Power & Energy: A Primer

Energy and socioeconomic development

The growth of human population, the evolution of its living standards, and most changes impacting the global environment over millennia are highly correlated to energy capture. Because the First Law of Thermodynamics rules that there is no creation or destruction of energy, only conversion from one form to another, it is technically more accurate to speak of energy capture than of generation and consumption of energy, which is the common parlance.

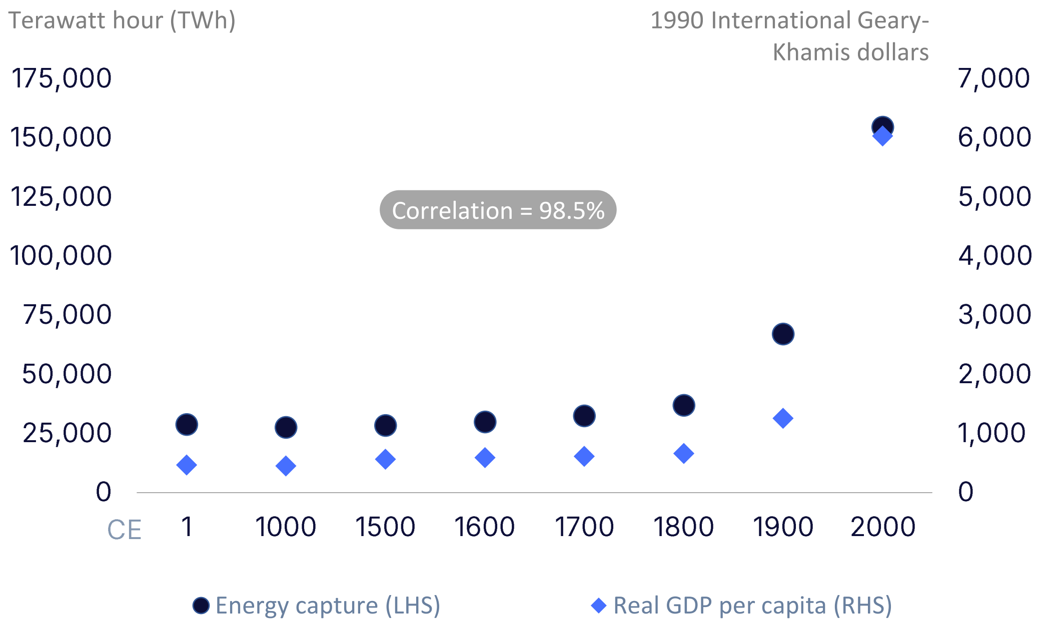
Human beings capture energy from the environment mainly to transform it into food (whether consumed directly, given as fodder to animals that provide labor, or to feed animals that are later eaten), fuel (whether for cooking, heating, or powering machines), and raw materials (whether for clothing, metalwork, construction or any other similar purpose). Against this backdrop, it is fair to argue that energy capture by the humankind is the foundation of its socioeconomic development[1].

Energy usage and climate change

After the end of the latest Ice Age, about 13,000 Before Common Era (BCE), non-food energy capture passed over several periods of modest growth, booms, stagnation, steady decline, and a few episodes of collapse, in line with the fate of human societies. Over the long-term, such nonlinear dynamics resulted in nonfood energy capture growing until it reached a level around 28,000 kilocalories/per capita/per day. Apparently, that was the ceiling on what was technologically feasible to achieve in preindustrial societies.

By mid-19th century Common Era (CE), though, major changes in the social, political, economic, and technical realms caused non-food energy capture to growth exponentially. Interestingly, the evolution of global real gross domestic product per capita, a proxy for wealth creation, follows the same trajectory (Chart I). Those were the hallmarks of the Industrial Revolution.

