produce electricity to grid-connected industrial buildings, warehouses, etc.	0,80 - 1,00
Small centralized PV 1-20 MW	Grid-connected, ground-mounted, centralized PV systems that work as central power station. The electricity generated in this type of facility is not tied to a specific customer and the purpose is to produce electricity for sale.	0,70 - 0,80
Large centralized PV >20 MW	Grid-connected, ground-mounted, centralized PV systems that work as central power station. The electricity generated in this type of facility is not tied to a specific customer and the purpose is to produce electricity for sale.	0,50 - 0,70

National Survey Report of PV Power Applications in Italy 2020 - IEA-PVPS, iea-pvps.org/wp-content/uploads/2021/11/NSR_Italy_2020.pdf.

As mentioned in the table above, even if it is not specified, the range of values probably indicated the difference between fixed and one-axis tracking systems, which is common today among large systems. It should also be noted that the VAT, which are the taxes paid in the case of entrepreneurial activity is credited in subsequent years and recovered; therefore, it has less of an impact. One of those tax aspects discussed earlier needs to be calculated in the basic setup for the LCOE calculation.

For simplicity, by referring to a fixed system it brings the simulation in the lower part of that range, but it must also be said that due to higher inflation, prices have slightly increased in the meantime. Therefore, prudently considering a value of 600 euros/kW as a specific cost would match. Assuming a plant size of 30 MW, this translates into an initial investment cost of 18 million euros.

It should be noted that in determining this value, it is also essential to evaluate the time it took to construct the plant. Sometimes, the system costs are provided in the form of an overnight cost, i.e., an estimate of the cost assuming that the system can be built overnight and be immediately available the next day. In reality, some types of plants require many years to be built. In these cases, it is necessary to consider the effective cost, which is always higher than the overnight cost because money is incurred during the construction period, which still needs to be offset by the business's revenues, leading to a loss of income. Therefore, in the updating scheme, the chronological reference point is the plant's entry into operation, representing the present or year zero. If, for the future, the values, as mentioned, are discounted at the real rate of return, for the construction period, the values are instead capitalized at the same rate.

The problem does not arise in this case because a 30 MW photovoltaic plant can be built in a few months. Therefore, the overnight cost and the investment cost practically coincide. However, if, hypothetically, the construction lasted ten years and the costs were all paid in the middle of the period to simplify, the 18 million would become around 24 million euros in current terms:

Initial investment cost = $18{,}000{,}000 * (1 + 0.06)^5 = 24{,}088{,}060$ €

Regarding annual operating costs, reference can be made to the same Fraunhofer Institute study from 2021 mentioned above. As seen in the table above, an operating cost (OPEX) of 13.3 euros/kW is indicated for large-scale photovoltaics. If desired, the EIA study can also consider the costs. In the table, it is specified that the operating cost (O&M) is 15.97 euro/kW which are the ones used.

However, this value is referred to as a system with a one-axis tracking system where maintenance is more expensive. Moreover, the kW in altering the current is considered instead of those in a direct current; therefore, the converted value would be lower. It should be noted that the plant costs in the USA are fairly higher than the European ones, both because the market is less developed and those questions of duties, but on the other hand, they have deserts that they can exploit.

In this case, always with a certain prudence, an operating cost of 15.97 euro/kW per year is considered. This means 30 MW plant costs 450,000 euros annually (15 * 30,000).

It should be noted that in all these data for the various technologies that are around, any extraordinary maintenance costs are never considered. However, these costs are likely included in the regular operating costs, spreading them over the plant's entire life. Again, in this case, it is noted that extraordinary maintenance costs are not considered. At this point, the following calculations can be represented by the table below:

Table 6: Solar power plant costs

Year	Cost		
	Invest + Operative Meuro	Discounted Value	Total Cumulated
0	18	18	18
1	0.45	0.424528302	18.4245283
2	0.45	0.400498398	18.8250267
3	0.45	0.377828677	19.20285538
4	0.45	0.356442148	19.55929753
5	0.45	0.336266178	19.8955637
6	0.45	0.317232243	20.21279595
7	0.45	0.299275701	20.51207165
8	0.45	0.282335567	20.79440721
9	0.45	0.266354309	21.06076152
10	0.45	0.25127765	21.31203917
11	0.45	0.237054386	21.54909356
12	0.45	0.223636214	21.77272977
13	0.45	0.21097756	21.98370733
14	0.45	0.199035434	22.18274277
15	0.45	0.187769277	22.37051204
16	0.45	0.177140828	22.54765287
17	0.45	0.167113988	22.71476686
18	0.45	0.157654706	22.87242157
19	0.45	0.148730855	23.02115242
20	0.45	0.140312127	23.16146455
21	0.45	0.132369931	23.29383448
22	0.45	0.124877294	23.41871177
23	0.45	0.117808768	23.53652054
24	0.45	0.111140347	23.64766089
25	0.45	0.104849384	23.75251027
26	0.45	0.098914513	23.85142478
27	0.45	0.093315578	23.94474036
28	0.45	0.088033564	24.03277393
29	0.45	0.083050532	24.11582446
30	0.45	0.078349559	24.19417402

As it can be seen, the initial investment cost has been entered in the first column of the costs section for the zero years, while in subsequent years, there are operating costs. This column reports costs at a fixed value of money, i.e., as if the rate of return and inflation did not exist. In the second column, for each row, the current value of the costs indicated in the first column is calculated with the formula seen previously, which is repeated here:

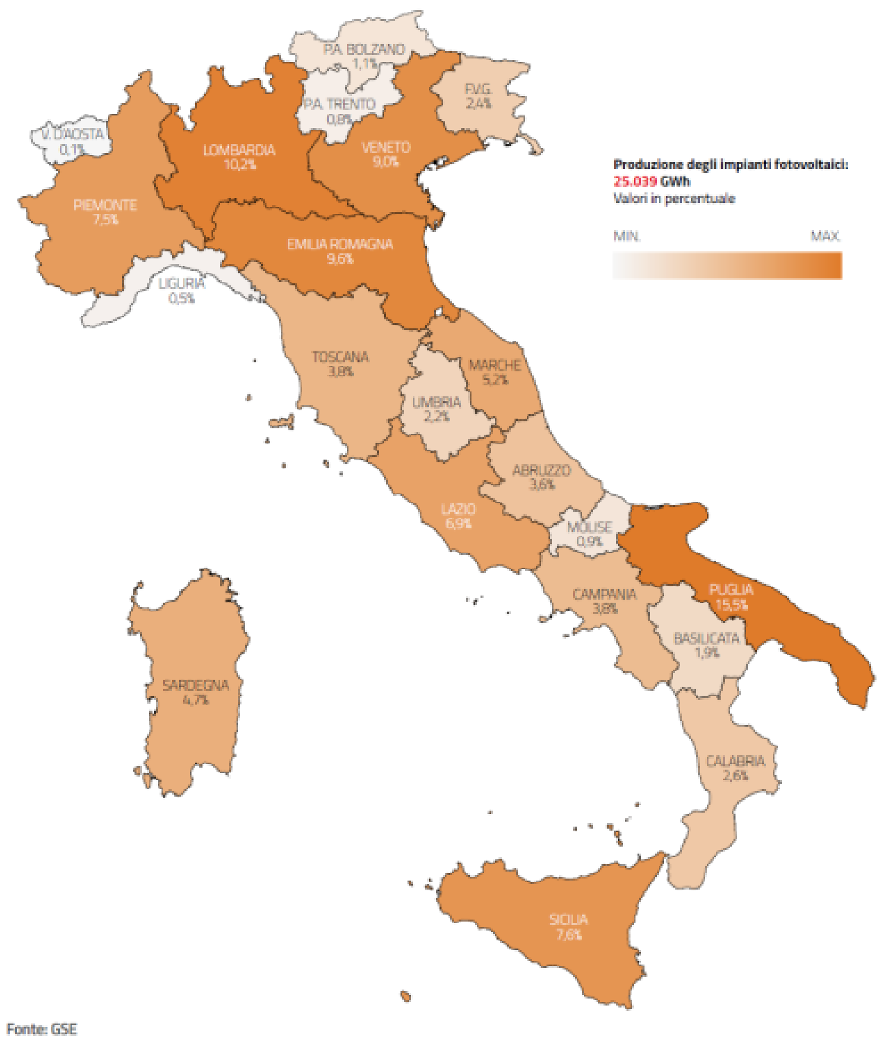
$$\text{Discounted Value} = \frac{Future\ Cash\ Flow}{(1 + real\ interest\ rate)^{n.of\ years}}$$

"Discount Rate Formula: Calculating Discount Rate [WACC/APV]." *Paddle*, www.paddle.com/resources/discount-rate-formula.

