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Energy

History and Prospects

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Human development is inextricably linked to energy consumption - a trend that is expected to persist. The world's population is set to increase from 8.1 billion in 2023 to 9.8 billion in 2050. Yet, the 21% increase in population is overshadowed by the associated 39% energy demand[1] increase from 94.6 billion barrels of oil equivalent (BBOE) to 131 BBOE. The much higher increase in energy demand affirms the strong relationship between energy and development. Total energy demand continues to grow globally due to population growth and the development demands of middle-income countries. Also, instead of a reduction in energy use in high-income countries, the energy demand for more data centres, artificial intelligence (AI) and cryptocurrency is expected to double by 2026 from 2% of global demand in 2022.

Using the work of Vaclav Smil, the Human Development Index (HDI) posits a minimum energy level of 8.62 barrels of oil per person per year (equivalent to 100 gigajoules) for rapid development. Diminishing returns become evident at higher levels of use and, above 16.34 BOE, there is no statistically significant relationship as a saturation effect sets in. Then other factors, such as the economy's structure (including, for example, the size of the manufacturing sector), institutional quality and social capital, increase in importance to fuel human development. Eventually, the effect of these differences in the development trajectory of high-income countries is large. Thus the energy demand of Norway is 25% lower than the US even though its GDP per capita is 3% higher.

The sources from which we obtain our energy have evolved over time. Until the mid-19th century, most energy came from traditional biomass—burning wood, crop waste, or charcoal. With the Industrial Revolution came the rise of peat, coal, and, later, oil and gas. Hydropower gained momentum at the turn of the 20th century. Today, China is the leader in hydropower globally, generating four times more than Canada and Brazil, which ranked second and third.

Renewable energy sources, such as solar and wind, only emerged in the 1980s but are now driven by the imperatives to curb global warming and climate change. Advances in technology and falling costs have positioned solar power as the lowest-cost electricity source, particularly in Africa, where high solar radiation levels provide exceptional generation potential. The result is that solar is considered the renewable energy source likely to ramp up most rapidly given the low costs of installation and improvements in efficiency. Wind energy, too, has evolved into a global industry, with modern turbines now producing up to 14 MW—roughly 700 times more than early models in the 1970s.

According to the IEA, a confluence of factors—including cost reductions, climate commitments, and industrial policies such as the US Inflation Reduction Act—has accelerated clean energy investment. While renewables receive much attention, the IEA estimates the value of consumer-facing fossil fuel subsidies at US$620 billion, which is still several times more than financing for consumer-facing renewable energies.

For several years, investment in global exploration and production of fossil fuels (upstream oil and gas investment) declined after it peaked in 2015, but is again increasing. Russia's invasion of Ukraine provided new incentives to increase the search for additional oil and gas demand as European countries scrambled for alternative sources to reduce the need to import gas from Russia. In response, the US ramped up its liquefied natural gas (LNG) exports, a move expedited by former President Trump's decision in 2025 to lift restrictions on LNG infrastructure development. While this expansion will take time to impact supply, it underscores ongoing reliance on fossil fuels despite decarbonisation efforts.

Since the 1960s, more countries have begun using nuclear power. Presently the United States, China, France, Russia and South Korea leading in installed capacity. A resurgence in nuclear energy is currently underway with the development of a new generation of small modular reactors (SMRs). These reactors, designed for prefabrication and modular assembly, provide potential scalable, low-carbon baseload power. Micro, small and medium-scale modular reactors (MMRs, and SMRs) that are factory-built and standardised could eventually benefit from economies of scale, with simplified design, fuel

efficiency, reduced nuclear waste management costs and hence faster deployments and lower construction costs with the potential to be ratcheted up or down to help balance the grid alongside surging renewable output in a decade or so. Thus, at the 2023 UN COP28 climate summit in Dubai, more than 20 countries agreed to triple global nuclear power capacity by 2050. China now accounts for 16% of global nuclear generation, and Russia's influence in the sector is growing, with the two countries providing the technology for 70% of the reactors under construction.

Africa is also exploring SMRs as part of its energy transition strategy. In January 2025, Ghana inaugurated the NuScale Energy Exploration (E2) Center at the Graduate School of Nuclear and Allied Sciences in Accra, the first such facility in sub-Saharan Africa. South Africa, meanwhile, is prioritising SMRs as part of its long-term energy mix, with government officials reiterating nuclear power's role in securing energy stability. In August 2024, Rwanda formalised a partnership with NANO Nuclear Energy Inc. to integrate SMRs and micro reactors, including the ZEUS solid-core battery reactor and ODIN low-pressure coolant reactor. These initiatives indicate that nuclear power could play an important role in Africa's decarbonisation efforts.