I. Estimated global energy capture vs. real GDP per capita

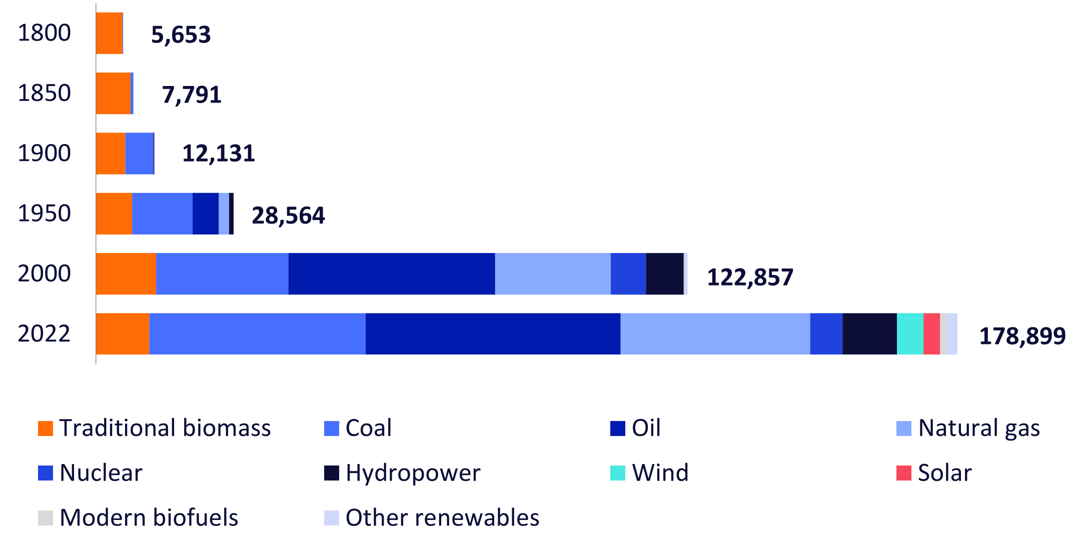


Until the mid-19th century, the dominant source of energy used across the world was traditional non-sustainable biomass, that is, the burning of solid fuels such as wood, crop waste, dung, or charcoal. The Industrial Revolution led to an exponential growth of energy usage to produce an ever-increasing store of goods and wealth.

In 2022 the estimated global primary usage of energy – for electricity, heating, transportation, manufacturing, etc. – reached 178,899 terawatt-hours, 6.3 times higher than it was in 1950 and nearly 15 times higher than it was in 1900 (Chart II). The long-term compound annual growth rate (CAGR) of terawatts hours used from 1850 to 1900 was 0.9%. A hundred years later, from 1950 to 2000, it had more than trebled, to 3%.

II. Global primary energy usage by source [2]

Terawatt hour (TWh)



Non-linear trajectories like those called for new, affordable energy sources, thus, the rise of fossil fuels, firstly coal; followed by oil and, in a later stage, natural gas. They still dominate the global primary energy usage by source today: no less than 83% of total as of 2022. Another non-renewable source nuclear energy, whose connection to power grids began in the 1950s, but it never played a key role (4% of total energy usage last year). As for modern-day sustainable renewables sources - hydropower, solar, wind and modern biofuels, which account for 13% of energy usage - it is a somewhat nuanced story.