In the third column, the sum of the current values of the second column is made, i.e., the cumulative total.

In Italy, the solar production in 2021 was 25039 GWh, and the region Puglia has been the best producer with 3.881 GWh; see the following map of the GSE 2021 report.

Image 6: Distribution of production per region in Italy



To estimate the production of a photovoltaic plant, it is essential to know the exact location where the plant will be installed because the specific radiation (kWh/m2/year) changes from region to region, as shown in the following map of the GSE report (2021).

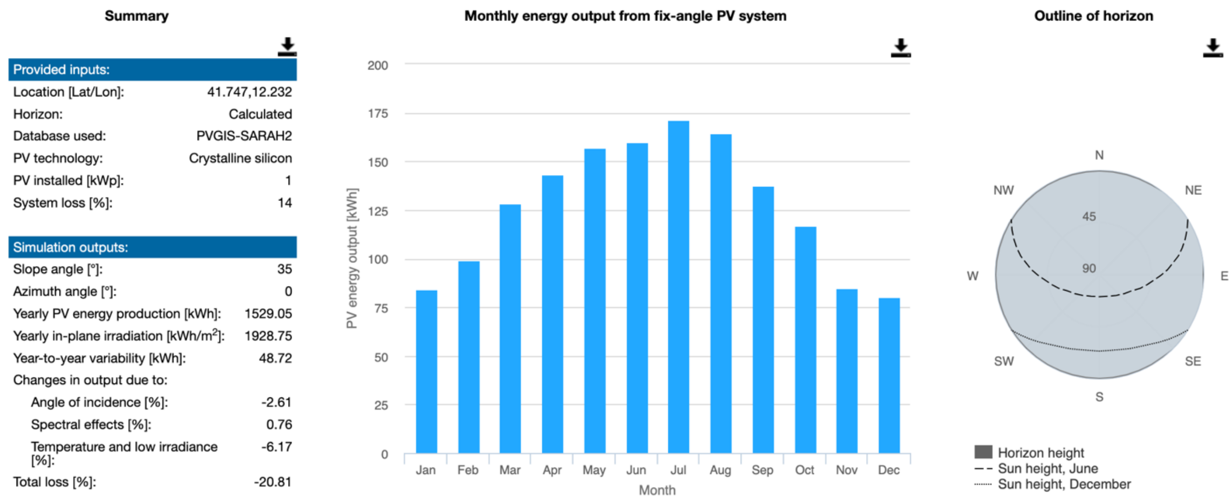
Image 7: Production of photovoltaic power plants per region in Italy

Therefore, the PVGIS service can be used as a reference location in Central Italy, with intermediate productivity between those in our country. Taking the area of the Roman coast as a reference, the PVGIS indicates that for a fixed plant with optimal orientation and inclination, there is a productivity of 1,529 hours, i.e., kWh for each kW installed:

"Energia da fonti rinnovabili in Italia" - https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20Statistico%20GSE%20-%20FER%202021.pdf

Solare Fotovoltaico, www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Solare%20Fotovoltaico%20-%20Rapporto%20Statistico%202019.pdf .

Image 8: Solar power plant production



In the case of a standard system, one could consider an average production of energy more or less constant over time. However, in a photovoltaic system, the panels are subject to progressive degradation, which reduces their production. These values are known because they are always indicated in the technical characteristics data of the panel. Currently, for monocrystalline modules, an efficiency loss of 2% is generally indicated during the first year, and a constant 0.55% is calculated on the second production for the following 24 years. No indications are usually provided for subsequent years. However, it can be assumed that the deterioration is usually provided for subsequent years, but it can be assumed that the deterioration will continue at the same rate. It should be noted that these data must be considered as threshold values, i.e., it is the maximum degradation that can be obtained in compliance with the guarantee of good panel operation. In reality, therefore, the degradation values will be lower on average.

Always waiting to be cautious, in this case, the indicated threshold is still applied. Therefore, for the first year, total production of 45,870 MWh (30*1,529) is indicated, which declines by 2% the following year and by 0.55% in all subsequent years, calculated fixed on the second year.

"Photovoltaic Geographical Information System (PVGIS)." *EU Science Hub*, joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis_en.

Below is the scheme of the spreadsheet with the addition of the production data:

Table 7: Costs and production for a solar power plant

Year	Costs (outgoing)			Production			LCOE
	Capex+ Opex	Discount vaule	Tot Cumulated	Energy	iscount Valu	Tot Cumulated	Solar Italy
	Mln euro			(MWh)			(Euro/MWh)
0	18	18	18				
1	0.45	0.424528302	18.4245283	45870	43274	43274	426
2	0.45	0.400498398	18.8250267	44953	40008	83281	226
3	0.45	0.377828677	19.20285538	44705	37535	120817	159
4	0.45	0.356442148	19.55929753	44459	35216	156033	125
5	0.45	0.336266178	19.8955637	44215	33040	189073	105
6	0.45	0.317232243	20.21279595	43972	30998	220071	92
7	0.45	0.299275701	20.51207165	43730	29083	249154	82
8	0.45	0.282335567	20.79440721	43489	27286	276440	75
9	0.45	0.266354309	21.06076152	43250	25600	302040	70
10	0.45	0.25127765	21.31203917	43012	24018	326057	65
11	0.45	0.237054386	21.54909356	42776	22534	348591	62
12	0.45	0.223636214	21.77272977	42541	21141	369733	59
13	0.45	0.21097756	21.98370733	42307	19835	389567	56
14	0.45	0.199035434	22.18274277	42074	18609	408177	54
15	0.45	0.187769277	22.37051204	41842	17459	425636	53
16	0.45	0.177140828	22.54765287	41612	16381	442017	51
17	0.45	0.167113988	22.71476686	41383	15368	457385	50
18	0.45	0.157654706	22.87242157	41156	14419	471804	48
19	0.45	0.148730855	23.02115242	40929	13528	485331	47
20	0.45	0.140312127	23.16146455	40704	12692	498023	47
21	0.45	0.132369931	23.29383448	40480	11908	509931	46
22	0.45	0.124877294	23.41871177	40258	11172	521103	45
23	0.45	0.117808768	23.53652054	40036	10481	531584	44
24	0.45	0.111140347	23.64766089	39816	9834	541418	44
25	0.45	0.104849384	23.75251027	39597	9226	550644	43
26	0.45	0.098914513	23.85142478	39379	8656	559300	43
27	0.45	0.093315578	23.94474036	39163	8121	567421	42
28	0.45	0.088033564	24.03277393	38947	7619	575040	42
29	0.45	0.083050532	24.11582446	38733	7148	582189	41
30	0.45	0.078349559	24.19417402	38520	6707	588896	41

As can be seen from the first column of the section, it is sufficient to enter the value of the entire production of the first year; the others are calculated automatically. In the second column, once again, the data are updated with the usual formula, and in the third column, the total sum is calculated.

4.1.1 Results

To further analyze the results, it is impossible to calculate the value of the LCOE by simply dividing the cumulative present value of costs by the cumulative present value of output (total cumulated). The final result of the calculation can be defined by:

