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Background report on the role of emerging technologies in sustainably advancing energy security in Africa

I. Introduction

1. The present background report is intended to highlight some of the new and emerging energy technologies that are likely to underpin future energy industries and, hence, some of the opportunities, advantages and urgent actions that Africa must take into consideration in order to participate in the rapidly growing new energy economy.

2. Currently, energy needs in Africa are met largely by biomass (about 50 per cent), fossil fuels (22 per cent), coal (14 per cent) and natural gas (14 per cent), and that energy mix has not changed in the past three decades.[1] By contrast, energy consumption in the United States of America is thought to have moved from about 70 per cent biomass in the 1870s to 70 per cent coal in 1900 to about 70 per cent oil and gas by 1960.[2] Each of these phases of transition represented different levels of technological know-how and innovation, which created industrial opportunities and opened up new markets, while also bringing improvements in people's lives.[3,4] While Africa missed a large share of those opportunities, the new and emerging energy technologies present unparalleled advantages for acquiring technological know-how and for leapfrogging previous energy revolutions in order to help the continent achieve the goals set out in the 2030 Agenda for Sustainable Development and Agenda 2063: The Africa We Want, of the African Union.

3. Research shows that investing in clean energy is likely to have a positive impact on the achievement of all 17 Sustainable Development Goals with the exception of Goal 17 (on partnerships), and that investing in decarbonization will have a positive effect on the achievement of all the Goals with the exception of Goal 4 (on education) (see table 1).[5] Various renewable energies present different opportunities, benefits, risks and challenges. For instance, biofuels have greater positive impacts on targets of the Sustainable Development Goals related to economics, technology and climate but could have negative impacts on other

[1] International Renewable Energy Agency, *Africa 2030: Roadmap for a Renewable Energy Future* (Abu Dhabi, International Renewable Energy Agency, 2015).

[2] Peter A. O'Connor, "Energy transitions", The Pardee Papers, No. 12 (Boston, Boston University, 2010).

[3] United Nations, Economic Commission for Africa (ECA), "Energy prices in Africa: transition towards clean energy for Africa's industrialization", 2021.

[4] International Finance Corporation, *The Dirty Footprint of the Broken Grid: the Impacts of Fossil Fuel Back-up Generators in Developing Countries* (Washington D.C., International Finance Corporation, 2019).

[5] Jeffrey D. Sachs and others, "Six transformations to achieve the Sustainable Development Goals", *Nature Sustainability*, vol. 2 (August 2019).

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dimensions of the Goals (e.g. land and water use and health).[6] Similarly, solar energy may be cheaper, easier to deploy and manage, and can be installed on wasted or unfertile lands, but it can have a lifespan of only 20–30 years, and the associated waste could have a negative environmental impact if not planned and managed.

Table 1
Energy outputs and outcomes of the Sustainable Development Goals

Output	*Goal1*	*Goal2*	*Goal3*	*SDG4*	*Goal5*	*Goal6*	*Goal7*	*Goal8*	*Goal9*	*Goal10*	*Goal11*	*Goal12*	*Goal13*	*Goal14*	*Goal15*	*Goal16*	*Goal17*
Clean energy access for all	2	1	2	2	2	1	3	2	3	2	3	2	3	1	2	1	0
Energy decarbonization	1	2	2	0	1	2	3	2	2	2	2	3	3	2	2	2	1

Source: Sachs and others, “Six transformations to achieve the Sustainable Development Goals”.

Note: Four-point scale: 3, output directly targets the Sustainable Development Goal outcomes; 2, output reinforces the Goals; 1, output enables the Goals; and 0, output does not interact with the Goals.