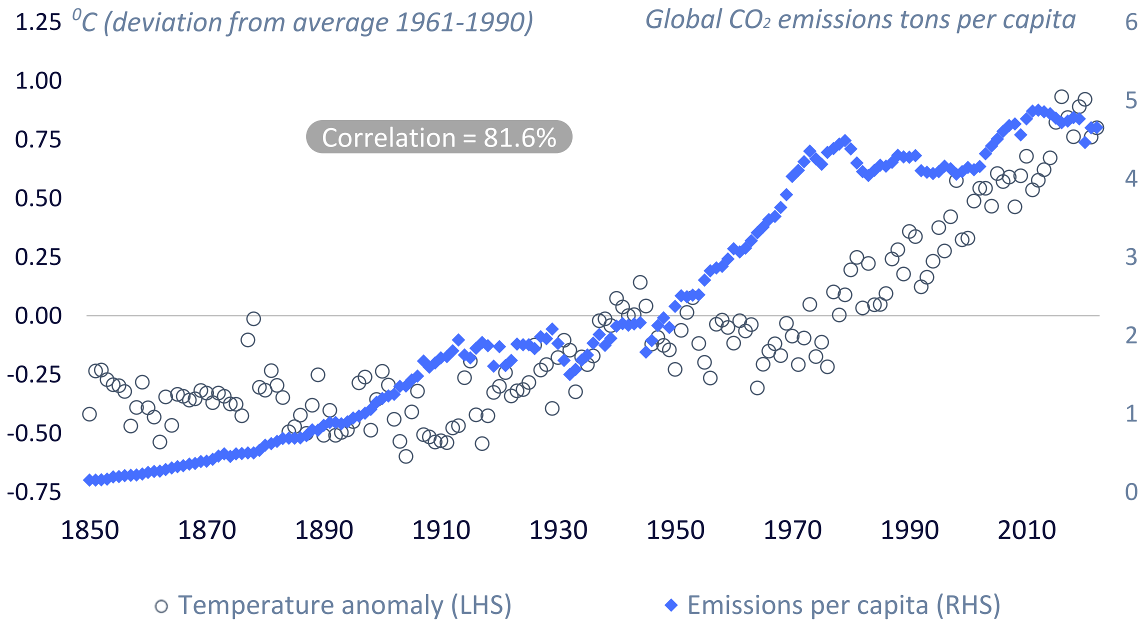
Since the last quarter of the 19th century water turbines have been generating electricity, whereas Rudolf Diesel himself designed his original internal combustion engine in 1892 and included natural plant oils (notably peanut) for direct use as fuel.

However, the ascent of the broad spectrum of non-fossil renewable alternatives dates to the 1970s, when escalating geopolitical tensions on major producing zones together with adverse supply shocks sharply raised world prices of oil and its derivatives.

Large relative price changes would by themselves increase the demand for non-fossil fuels. But then, coincidentally, systematic scientific assessments of worrisome variations in weather conditions across the globe also began in the 1970s. What entities such as the Intergovernmental Panel on Climate Change (IPCC) have been systematically reporting are more significant average temperature anomalies that correlate highly with carbon dioxide (CO2) and greenhouse gas emissions (GHG; Chart III).

Over time, research demonstrated that the burning of fossil fuels, along with the production of industrial materials (especially iron and steel, cement, chemicals and petrochemicals, and pulp & paper), and even the growing food generate substantial emissions of CO2. Also, they account for substantial share of greenhouse gases in the atmosphere like methane, hydrofluorocarbons, and nitrous oxide.