Table 8: Data for calculating LCOE for a solar power plant in Italy

Year	Costs(outgoing)			Production			LCOE
	Capex+ Opex	Discounted Value	Tot Cumulated	Energy	scounted Valu	Tot Cumulated	Solar Italy
	Mln euro			(MWh)			(Euro/MWh)
-	18.00	18.00	18.00				
1.00	0.45	0.42	18.42	45,870.00	43,273.58	43,273.58	425.77
2.00	0.45	0.40	18.83	44,952.60	40,007.65	83,281.24	226.04
3.00	0.45	0.38	19.20	44,705.36	37,535.48	120,816.72	158.94
4.00	0.45	0.36	19.56	44,459.48	35,216.07	156,032.80	125.35
5.00	0.45	0.34	19.90	44,214.95	33,039.99	189,072.78	105.23
6.00	0.45	0.32	20.21	43,971.77	30,998.36	220,071.14	91.85
7.00	0.45	0.30	20.51	43,729.93	29,082.90	249,154.04	82.33
8.00	0.45	0.28	20.79	43,489.41	27,285.80	276,439.84	75.22
9.00	0.45	0.27	21.06	43,250.22	25,599.74	302,039.58	69.73
10.00	0.45	0.25	21.31	43,012.34	24,017.87	326,057.45	65.36
11.00	0.45	0.24	21.55	42,775.78	22,533.75	348,591.19	61.82
12.00	0.45	0.22	21.77	42,540.51	21,141.33	369,732.52	58.89
13.00	0.45	0.21	21.98	42,306.54	19,834.96	389,567.48	56.43
14.00	0.45	0.20	22.18	42,073.85	18,609.30	408,176.78	54.35
15.00	0.45	0.19	22.37	41,842.44	17,459.39	425,636.17	52.56
16.00	0.45	0.18	22.55	41,612.31	16,380.53	442,016.71	51.01
17.00	0.45	0.17	22.71	41,383.44	15,368.34	457,385.04	49.66
18.00	0.45	0.16	22.87	41,155.83	14,418.69	471,803.73	48.48
19.00	0.45	0.15	23.02	40,929.48	13,527.72	485,331.46	47.43
20.00	0.45	0.14	23.16	40,704.37	12,691.81	498,023.27	46.51
21.00	0.45	0.13	23.29	40,480.49	11,907.56	509,930.83	45.68
22.00	0.45	0.12	23.42	40,257.85	11,171.76	521,102.59	44.94
23.00	0.45	0.12	23.54	40,036.43	10,481.43	531,584.01	44.28
24.00	0.45	0.11	23.65	39,816.23	9,833.75	541,417.77	43.68
25.00	0.45	0.10	23.75	39,597.24	9,226.10	550,643.87	43.14
26.00	0.45	0.10	23.85	39,379.46	8,656.00	559,299.87	42.65
27.00	0.45	0.09	23.94	39,162.87	8,121.12	567,421.00	42.20
28.00	0.45	0.09	24.03	38,947.47	7,619.30	575,040.30	41.79
29.00	0.45	0.08	24.12	38,733.26	7,148.48	582,188.78	41.42
30.00	0.45	0.08	24.19	38,520.23	6,706.76	588,895.54	41.08

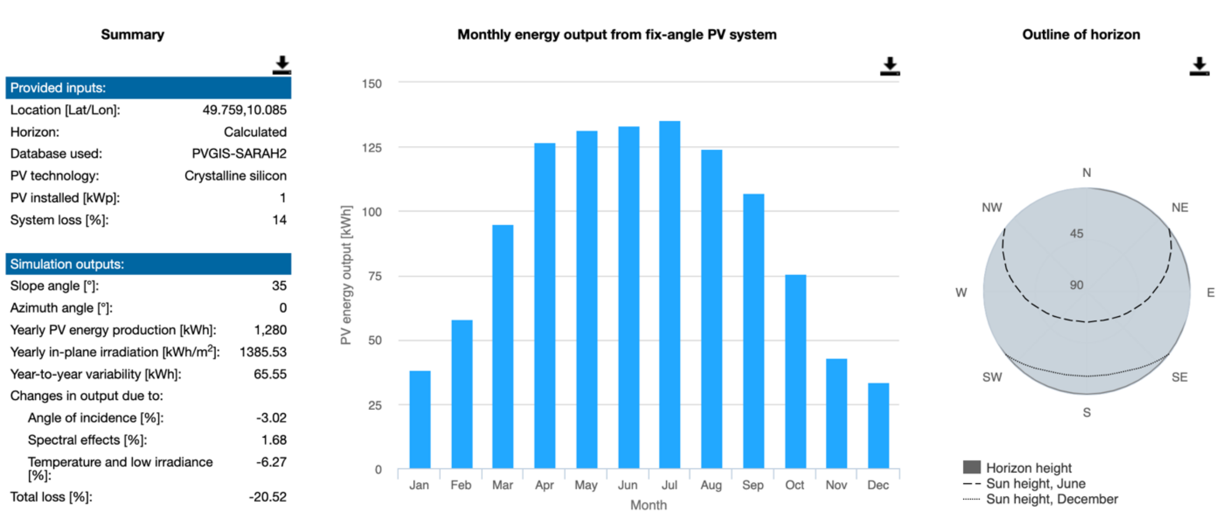
From the graph above, it can be demonstrated that over a 30-year period, that is obtained. Even if not shown, over 60 years would be slightly different (37.6), confirming what was previously said about the fact that evaluations over such a long period of time make little sense.

Recalling that a prudent approach was followed as input data and even if the value thus calculated represents the pure cost of the technology and not the final sale price since there is no assessment of the tax charges, the result is meager. It is enough to know that in recent years, before the energy crisis, the price of energy on the wholesale electricity market in Italy remained on average at 55 euros/MWh, while now it is between 200 and 500 euros/MWh. Therefore, solar plants were already competitive before the energy crisis and are even more than today.

4.2 German Solar Power Plant

It is interesting to analyze Germany due to fewer comparable hours of sunshine. Germany's solar power landscape is predominantly based on photovoltaic systems, with costs traditionally driven by the need to compensate for lower solar yields through technological developments and supporting regulations. In contrast, Italy's more favorable solar circumstances have made PV systems a more cost-effective option, benefiting from increased solar irradiance and potentially reduced costs per kilowatt-hour generated. Both nations have investigated concentrated solar power, although it is a less prevalent and substantially more expensive technology due to its reliance on direct sunlight, making it less economically viable in areas with limited sun exposure. Using the same program from before to find production for a year, a location in central Germany has been selected to analyze.

Image 9: Production for a solar power plant in Germany



“Photovoltaic Geographical Information System (PVGIS).” *EU Science Hub*, joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis_en.

4.2.1 Results

The Same calculations can also be done on a solar plant in Germany. In this case, the equivalent hours are 1,280.

Table 9: Data for calculating LCOE for a solar power plant in Germany

Rates			Costs		Power (MW)	30
Nominal interest	**Inflation**	**Real interest**	**Capex Inv. (Euro/MW)**	600.00	Equivalent hours	1,280.00
10.24%	4.00%	6.00%	Capex + Opex (Euro/k\	15.00	degradation in 1 year	2.00%
					degradation after 1 yea	0.55%

Year	Costs(outgoing)			Production			LCOE
	Capex+ Opex Mln euro	Discounted Value	Tot Cumulated	Energy (MWh)	scounted Val	Tot Cumulated	Solar Germany (Euro/MWh)
-	18.00	18.00	18.00				
1.00	0.45	0.42	18.42	38,400.00	36,226.42	36,226.42	508.59
2.00	0.45	0.40	18.83	37,632.00	33,492.35	69,718.76	270.01
3.00	0.45	0.38	19.20	37,425.02	31,422.77	101,141.53	189.86
4.00	0.45	0.36	19.56	37,219.19	29,481.08	130,622.61	149.74
5.00	0.45	0.34	19.90	37,014.48	27,659.37	158,281.99	125.70
6.00	0.45	0.32	20.21	36,810.90	25,950.23	184,232.22	109.71
7.00	0.45	0.30	20.51	36,608.44	24,346.70	208,578.93	98.34
8.00	0.45	0.28	20.79	36,407.09	22,842.26	231,421.19	89.86
9.00	0.45	0.27	21.06	36,206.86	21,430.78	252,851.97	83.29
10.00	0.45	0.25	21.31	36,007.72	20,106.52	272,958.49	78.08
11.00	0.45	0.24	21.55	35,809.68	18,864.09	291,822.58	73.84
12.00	0.45	0.22	21.77	35,612.72	17,698.43	309,521.01	70.34
13.00	0.45	0.21	21.98	35,416.85	16,604.80	326,125.82	67.41
14.00	0.45	0.20	22.18	35,222.06	15,578.75	341,704.57	64.92
15.00	0.45	0.19	22.37	35,028.34	14,616.10	356,320.67	62.78
16.00	0.45	0.18	22.55	34,835.68	13,712.94	370,033.61	60.93
17.00	0.45	0.17	22.71	34,644.09	12,865.58	382,899.19	59.32
18.00	0.45	0.16	22.87	34,453.54	12,070.59	394,969.77	57.91
19.00	0.45	0.15	23.02	34,264.05	11,324.71	406,294.49	56.66
20.00	0.45	0.14	23.16	34,075.60	10,624.93	416,919.42	55.55
21.00	0.45	0.13	23.29	33,888.18	9,968.39	426,887.81	54.57
22.00	0.45	0.12	23.42	33,701.80	9,352.42	436,240.23	53.68
23.00	0.45	0.12	23.54	33,516.44	8,774.51	445,014.74	52.89
24.00	0.45	0.11	23.65	33,332.10	8,232.31	453,247.05	52.17
25.00	0.45	0.10	23.75	33,148.77	7,723.62	460,970.67	51.53
26.00	0.45	0.10	23.85	32,966.45	7,246.36	468,217.03	50.94
27.00	0.45	0.09	23.94	32,785.14	6,798.59	475,015.61	50.41
28.00	0.45	0.09	24.03	32,604.82	6,378.49	481,394.10	49.92
29.00	0.45	0.08	24.12	32,425.49	5,984.34	487,378.44	49.48
30.00	0.45	0.08	24.19	32,247.15	5,614.56	492,993.00	49.08

For a German solar power plant, the LCOE value obtained is 49 Euro/MWh, slightly higher than Italy.