Many challenges in the energy sector remain. The use of solid fuels (biomass, coal and charcoal) as a household energy source is still used every day by more than 3 billion people globally but is declining with more citizens accessing electricity to cook, heat and cool. Many of these households are in Africa, such as Ethiopia, DR Congo, Tanzania, Nigeria and Mozambique, where most citizens in rural areas continue to use traditional biomass for cooking and heating. Solid fuel use , particularly indoors, is associated with increased mortality from pneumonia and other acute lower respiratory diseases among children, as well as increased mortality from chronic obstructive pulmonary disease, cerebrovascular and ischaemic heart diseases, and lung cancer among adults. Household air pollution caused more than 3.2 million premature deaths in 2022.

In advanced economies, biomass is being integrated into renewable energy strategies, supporting decentralised energy production at household and municipal levels. The transition to renewable sources, coupled with advancements in battery storage and distributed energy grids, could enable more resilient, self-sustaining energy systems. However, large-scale bioenergy deployment remains constrained by land and water use concerns.

Because of the large volumes of feedstock that are required to produce energy from biomass, energy production is generally produced near the source of the feedstock. By contrast, fossil fuels such as coal, oil and gas can be transported in their original form between countries by rail, road or sea. Natural gas, oil and hydrogen can be transported by pipelines, but other means, such as by long-distance transport by ship, require that natural gas and hydrogen be refrigerated and compressed (or converted into ammonia in the case of hydrogen) which are expensive and energy intensive. The result is a complex system in which energy sources are connected and transported across national boundaries either in unrefined or final form. In this manner, production in one country feeds demand in another and shortages reverberate across regions and countries that are increasingly interdependent.

Using a common yardstick to measure energy production, in this instance billion barrels of oil equivalent (BBOE), only about 1.3% of the global energy production came from solar, 1.5% from wind and less than 1% from geothermal in 2023. Global energy production remains heavily reliant on fossil fuels: oil (32%), gas (26%) and coal (30%), with nuclear and hydro accounting for 5.2% and 2.9%, respectively. While fossil fuels continue to dominate (remaining above 80% in the last two decades), coal production is expected to peak by 2033, while global oil output is already in decline. Peak gas production is projected to occur before mid-century.

Fossil fuel producers continue to exert significant influence. For example, for several decades towards the end of the 20th century, large energy producers, mainly in the Middle East, established a cartel, the Organization of the Petroleum Exporting Countries (OPEC), that effectively controlled petroleum prices globally. OPEC market dominance was subsequently disrupted, particularly by large-scale oil and gas fracking in the US, to the extent that, together with an increase in energy efficiency and renewable energy, the US has emerged as the largest oil and gas producer globally. It

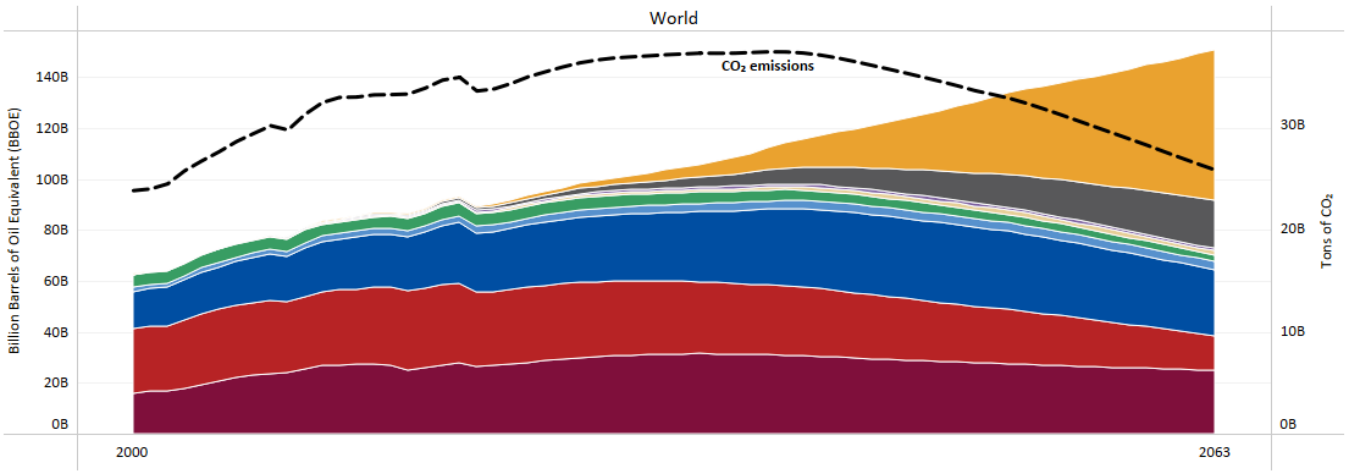
became energy-independent in 2019, now exporting large amounts of natural gas to others. Today, China, too, is actively pursuing energy self-sufficiency but has yet to satisfy domestic demand for its national resources. It has replaced the US as the largest market for oil and gas with sources generally imported from the Middle East and recently from Russia.

Emerging markets, particularly in Asia, will play a growing role in shaping future energy demand.

Chart 1 presents the current path of energy production used in our forecasts and modelling from IFs. The user can also view the associated CO_2 emissions from fossil fuels.