III. Temperature anomalies vs. CO2 emissions

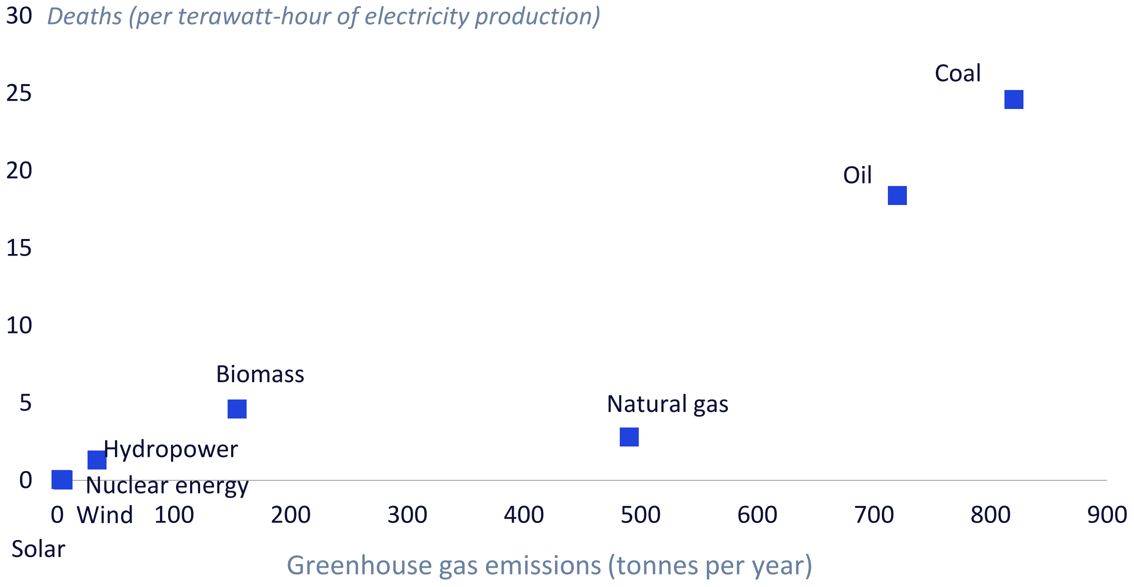


The drive to renewable, low-carbon energy sources gained further impetus when scientific investigation revealed that millions of people die prematurely every year because of air pollution resulting from the burning of fossil fuels and traditional biomass – particularly wood, dung, and charcoal. Also, there are disproportionate deaths caused by accidents in the mining and extracting of non-renewable fuels - coal, uranium, shale, oil, and gas, as well as in the operation and maintenance of the respective power plants.

In this context, greenhouse gas emissions related to coal are 57 times greater than the average of wind, solar and hydropower, while deaths resulting from air pollution and accidents are 54 times higher (Chart IV). The respective numbers for oil are 50 times greater and 41 times higher.

The prime choice for transition to power matrices with lower carbon footprint is natural gas, yet its GHG emissions are 34 times greater than the average of wind, solar and hydropower, whilst deaths resulting from air pollution and accidents are six times higher.

IV. GHG emissions vs. deaths (air pollution & accidents)



Sustainable renewable energy takes off

Government actions, along with appropriate market price signals, paved the way for the ascent of renewable energy. However, the most impressive achievement in this area and a key component of this success story is the sharp cost decline of low-carbon, non-nuclear alternatives for electricity generation.

The levelized cost of electricity (LCOE) is a widely used metrics for investment planning and to compare different methods of electricity generation on a consistent basis. More specifically, LCOE calculates the average net present cost of electricity generation for a power plant over its lifetime. In market parlance, it estimates the minimum price that customers would need to pay for the electricity supplied so that the power plant would break even over its lifetime.

It is instructive to note that the LCOE of fossil fuels and nuclear power depends mostly on two factors, the price of the fuel burned, and the expenses required to run the power plant, which can be considerable.

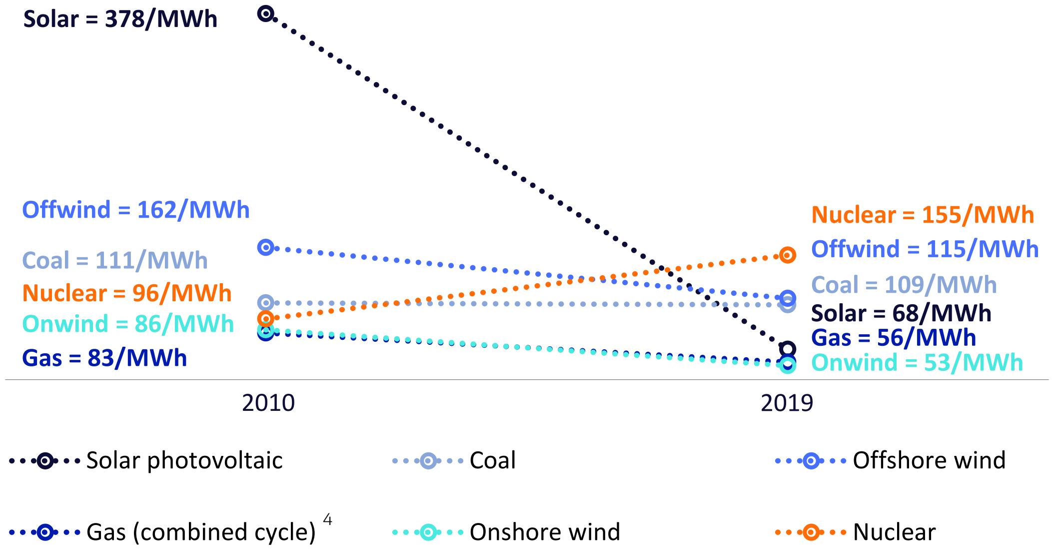
Conversely, the operating costs of most renewable energy plants and the price tag of their fuels are comparatively much lower: the wind, water and sunlight need no digging out of the ground nor transportation over long distances. At the margin, what matters for renewables is the cost of the technology embedded in the power plant itself.