Fraunhofer Diffraction and the State of Polarization of Partially ..., grafici.altervista.org/wp-content/uploads/Dati-Fraunhofer-01.png.

"Study: Levelized Cost of Electricity - Renewable Energy Technologies - Fraunhofer ISE." *Fraunhofer Institute for Solar Energy Systems ISE*, 3 Aug. 2021, www.ise.fraunhofer.de/en/publications/studies/cost-of-electricity.html.

4.3 Nuclear Power Plant

Nuclear technology is often considered by many to be a cheaper solution. Is it really like this? To perform the calculations, it is necessary to retrieve the input data. Regarding the cost of the initial investment in the plant, the problem is that many data sources report "project" values that are irrelevant to those recorded in reality. For example, the EIA, in its assumptions of the 2022 study, considered an overnight cost of $7,030/kW for nuclear power. For now, the only two plants that are being built in the USA are two reactors of 1,100 MW and are recording an initial investment cost of 30 billion dollars, or 13,636 dollars/kW.

There are also plants in Europe, one in France of 1,600 MW currently under construction in Flaman Ville, and it is expected to require an initial investment of 19.1 billion euros, or 11,937 euros/kW.

In a report by Lazard in 2021, more realistic estimates can be found, considering a range of values from 7,800 to 12,800 dollars/kW as the initial investment cost. Therefore, wanting to make a comparison with what is being built today in Europe and the United States, the value of the investment cost for nuclear power to be considered is at least 11,000 euros/kW.

For the operating costs, the EIA indicated the variable costs are $2.48/MWh and a fixed cost of $127.35/kW. In comparison, Lazard indicated an intermediate variable cost of $4.25/MWh and a fixed cost of $130.75/kW. For these calculations, it is easier to take an average of these values. Therefore, considering the euro-dollar exchange rate parity, 3.36 euro/MWh as variable costs and 129 euro/kW fixed costs.

Considering a 1,600 MW plant, the initial investment cost is 17.6 billion euros, which can be calculated as 11,000 euros/kW * 1,600 MW.

Energy, Duke. "Capacity Factor – It's a Measure of Reliability." *Duke Energy | Nuclear Information Center*, 18 May 2021, nuclear.duke-energy.com/2021/05/18/capacity-factor-it-s-a-measure-of reliability#:~: text=As%20you %20can%20see%2C%20nuclear,90%20percent%20of%20the%20time.

"Nuclear Energy." *Education*, education.nationalgeographic.org/resource/nuclear-energy/.

In general, modern nuclear power plants operate with a capacity factor of 90%, i.e., they have an annual production equivalent to operating at maximum rated power for 90% of the time. This corresponds to a productivity of 7,884 hours, which is 90% of the 8,760 hours present in a year. The 1,600 MW considered, therefore, produces 12,614.4 GWh per year (7,884*1,600 MW). Production is considered to be constant over time.

It is now possible to calculate the variable operating costs, which are 42,384,384 euros, production for 3.36 euros, and the fixed costs of 206,400,000 euros (1,600 MW*129 euros/kW). Therefore, the total annual operating costs are 248,784,384 euros, which is the sum.

4.3.1 Results

After all this data has already been entered into the spreadsheet. As can be seen, the LCOE value for nuclear power over 30 years is 121.1 euro/MWh, about three times the estimated cost for photovoltaics:

Table 10: Data for calculating LCOE for a nuclear power plant

Rates			Costs		Power (MW)	1600
Nominal Interest	**Inflation**	**Real Interest**	**Capex Inv. (MEuro/MW)**	11		
10.2%	4%	6%	Variable Opex (Euro/MWh	3.36	Capacity factor	90%
			Fixed Opex (Euro/kW)	129		

Year	Cost			Production			LCOE
	Invest + Operative Meuro	Discounted Value	otal Cumulate	Energy (MWh)	DV	otal Cumulate	Nuclear (Euro/MWh)
0	17600	17600	17600				
1	249	235	17835	12614	11900	11900	1499
2	249	221	18056	12614	11227	23127	781
3	249	209	18265	12614	10591	33718	542
4	249	197	18462	12614	9992	43710	422
5	249	186	18648	12614	9426	53136	351
6	249	175	18823	12614	8893	62029	303
7	249	165	18989	12614	8389	70418	270
8	249	156	19145	12614	7914	78333	244
9	249	147	19292	12614	7466	85799	225
10	249	139	19431	12614	7044	92843	209
11	249	131	19562	12614	6645	99488	197
12	249	124	19686	12614	6269	105757	186
13	249	117	19802	12614	5914	111671	177
14	249	110	19912	12614	5579	117251	170
15	249	104	20016	12614	5264	122514	163
16	249	98	20114	12614	4966	127480	158
17	249	92	20207	12614	4685	132164	153
18	249	87	20294	12614	4419	136584	149
19	249	82	20376	12614	4169	140753	145
20	249	78	20454	12614	3933	144686	141
21	249	73	20527	12614	3711	148397	138
22	249	69	20596	12614	3501	151897	136
23	249	65	20661	12614	3302	155200	133
24	249	61	20722	12614	3115	158315	131
25	249	58	20780	12614	2939	161254	129
26	249	55	20835	12614	2773	164027	127
27	249	52	20887	12614	2616	166643	125
28	249	49	20935	12614	2468	169111	124
29	249	46	20981	12614	2328	171439	122
30	249	43	21024	12614	2196	173635	121

This shows that nuclear energy is not economical at all; it is actually one of the most expensive to exist. It must be reiterated that here, an equal comparison was made, taking into consideration an equal intermediate rate of return for the two technologies, when instead, in the real world, photovoltaic technology, due to its characteristics, enjoys lower rates than nuclear.

4.4 Geothermal Power Plant

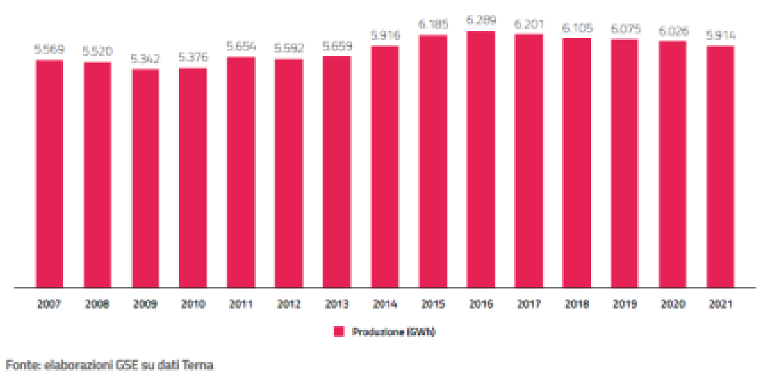
Another technology that has been arousing interest in recent years, following the energy crisis, is geothermal energy, which is an endogenous resource that can be used not only to produce electricity but also for producing heat for district heating in domestic homes. In this case, it is a valid alternative to using gas with a view to the energy transition and reduction of dependence on fossil fuels.

A geothermal power plant is a type of electrical power plant that can harnesses heat energy from the interior of the Earth. Geothermal plants direct this heat energy through fluid circulation and carry it to plants to produce electricity.

The main advantage of geothermal energy over other power sources is that it offers an essentially limitless supply of clean energy generated from the planet's core. Geothermal energy does not produce greenhouse gasses and can help establish energy independence from foreign fuel sources.

In the following chart, the trend of geothermal production in Italy is reported:

Image 10: Geothermal production



Like most power plants, geothermal power plants have a significant upfront cost and relatively lower costs for maintenance and upkeep. The main reason initial costs are much higher is site development and pipeline construction.

In order to build a functioning power plant, construction companies must drill wells deep into the earth's crust to reach a spot with enough heat energy to harness. They then must install a complex series of pipes that can circulate fluid. Then comes the actual construction of the power plant itself.