4. With regard to renewable energy potential, Africa has abundant resources, with a solar energy capacity of 10 TW, a hydropower capacity of 350 GW, a wind energy capacity of 110 GW and a geothermal energy capacity of 15 GW. A major challenge and bottleneck that many countries face is the question of how to convert these immense energy resources into forms of energy to cost-effectively, safely and reliably power homes, transportation, businesses, farms and social amenities. In addition to providing an energy supply, these resources can also help Africa to participate in innovations and industrial applications (e.g. electric mobility, manufacturing and electricity) relating to new and emerging technologies. For instance, the innovations involving batteries have created exciting new markets for wired and wireless recharging stations and a new generation of cars, scooters and bikes, each with their own value chains. It is in this manner that new players enter the market, new industries are born, new jobs and wealth are created, and new knowledge is generated, with significant positive impacts on economic, social and environmental development.

II. Development and growth of emerging energy technologies

5. In the present section, a few emerging energy technologies that Africa should seriously consider and pursue are examined – noting that renewable energy produces lower life cycle greenhouse gas emissions than conventional fossil fuels and that it may be faster to install, easier to maintain and more adaptable to local needs than current energy technologies. For example, life cycle greenhouse gas emissions from solar photovoltaic energy and wind energy are 4 per cent and 1.5 per cent, respectively, and the facilities can easily be monitored remotely and managed by local communities.[7]

6. There are various emerging technologies for energy capture, conversion, storage and use. The following sections of the present report are focused on a select

[6] Fernanda Silva Martinelli and others, “Will Brazil’s push for low-carbon biofuels contribute to achieving the SDGs? A systematic expert-based assessment”, *Cleaner Environmental Systems*, vol. 5 (2022).

[7] Thomas Bruckner and others, “Energy systems” in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, Cambridge University Press, 2014).

set of energy technologies – solar energy, batteries and hydrogen – in which Africa has a good chance at being successful and acquiring technological know-how.

A. Solar photovoltaic technologies

7. Solar photovoltaics is one of the cleanest, safest and most well-established renewable energy technologies for generating electricity both at small and large scales, and it involves different types of solar cell technologies. At the heart of photovoltaic systems are solar cells – the electrical devices that convert solar energy into electrical energy.[8] The average solar cell provides about 0.5 volts, which is not enough to power basic devices, so several cells are combined to create a solar module, and a series of solar modules make up a solar panel.

Table 2
Market size of different photovoltaic system components

	Cells 	*Panels* 	*Batteries* 	*Inverters* 	*Services* 
Market value in 2021 or latest available	$26 billion	$180 billion	$3.1 billion	$16 billion	$151 billion
Market value by 2030	$37 billion	$641 billion	$9.5 billion	$34 billion	$292 billon
Related skills and personnel	Research and development chemists, physicists, engineers and material scientists, and manufacturing, quality assurance and sales personnel, among others				Architects, project designers, managers, electricians and plumbers

Source: Economic Commission for Africa (ECA) estimates, which are based on various market research sources.

8. With regard to market size, first-generation, crystalline, silicon-based solar cells account for about 93 per cent of the global market, followed by thin film at 7 per cent. The estimated total value of the global market was $26 billion in 2021[9] and may hit $37 billion by 2028 (see table 2). Similarly, the global market for solar panels was valued at $180.4 billion in 2020 and may rise to $641.1 billion by 2030,[10] while the market for solar batteries was valued at $6.8 billion in 2020 and is projected to reach $18 billion by 2027.[11] The global market for solar photovoltaic inverters was estimated at $16.3 billion in 2022 and may rise to $33.9 billion by 2028.[12]

[8] Mahmood H. Shubbak, "Advances in solar photovoltaics: technology review and patent trends", *Renewable and Sustainable Energy Reviews*, vol. 115 (November 2019).

[9] Global Market Insights, *Solar Cells Market Size, By Material (Crystalline {N Material, P Material}, Thin Film), By Product (BSF, PERC/PERL/PERT/TOPCON, HJT, IBC & GWT), By Technology (Monocrystalline, Polycrystalline, Cadmium Telluride (CDTE), Amorphous Silicon (A-Si), Copper Indium Gallium Diselenide), COVID-19 Impact Analysis, Regional Outlook, Application Potential, Competitive Market Share & Forecast, 2022–2028* (Selbyville, United States, Global Market Insights, 2022), available at www.gminsights.com/industry-analysis/solar-cells-market.