Faster learning curves combined with rapid technological progress led to sharply lower costs for power provided by plants running on sustainable renewable sources. According to the LCOE calculations, the real price (i.e., adjusted for inflation) in U.S. dollars of the megawatt-hour of electricity generated by photovoltaic solar panels fell by 82% from 2010 to 2019 (Chart V). The respective rates for onshore and offshore wind are -38% and -29%.

The cost of the cheapest and most efficient fossil fuel option, combined cycle gas thermal (CCGT) plants, decreased by a third in the same period and its present level is no longer significantly below that of plants that use non-fossil fuels. All else, energy transition towards low-carbon, non-nuclear sources, makes market sense and, therefore, the narrative should be of high momentum of growth.

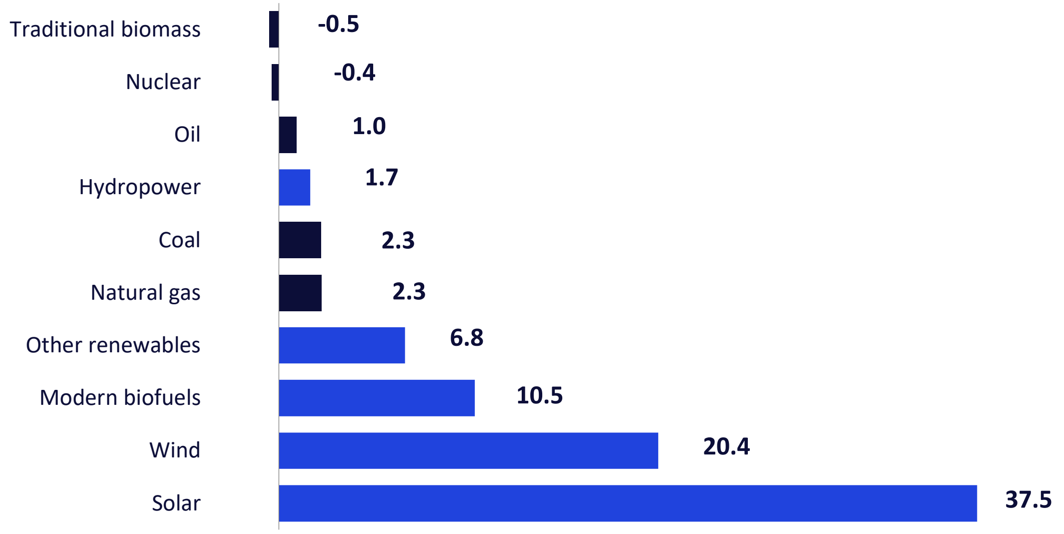
V . Real price per megawatt–hour of electricity (LCOE) [3]

US $ values as of 2019



VI . Global primary energy usage: growth in the 21st century

CAGR (%)



And, indeed, it is. Global energy usage in 2022 reached 178,899 terawatt-hours, as noted before, and that speaks of a CAGR of 1.7% since the turn of the century. The rate of low-carbon, non-nuclear sources, is 4.7%, which compares to 1.5% of fossil fuels and traditional biomass. The rates of growth of solar, wind and biofuels are in the double digits (Chart VI) and only the progress of hydropower is sluggish.