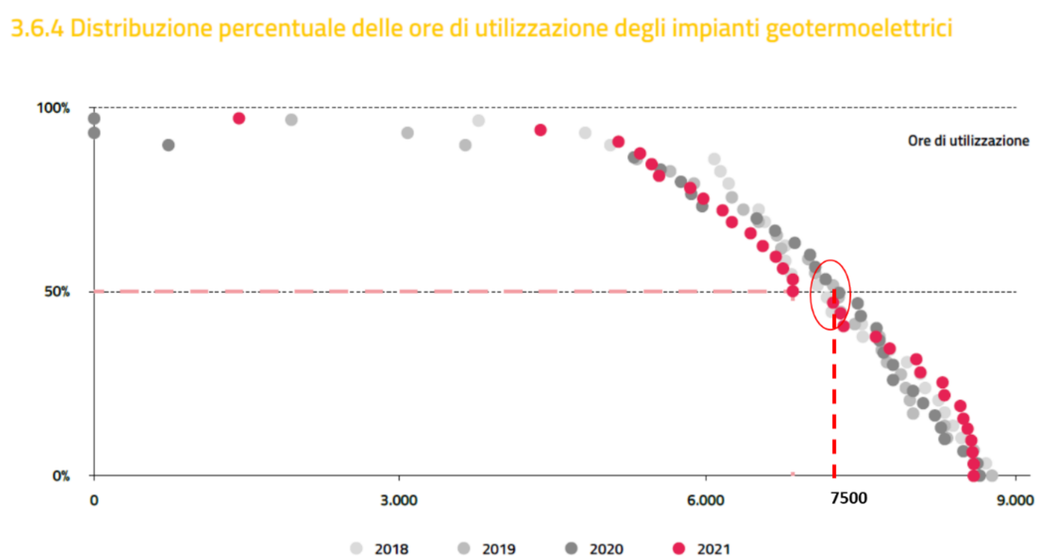
According to the Office of Energy Efficiency and Renewable Energy (EERE), the average cost to develop a geothermal power plant is an estimated minimum of $2,500 per installed kW up to $5,000 per installed kW. The values of the EIA, in its assumptions mentioned above of the 2022 study from the previous table, consider an overnight cost of 3076 US$/kW for geothermal for a 50 MW plant size.

Considering that 40% of the cost is related to drilling the wells and the average depth is increasing with time, assuming a value of 4000 Euro/kW for our calculation seems more conservative.

For the operating costs, the EIA indicates variable costs of US$1.21/MWh and fixed costs of US$143/kW. Considering parity with the dollar and taking a 50 MW plant as a reference, the initial investment cost is 200 million euro (4000 euro/kW*50000 kW).

In general, geothermal power plants operate with a capacity factor, compared to the installed power, of 90%, and they also operate 24/7 throughout the year except for scheduled and unscheduled shutdowns due to accidental unavailability. The average annual unavailability value for a Geothermal plant, due to planned and unplanned maintenance, is assumed to be equal to 5%. The equivalent working hours at maximum capacity can then be calculated, which are 7490 (0.9*0.95*8760), number that is aligned with average equivalent hours of the following chart, from GSE 2021 report.

Image 11: Equivalent hours for geothermal power plants



"Energia da fonti rinnovabili in Italia" - https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20Statistico%20GSE%20-%20FER%202021.pdf

The graph above is able to provide the utilization hours for a geothermal power plant, and marked are the 7490 equivalent hours calculated before. Geothermal fields can show an annual production decline due to possible depressurization of the geothermal reservoir; in this case, a declining value of 2% per year is assumed. This value is aligned with the trend of the last 5 years for geothermal production in Italy, as shown in the previous chart of geothermal production (GES 2021 report). Therefore, the annual production will be given by the installed power, or the maximum nominal power multiplied by the load factor and by the annual unavailability; this corresponds to a production of 375 GWh for the first year (50 MW*7490h/y). Production From the second year onwards will decline by 2% per year.

Now, it is also possible to calculate the variable operating costs, which are 454,000 euros, production for 1.21 euros, and the fixed costs, which are 7,150,000 euros, 50 MW*143 euros/kW. Therefore, the total annual operating costs are 7,604,000 euros, which is the sum.

4.4.1 Results

All these data have already been entered into the spreadsheet. As can be seen, the LCOE value for geothermal over 30 years is 72 euros/MWh.

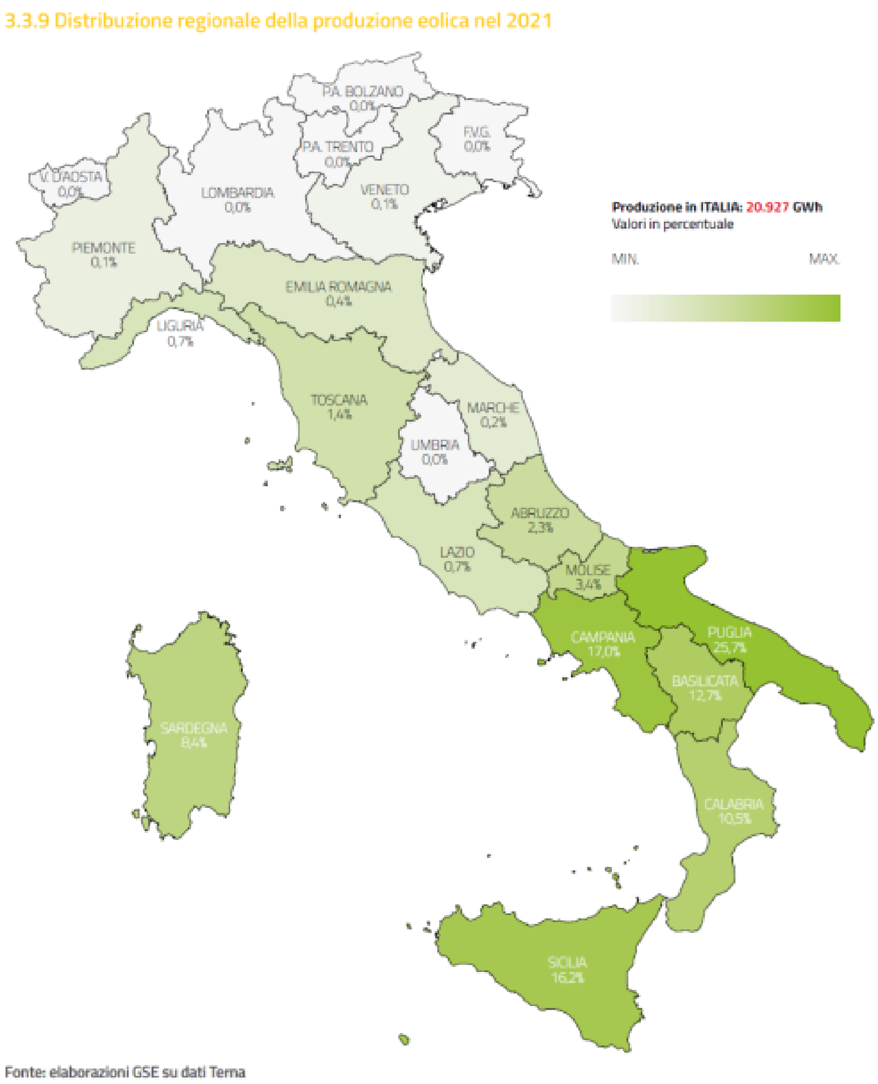
Table 11: Data for calculating LCOE for a geothermal power plant

Year	Cost			Production			LCOE
	Invest + Operative	Discounted Value	Total Cumulated	Energy	DV	Total Cumulated	Geothermal
	Meuro			(GWh)			(Euro/MWh)
0	200	200	200				
1	7.60	7	207	374	353	353	586
2	8	7	214	367	327	680	315
3	8	6	220	360	302	982	224
4	8	6	226	352	279	1261	179
5	8	6	232	345	258	1519	153
6	8	5	237	339	239	1758	135
7	8	5	242	332	221	1978	122
8	8	5	247	325	204	2182	113
9	8	4	252	319	189	2371	106
10	8	4	256	312	174	2545	100
11	8	4	260	306	161	2707	96
12	8	4	263	300	149	2856	92
13	8	4	267	294	138	2993	89
14	7	3	270	288	127	3121	87
15	7	3	273	282	118	3239	84
16	7	3	276	277	109	3347	83
17	7	3	279	271	101	3448	81
18	7	3	282	266	93	3541	80
19	7	2	284	260	86	3627	78
20	7	2	286	255	80	3707	77
21	7	2	289	250	74	3780	76
22	7	2	291	245	68	3848	76
23	7	2	293	240	63	3911	75
24	7	2	295	235	58	3969	74
25	7	2	296	231	54	4023	74
26	7	2	298	226	50	4073	73
27	7	2	299	221	46	4119	73
28	7	1	301	217	42	4161	72
29	7	1	302	213	39	4200	72
30	7	1	304	208	36	4237	72

4.5 Wind Power plant

The majority of the production for wind energy in Italy comes from the southern part, as the northern part has a limited capacity installed. Puglia is number one from all the regions, with 25.7% of national production in 2021, with Campania at 17.0%, Sicily at 16.2%, Basilicata at 12.7% and Calabria at 10.5%.