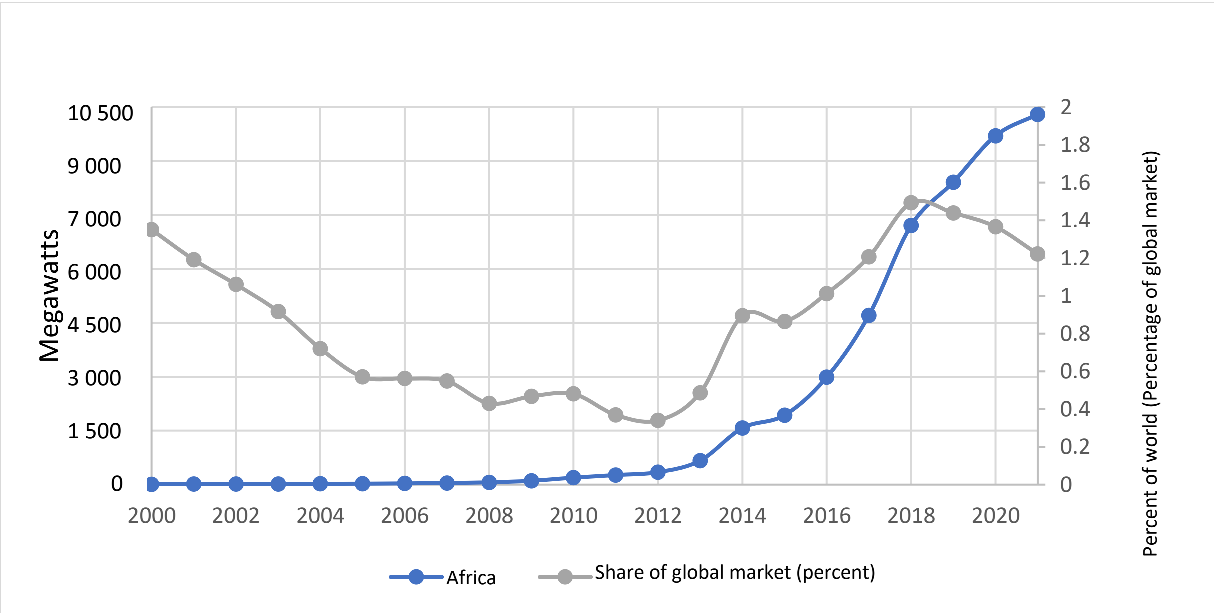
[10] Allied Market Research, *Solar Photovoltaic (PV) Panel Market by Technology (Crystalline Silicon, Thin Film, and Others), Grid Type (On-grid and Off-grid), and End Use (Residential, Commercial & Industrial, and Others): Global Opportunity Analysis and Industry Forecast, 2021–2030* (Portland, United States, Allied Market Research, 2022), available at www.alliedmarketresearch.com/solar-photovoltaic-panel-market.

[11] Global Industry Analysts, Inc., *Solar Batteries: Global Strategic Business Report*, available at www.researchandmarkets.com/reports/5030432/solar-batteries-global-market-trajectory-and.

[12] Markets and Markets, *Inverter Market by Type (Solar Inverters, Vehicle Inverter, others), Output Power Rating (Up to 10 kW, 10–50 kW, 51–100 kW, above 100 kW), End User (PV Plants, Residential,*