To be sure, hydro plants presently account for more electricity generation than all other non–fossil fuels technologies combined, and it should remain the world’s largest renewable source into the 2030s. But then this has become an[5] intriguing story of tougher environmental standards calling for technological innovation that eventually happened.

Regrettably, dams and reservoirs tend to disrupt river ecosystems and such adverse environmental effects led to more strict government oversight together with more painstaking licensing processes.

The reaction to the new situation has been the development of innovative concepts for hydroelectric energy storage with a focus on underwater storing and hybridization with fast energy storage systems.

In addition to advances in the electro-mechanical components and generator design, successful efforts to minimize hydropower's environmental footprint are also under way via the utilization of small-scale and fish-friendly installations. Therefore, a new, more sustainable kind of hydropower[6] is emerging.

How may the future look like?

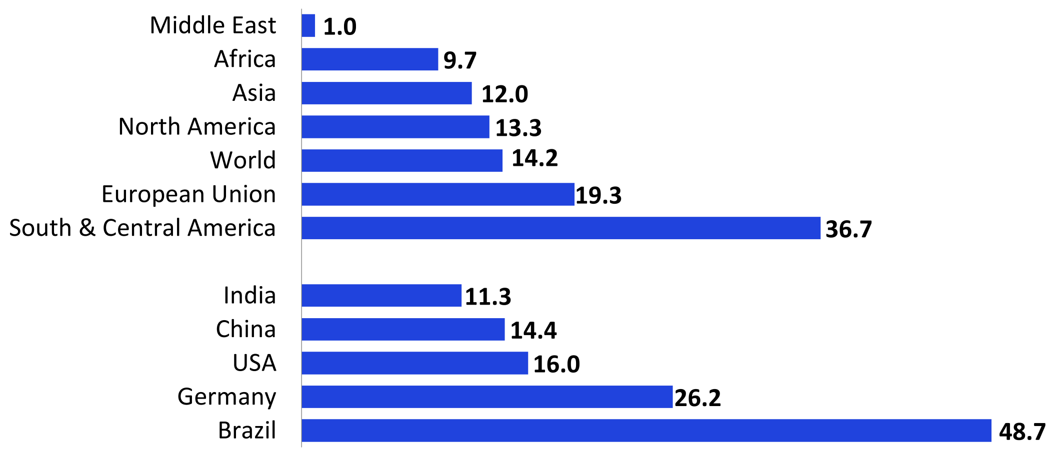
The drive towards renewable energy is exceedingly uneven across the globe, so forecasting exercises warrant caution.

Countries with a suitable endowment of natural resources vastly outperform their least endowed peers. Because of its comparative advantage on hydropower, wind, solar and biofuels, Central and South America's share of primary energy usage that came from low-carbon, non-nuclear sources, is second to none: 36.7% in 2022, more than twice the world's average. In the region's largest economy, Brazil, the share was almost 50%. (Chart VII).

On the other hand, the percentage in the Middle East, rich in oil and gas, was a slim 1%. Moreover, wealthier geographies with more substantial budget resources can use state-oriented policies to reduce their carbon footprint, thus compensating for inadequate natural resources. Accordingly, the share of primary energy usage that came from low-carbon sources in the European Union, for instance, is almost thrice that of Africa: 19.3% vs. 9.7%, respectively, even though the potential of hydro, wind and solar power of the latter is considerably greater.