Image 12: Regional distribution of wind production in Italy for 2021



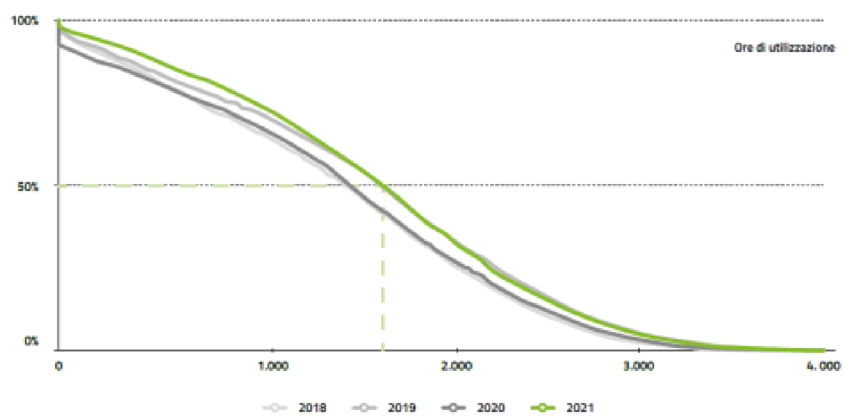
“Energia da fonti rinnovabili in Italia” - https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20Statistico%20GSE%20-%20FER%202021.pdf

In order to perform the calculations, it is necessary to retrieve the input data by taking the values of the EIA in its before-mentioned assumptions of the 2022 study from the previous table. As for the initial investment cost, consider an overnight cost of 1700 US$/kW for an onshore wind farm of 200 MW plant size. The EIA indicates a fixed cost of US$ 27,57/kW for operating costs. Considering parity with the dollar and taking a 200 MW plant as a reference, the initial investment cost is 340 million euro (1700 euro/kW*200000 kW).

In general, in Italy, the wind power plants operate with 1711 equivalent hours, as is shown in the following figure reported in the GSE 2021 report.

The image below shows the percentage distribution of the utilization hours of wind energy power plants:

Image 13: Equivalent hours for a wind power plant



In 2021, 50% of the wind power plant was produced for 1711 equivalent hours, a value significantly higher than the one of 2020, which was 1544.

Therefore, the annual production will be given by the installed power which is the maximum nominal power multiplied by the ratio equivalent hours/yearly hours, corresponding to a production of 342 GWh (200 MW*1711h).

The operating costs are 5,5 Million euros (200000 kW*27,57 euros/kW).

4.5.1 Results

After entering all the data into the spreadsheet, the LCOE value for wind over 30 years is 88 euros/MWh.

Table 12: Data for calculating LCOE for a wind power plant

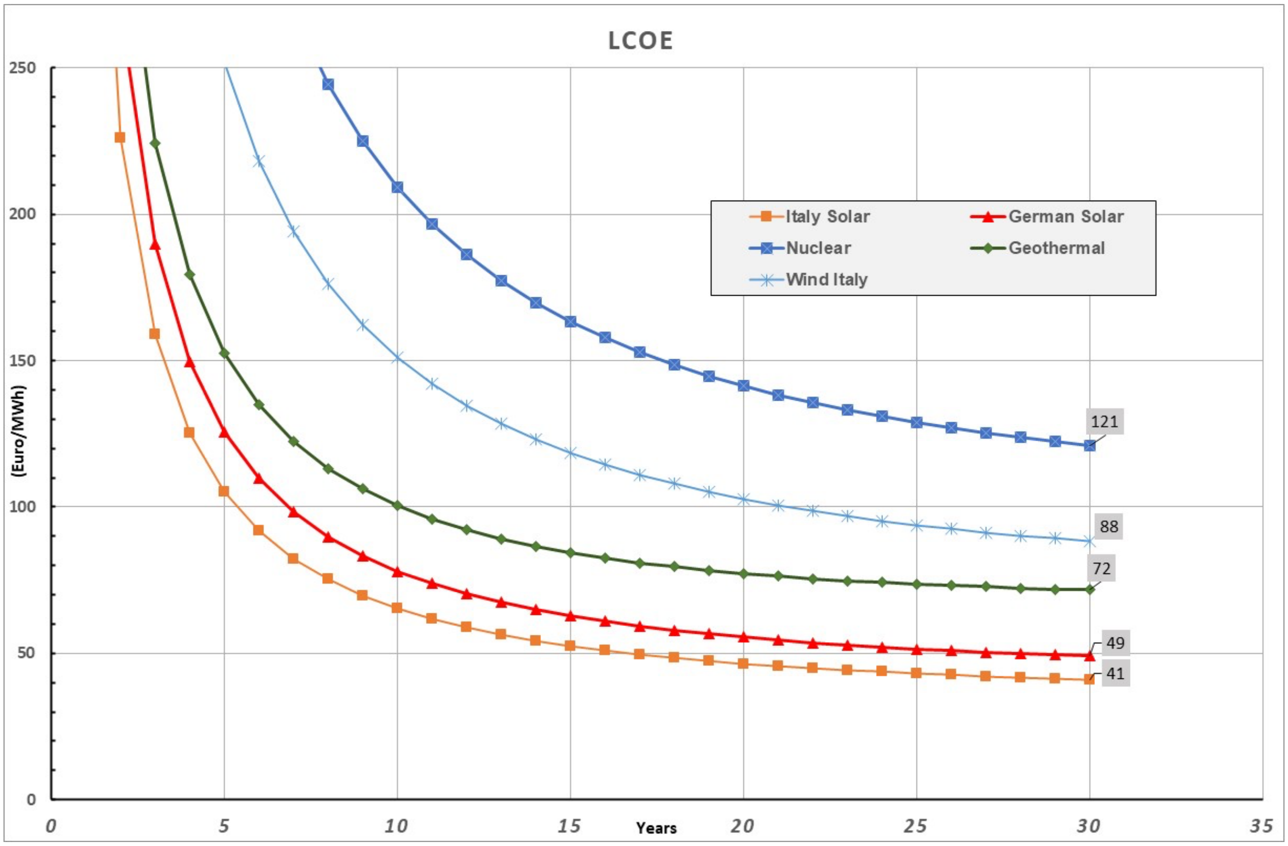
Year	Cost			Production			LCOE
	Invest + Operative	Discounted Value	Total Cumulated	Energy	DV	Total Cumulated	Wind Italy
	Meuro			(MWh)			(Euro/MWh)
0	340	340	340				
1	5,514	5,201886792	345,2018868	342200	322830	322830	1069
2	5,514	4,90744037	350,1093272	342200	304557	627387	558
3	5,514	4,629660727	354,7389879	342200	287318	914705	388
4	5,514	4,367604459	359,1065923	342200	271054	1185759	303
5	5,514	4,120381565	363,2269739	342200	255712	1441471	252
6	5,514	3,88715242	367,1141263	342200	241237	1682708	218
7	5,514	3,667124925	370,7812513	342200	227583	1910291	194
8	5,514	3,459551816	374,2408031	342200	214701	2124991	176
9	5,514	3,263728128	377,5045312	342200	202548	2327539	162
10	5,514	3,0789888	380,58352	342200	191083	2518622	151
11	5,514	2,904706415	383,4882264	342200	180267	2698888	142
12	5,514	2,740289071	386,2285155	342200	170063	2868951	135
13	5,514	2,585178369	388,8136939	342200	160437	3029388	128
14	5,514	2,438847518	391,2525414	342200	151355	3180743	123
15	5,514	2,300799545	393,5533409	342200	142788	3323532	118
16	5,514	2,170565608	395,7239065	342200	134706	3458237	114
17	5,514	2,047703404	397,7716099	342200	127081	3585318	111
18	5,514	1,931795664	399,7034056	342200	119888	3705206	108
19	5,514	1,82244874	401,5258543	342200	113102	3818307	105
20	5,514	1,719291264	403,2451456	342200	106700	3925007	103
21	5,514	1,621972891	404,8671185	342200	100660	4025667	101
22	5,514	1,530163104	406,3972816	342200	94962	4120629	99
23	5,514	1,443550098	407,8408317	342200	89587	4210216	97
24	5,514	1,361839716	409,2026714	342200	84516	4294732	95
25	5,514	1,284754449	410,4874259	342200	79732	4374464	94
26	5,514	1,212032499	411,6994584	342200	75219	4449683	93
27	5,514	1,143426886	412,8428852	342200	70961	4520645	91
28	5,514	1,078704609	413,9215898	342200	66945	4587589	90
29	5,514	1,017645858	414,9392357	342200	63155	4650745	89
30	5,514	0,960043262	415,899279	342200	59580	4710325	88

"Statistics Explained." *Statistics Explained*, ec.europa.eu/eurostat/statistics-explained/index.php?title=Electrical_capacity_for_wind_and_solar_photovoltaic_power_-_statistics.