Chart 1: Energy production by type and CO_2 equivalent emissions, 2000-2063

Energy production measured in barrels of oil equivalent; CO_2 equivalent emissions from fossil fuels



Source: IFs 8.34 initialising IEA World Energy Balances

The war in Ukraine temporarily created a tight LNG market, resulting in record-high prices in 2022 and a European rush for imports, although 2023 prices were significantly lower. In time, a significant gas supply will come to the market due to the European scramble for alternative supply and the steady increased US production, potentially creating an oversupply towards the end of the decade. Gas is less carbon intensive than coal or oil so this is potentially good news although it is important to recognize that low gas prices may delay the shift to renewables.

Because energy demand and carbon emissions from China are the highest globally, it will play an outsized role in shaping global energy and emission trends. In the last decade, China accounted for almost two-thirds of the rise in global oil use, and nearly one-third of the increase in natural gas, and has been the dominant player in coal markets. Yet, China has emerged as a powerhouse in renewables, accounting for around half of wind and solar additions and over half of global electric vehicle (EV) sales. In 2023, China surpassed the rest of the world's collective 2022 solar PV installations while its wind power additions increased by 66% from 2022 to 2023. As a result, China is likely to achieve its 2030 target for wind and solar PV installations in 2024, six years ahead of schedule. According to the IEA, two-thirds of global wind manufacturing expansions planned for 2025 will occur in China, primarily for its domestic market. Hence, the view that China will drive global renewable energy deployment to global benefit. However, the IEA forecast of China's economic growth at just below 4% per annum to 2030 is conservative. China may grow more rapidly which will release substantially more carbon into the atmosphere.

While things are also changing rapidly in the US, given its volatile presidential politics, its model is quite different. In 2023, fossil fuels (natural gas, petroleum and coal) accounted for 84% of US primary energy production, nuclear for 8% and renewables including hydro also at 8%. Total energy production in the US has exceeded annual energy consumption since

2019—a remarkable turnaround for a country previously dependent on oil from the Middle East. Instead of debating energy import dependence, policymakers are seized with decisions regarding investments in LNG terminals to export its surplus of natural gas—with newly re-elected President Donald Trump rapidly overturning the pause on LNG export licence approvals imposed by the Biden administration.

While many high-income countries have enacted policies and laws specific to renewable energy, only half of least developed countries (LDCs) and a third of small island and developing states (so-called SIDS) have done so, finds UNCTAD. Efforts to develop comprehensive legal and regulatory frameworks to advance clean energy technologies are limited mainly to developed and large emerging economies. Instead, countries like Gabon, Tanzania, Liberia, Kenya, Zambia and Angola engage with carbon credit arrangements with debatable impacts on emission reductions. Through a carbon credit scheme, a polluter can buy a carbon credit typically worth one metric ton of carbon dioxide (CO_2), with the money paid then used for carbon-lowering projects such as protecting natural ecosystems and wildlife resources, planting trees and generating renewable electricity. The intention is to create a financial incentive for companies to reduce emissions.

Roughly 24% of global emissions are now covered by some form of carbon credit pricing, with the newly established Africa Carbon Markets Initiative (ACMI) aiming to unlock US$6 billion in revenue to create 30 million jobs by 2030. These forecasts need to be treated with care, however, since verification is complex. For example, the UAE-based Blue Carbon, the company leading most efforts, was, in 2023, barely a year old without any track record in the area.

With limited state resources and amidst competing demands, poor countries struggle to invest in the efforts required to unlock a different pathway to the fossil-fueled example set by others. These findings underpin UNCTAD's calls for the international community to help developing countries urgently attract sufficient investment to transition to clean energy. The associated estimate is that the world needs to invest US$1.5 trillion annually to triple renewable power and double energy efficiency by 2030 as critical steps towards keeping the 1.5^{o}C Paris goal alive.

Endnotes

1. Excluding biomass. Demand consists of consumption and unmet demand.

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Dr Jakkie Cilliers is the ISS's founder and former executive director. He currently serves as chair of the ISS Board of Trustees and head of the African Futures and Innovation (AFI) programme at the Pretoria oce of the Institute. His 2017 best-seller Fate of the Nation addresses South Africa's futures from political, economic and social perspectives. His three most recent books, Africa First! Igniting a Growth Revolution (March 2020), The Future of Africa: Challenges and Opportunities (April 2021), and Africa Tomorrow: Pathways to Prosperity (June 2022) take a rigorous look at the continent as a whole.

Ms Alize le Roux joined the AFI in May 2021 as a senior researcher. Before joining the ISS, she worked as a principal geo-informatics researcher at the CSIR, supporting various local and national policy- and decision-makers with long-term planning support. Alize has 14 years of experience in spatial data analysis, disaster risk reduction and urban and regional modelling. She has a master's degree in geographical sciences from the University of Utrecht, specialising in multi-hazard risk assessments and spatial decision support systems.

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