9. Africa needs to make great efforts to enter the market by supporting skills development, research and development and manufacturing capabilities. The range of skills needed include those for research and development (e.g. those held by professionals in the fields of chemistry, physics, engineering, digital technology and nanotechnology); those for the manufacturing of cells, modules, panels, batteries, inverters, controllers and other electronic components (e.g. those held by production and process engineers, chemists, physicists, and quality assurance and marketing managers); and those for the design, installation, maintenance, upgrading and safe decommissioning of solar energy systems (e.g. those held by environmental impact assessment experts, electricians, welders and plumbers). A multipronged approach may be needed whereby Africa encourages collaboration in the development of large, grid-size plants among foreign suppliers, research and development and learning institutions, and emerging knowledge-intensive start-ups interested in growing, so as to quickly build skills across the entire value chain. This should not be difficult, considering that the solar energy market is growing rapidly in Africa – from about 10.9 MW in 2000 to 10,302.2 MW in 2021. Most of that growth was achieved after 2012 (see figure I). However, as a share of the global solar energy market, Africa accounts for about 1.2 per cent.

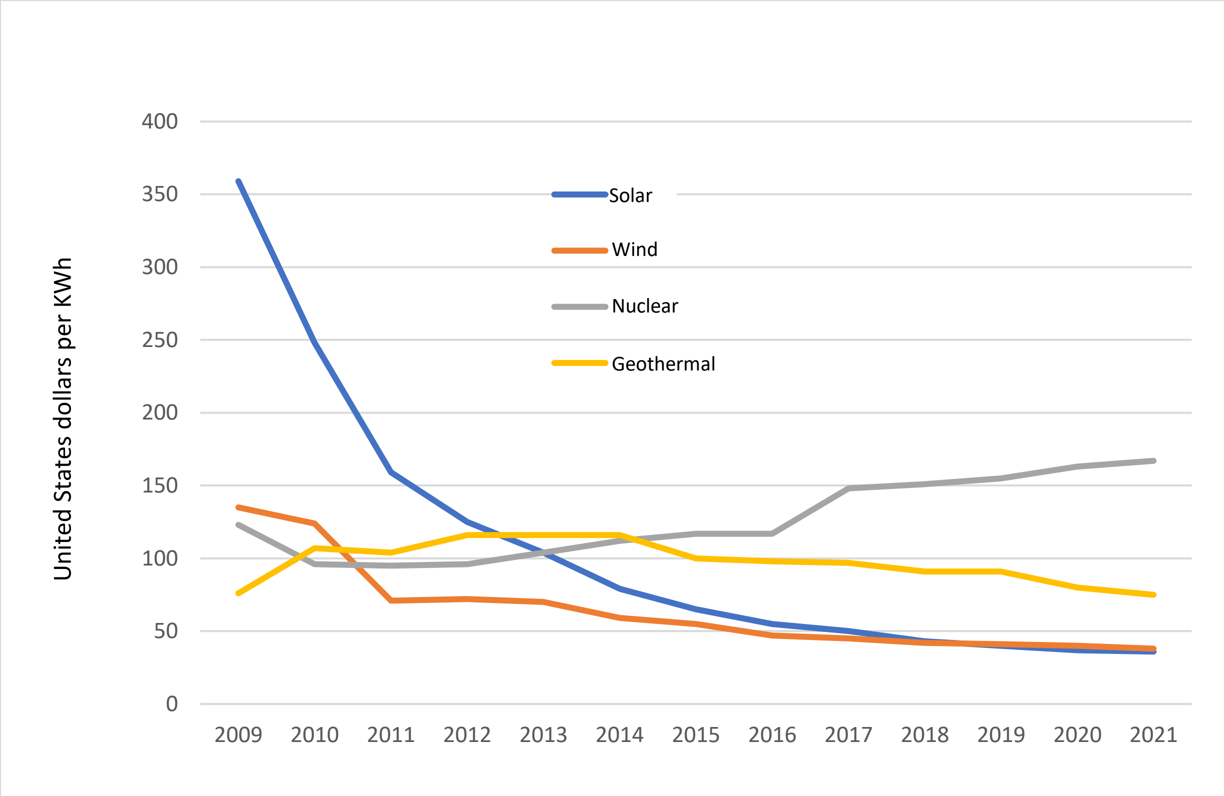
Figure I
Photovoltaic electricity capacity in Africa



Source: International Renewable Energy Agency database, available at www.irena.org/Data, accessed on 16 April 2022.