4.6 Combined Technologies Comparison

In the following figure, there is a comparison of all the technologies that have been considered in LCOE calculation. Nuclear energy has proved to be the most expensive power plant to install, while solar energy in Italy is clearly the cheapest.

Image 14: LCOE comparison across different technologies



5. Impact of Financial Costs

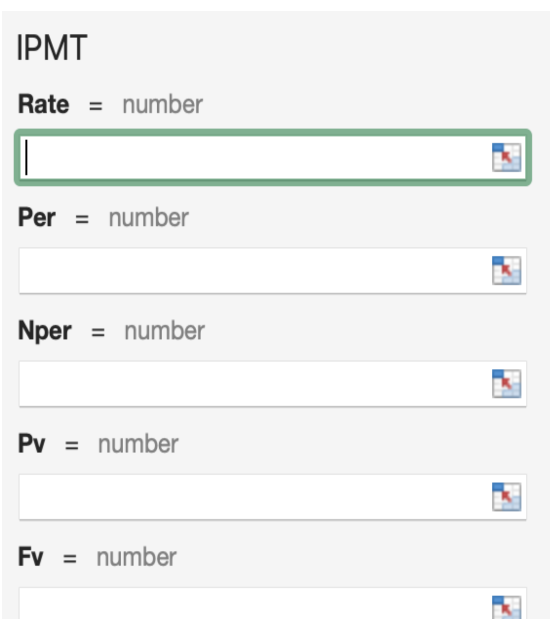
In most cases to build an electrical generation project it requires borrowing a certain amount of money from banks that cover a part of the initial investment cost, that is to build the project through project financing. In this case, the calculation of the LCOE must also take into consideration the interest cost of debt.

In this section, the influence of interest costs for a geothermal project will be analyzed, stemming from a different level of debt for an initial investment cost, considering a scenario in which the project is funded through a 20-year loan with two different fixed annual interest rates.

The subsequent charts depict the outcomes achieved under a constant interest rate while varying the percentage of debt. The visualizations will shed light on the relationship between interest costs and the LCOE, providing a comprehensive understanding of their impact on the project.

5.1 Mathematical Formula

Image 15: Interest costs formula



Using the IPMT formula that is found in the finance section under formulas in Excel allows one to find the interest costs per year. The "Rate" is the interest rate used. In this simulation, we considered 3% and 6%. The "Per" is the period in which you calculate the interest. "Nper" is the total number of payments in an annuity. In this case, we are considering 20 years. The Pv, in this case, is the amount borrowed. For example, in 100% debt, we would consider borrowing 100% of the total Investment Cost, which is 200 million * 100%. In 60% debt, we would weigh 200 million * 60%, resulting in 120,000,000 million; in 20% debt, the calculations would be 200 million * 20%, resulting in 40,000,000 million. The debt we are considering is a fixed rate with annual debt payments.

5.2 3% Annual Interest Rate

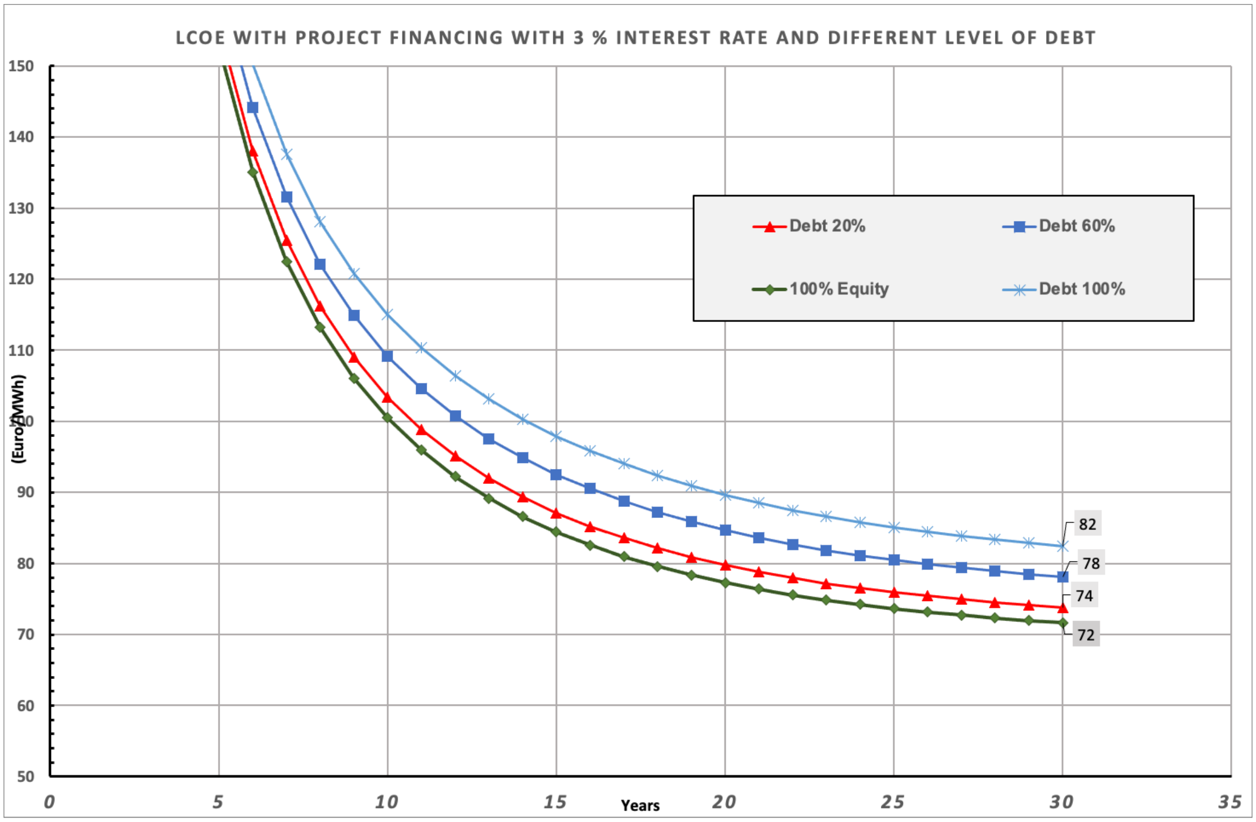
In the chart below, a LCOE calculation was done by taking into account a geothermal power plant, considering three different percentages of initial investment cost (100%, 60%, 20%) with a fixed annual interest rate of 3% for a 20-year period.