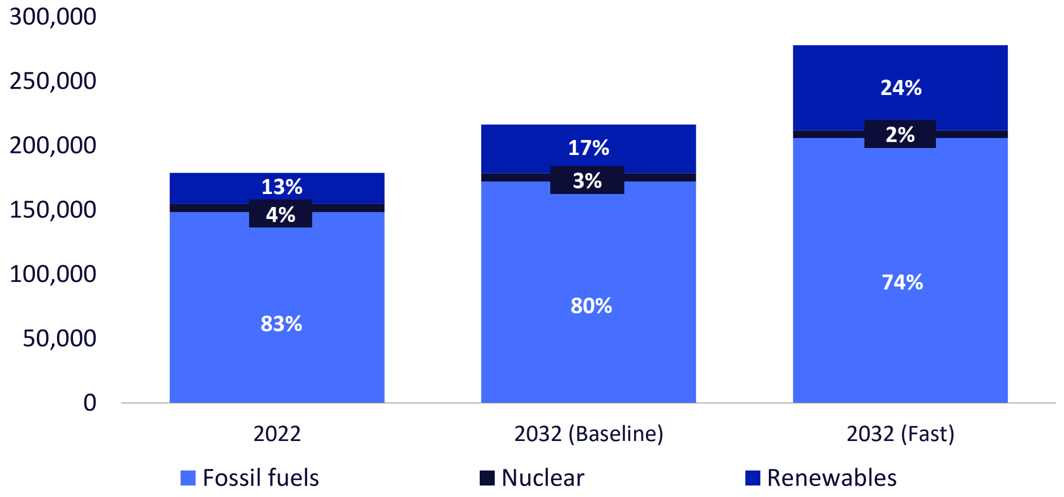
VII . Share of sustainable renewables in total energy usage

% of total in 2022



VIII. Total energy usage: latest vs. forecasts

Terawatt hour (TWh)



A baseline scenario featuring the extrapolation of the trends recorded since the turn of the century would increase the share of renewable sources in total energy usage from 13% to 17% over the next 10 years (Chart VIII).

Yet there are reasonable grounds to believe that disruptive innovations may speed up the CAGR of global energy usage within the next few years, with additional increase in the share of renewable sources.

For instance, blockchain networks, particularly those using proof-of-work (PoW) consensus mechanisms to verify transactions and create new blocks, are most energy-intensive revolution. A plausible alternative scenario incorporating such developments hints at a more relevant role for renewables, given the fast-growing demand for electricity. Accordingly, its share might grow up to 24% until 2032.

Countries and geographies that are already leading the way to sustainable low-carbon fuels will continue taking center stage.

Investment opportunities in this sector

The drive to renewable, low-carbon sources is the fundamental story in power & energy in the foreseeable future. Yet, fossil fuels will continue to account for the major share of energy usage in world for many years because there are several countries or regions that cannot prescind from hydrocarbons. Moreover, even in those geographies that can rely more heavily on wind, solar, hydro and biofuels there is the need to address the problem of their intermittency.

Against this backdrop, there are attractive risk-adjusted returns for capital allocation in gas fired power plants, especially in those using the latest combined cycle gas thermal (CCGT) technologies. Not only they are the cheapest and most efficient fossil fuel option, but also because they are a very effective stabilizing factor in power matrices with larger shares of renewables sources, which must cope with intermittencies.

Admittedly, the most straightforward proposition is to invest in renewable sources. In addition to their higher rates of demand growth, there are much fewer problems related to environment, social and governance (ESG) compared to fossil or nuclear fuels. However, not all renewables were created equal.

At this stage, there are brighter prospect for onshore wind and solar power in the light of the sharp reduction in the cost of the megawatt-hour generated. But then not all geographies are like Latin America, where the available land for wind and solar farms is plenty. Offshore solar panels and turbines may then become an option. The cost proposition is not as effective and typically there is the need for some sort of government support in the form of a subsidy, which adds another layer of risk to this investment thesis.

Hydropower without dams and reservoirs to prevent ESG issues also makes sense. Yet, that means producing at a smaller scale, typically from a facility designed to operate in a river without interfering in its flow.

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Footnotes

[1] For a more elaborated argument, see Morris (2013).

[2] Estimated using the substitution method, which approximates the energy lost as heat during combustion by estimating the primary input equivalents' if the same amount of energy were produced from fossil fuels.

[3] LCOE does not consider costs and benefits at an energy system level: such as price reductions due to low-carbon generation and higher systemic costs when storage or backup power is needed because of the variable output of renewable sources.

[4] fossil fuels also include traditional, non-renewable biomass.

[5] As forecasted by the International Energy Agency (IEA).

[6] Kougias, I., Aggidis, G. et al. (2019).

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