Table 13: Interest costs with 3% annual interest rate

Year	Project financing	Cost	LCOE	Project financing	Cost	LCOE	Project financing	Cost	LCOE
	Debt 100%	Tot Cum	Geothermal	Debt 60%	Tot Cum	Geothermal	Debt 20%	Tot Cum	Geothermal
	Interest 3%		(Euro/MWh)	Interest 3%		(Euro/MWh)	Interest 3%		(Euro/MWh)
0	years 20	Meuro		years 20	Meuro		years 20	Meuro	
1	5.66	213	602	3.40	211	596	1.13	208	590
2	5.14	225	331	3.08	220	324	1.03	216	318
3	4.66	236	240	2.79	230	234	0.93	223	228
4	4.21	246	195	2.52	238	189	0.84	230	183
5	3.79	255	168	2.27	246	162	0.76	237	156
6	3.39	264	150	2.04	253	144	0.68	243	138
7	3.03	272	138	1.82	260	132	0.61	248	125
8	2.69	280	128	1.61	267	122	0.54	254	116
9	2.38	286	121	1.43	272	115	0.48	258	109
10	2.08	293	115	1.25	278	109	0.42	263	103
11	1.81	299	110	1.09	283	105	0.36	267	99
12	1.56	304	106	0.94	288	101	0.31	271	95
13	1.33	309	103	0.80	292	98	0.27	275	92
14	1.11	313	100	0.67	296	95	0.22	279	89
15	0.91	317	98	0.55	300	93	0.18	282	87
16	0.73	321	96	0.44	303	91	0.15	285	85
17	0.56	324	94	0.33	306	89	0.11	288	84
18	0.40	327	92	0.24	309	87	0.08	291	82
19	0.26	330	91	0.15	312	86	0.05	293	81
20	0.12	332	90	0.07	314	85	0.02	296	80
21	0.00	334	88	0.00	316	84	0.00	298	79
22	0.00	337	87	0.00	318	83	0.00	300	78
23	0.00	339	87	0.00	320	82	0.00	302	77
24	0.00	340	86	0.00	322	81	0.00	304	77
25	0.00	342	85	0.00	324	80	0.00	305	76
26	0.00	344	84	0.00	325	80	0.00	307	75
27	0.00	345	84	0.00	327	79	0.00	309	75
28	0.00	347	83	0.00	328	79	0.00	310	75
29	0.00	348	83	0.00	330	79	0.00	311	74
30	0.00	349	82	0.00	331	78	0.00	313	74

From the graph below, and the calculations made above, it can be concluded that interest costs have as maximum impact on LCOE of up to 14%, from 72 €/MWh with no debt, to 82 €/MWh with debt that covers 100% of the initial investment cost.

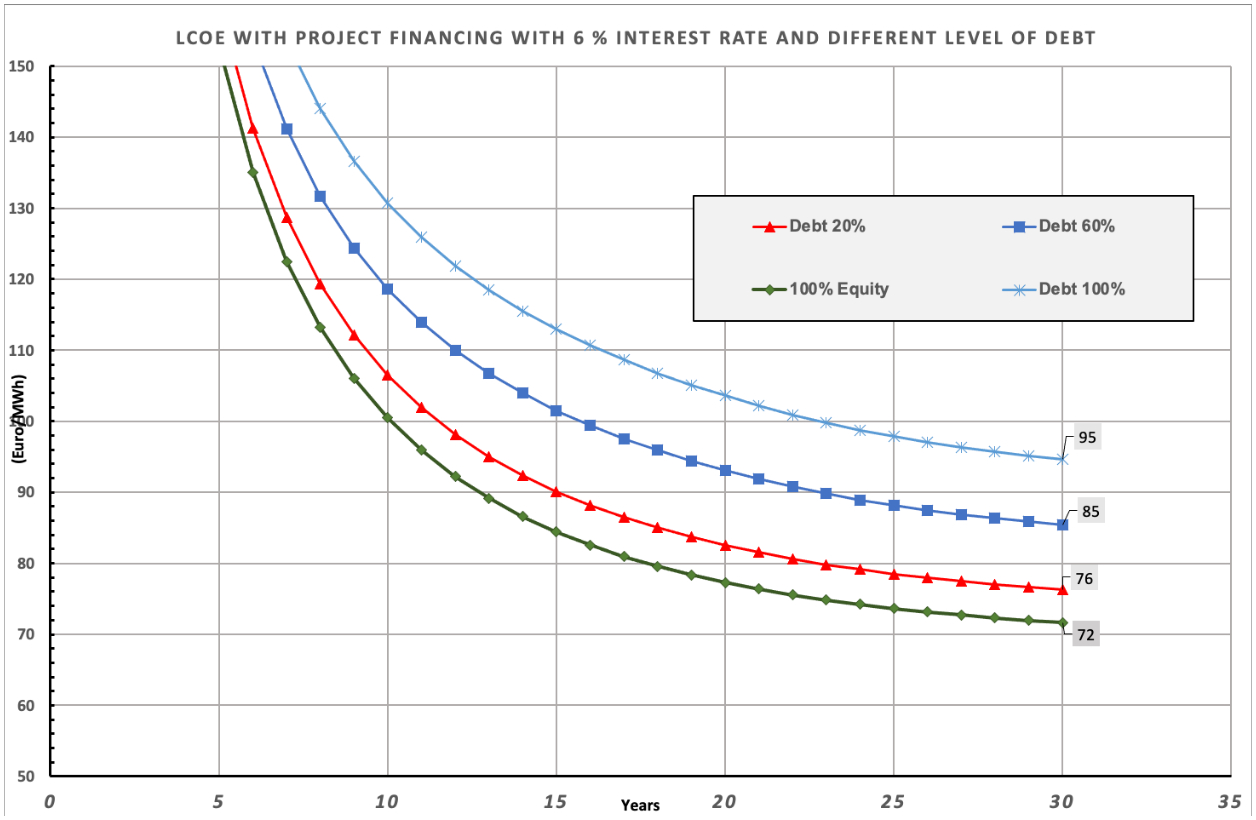
Image 15: LCOE with project financing with 3% interest rate and different level of debt



5.3 6% Annual Interest Rate

In the chart below, a LCOE calculation was done by taking into account a geothermal power plant, considering three different debt percentages of initial investment cost (100%, 60%, 20%) with an annual fix interest rate of 6%, for 20 years period.

Image 16: LCOE with project financing with 6% interest rate and different level of debt



From the graph above, in this case, the interest costs have a maximum impact on LCOE of up to 32%, from 72 €/MWh, with no debt, to 95 €/MWh, with debt that covers the 100% of the initial investment cost.

In the actual case, the amount of debt the company manages to cover a loan goes from 20% to 60% of the total investment cost, and the impact on LCOE can range between 3% to 20%.

The European Union's interest rates have risen significantly, currently at around 4.5%. Only two years ago, these rates were hovering about 0%. This sharp and rapid transition highlights the tremendous effect that fluctuating interest rates may have on project finance dynamics and the repercussions for energy projects.

6. Conclusion

The energy transition emerges as a fundamental mechanism to counteract climate change, moving away from fossil fuels and leading towards cleaner renewable energy sources. The main focus of the energy transition's role in climate change mitigation is its potential to recalibrate the composition of energy sources. Through solar, wind, hydro, nuclear, and geothermal renewable energy technologies, the world is able to shift away from fossil fuels. This pivotal characteristic fundamentally alters the carbon footprint of energy generation and consumption, thus constituting a crucial tool to combat climate change at its roots.

The European energy grid is rapidly moving towards greener solutions by increasing the net maximum electrical capacity yearly. The EU is working towards achieving the goal of net zero by 2050 and to reduce 55% of emissions by 2030. The share of renewable energy in the EU doubled from 2004 to 2019. In the transition towards renewable energy, companies are faced with costs that need to be analyzed before construction starts.

The Levelized Cost of Electricity (LCOE) is a fundamental metric to compare different energy sources to understand the total cost of a single technology. The LCOE methodology covers the entire lifecycle of an energy source. It encapsulates the initial capital investment, operating and maintenance expenses, fuel costs, and even the duration of the asset's lifetime.

In this thesis, the LCOE methodology has been analyzed, and a calculation for the base LCOE has been considered to compare different forms of renewable energy in Italy, like solar, wind, and geothermal power. Moreover, a LCOE calculation in Germany has been carried out for the solar plant to compare with the value in Italy. Nuclear energy has no CO2 emissions and can meet the goals set for 2050, so this energy source was also included in the LCOE calculation.

Solar energy in Italy resulted in the lowest (LCOE 41 €/MWh), making it the cheaper technology. In Germany, the results were higher (LCOE 49 €/MWh) since the equivalent hours are lower due to lower sun radiation—nuclear energy is the most expensive technology with a value of 121 €/MWh. Geothermal energy comes with a LCOE of 72 €/MWH, and wind energy with a LCOE of 88 €/MWh.

The LCOE is also a great indicator to understand whether the electric tariff is worth the investment. In Italy, for example, through the FER decree, the government sets an electrical energy price higher than the market one in order to incentivize the development of a single renewable energy source.

The impact of financial cost on LCOE base calculation has been analyzed, and the results show that in case the amount of debt is around 20% of the total initial investment and the fixed annual interest is 3%, the LCOE differs only by 3% respect the case the project has carried no debt.

In case a 60% debt of initial investment is set at a 6% fixed annual interest rate, the LCOE differs by 20%, respecting the case the project has carried no debt.

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