Automotive), Connection, Voltage, Sales Channel & Region – Global Forecast to 2027), available at www.marketsandmarkets.com/Market-Reports/inverter-market-263171818.html.

Figure II
Levelized prices of electricity, by source



10. Growing a domestic knowledge base is important, as the rapid uptake of solar photovoltaic systems has been driven by improvements in solar technology, reductions in manufacturing costs, increased funding for renewable energy and the enabling of renewable energy policies.[13] Photovoltaic technologies (e.g. crystalline silicon and cadmium telluride) are now produced at an industrial scale, and many more technologies are in development.[14] As a result, the price of photovoltaic systems has decreased significantly since 2010 (see figure II). As of 2019, the average levelized cost of the generation of solar photovoltaic electricity was $51 per MWh – making it a cheaper source of grid-scale electricity than coal.

B. Battery technologies for energy storage

11. There are several battery technologies, of which the most common and advanced include lithium-ion, lead-acid, redox flow, sodium-sulfur, sodium metal halide, zinc-hybrid and cathode batteries. Each has its own advantages, strengths and limitations. The lithium battery is perhaps the most used in mobile devices and in the mobility sector (e.g. laptops, mobile phones, electric vehicles, electric scooters and electric bicycles). Developed in the 1970s during the oil crisis, it has laid the foundation for a wireless, fossil-free society.[15] Rapid technological advancement has driven down prices per kWh from $1,160 in 2010 to $176 in 2018, and the price is expected to drop further.[16] Lithium-ion batteries hold more charge per volume (about

[13] Gregory M. Wilson and others, “The 2020 photovoltaic technologies roadmap”, *Journal of Physics D: Applied Physics*, vol. 53, No. 49 (2020).

[14] National Renewable Energy Laboratory, “STAT FAQs part 2: lifetime of PV panels”, 23 April 2018, available at www.nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html.

[15] Nobel Foundation, “They developed the world’s most powerful battery”, available at www.nobelprize.org/prizes/chemistry/2019/popular-information/.

[16] Bloomberg, “Gasoline prices around the world: the real cost of filling up”, 4 August 2020.

126 W per kg), require less, if any, maintenance and have a lifespan of up to 15 years. These batteries are equally accessible both for small-scale installations (e.g. mobile phones) and for large-scale installations (e.g. power utilities) but are still relatively expensive and pose a low but possible risk of fire.

12. Other batteries with high storage capacity include the nickel-cadmium and the nickel-metal halide batteries. These batteries can hold a high density of energy and are capable of instantaneous and continuous high energy discharges, which is important in various applications, such as power tools and emergency applications (e.g. powering the emergency system of aeroplanes if their engines lose power). While they are still in use, the cost of the metals used and the toxicity of cadmium have limited their applications. The European Union, for example, has banned cadmium-based batteries in portable devices.[17]

13. Lead-acid batteries offer a cheaper energy storage solution for home solar systems and are used in automobiles to start and run vehicle accessories. They are easy to dispose of and recycle but require maintenance (that is, they may leak), have a shorter lifespan (about five years if cared for properly) and are bulkier and require more space for the same energy storage capacity as lithium batteries. They are estimated to have a power density of about 7 W per kg and thus are useful in cases where space is not a major limitation or where a small amount of power is needed (e.g. to start a car).

14. Similarly, flow batteries contain a water-based electrolyte that stores chemical energy. They are bulky and expensive. Unlike other batteries, however, they can be discharged fully and can run for up to 10,000 cycles without a loss in performance. Flow batteries have a lifespan of up to 30 years, are adaptable to various environments and case uses, and do not require much maintenance. They are suitable for grid-sized storage rather than for mobility-related uses.

15. While household-sized and office-sized batteries are likely to be generic to fit general use cases, grid-type batteries are likely to be purpose-built and customized to meet the desired specifications with regard to the amount of power they should hold and discharge to keep large business operations (e.g. mines) running or entire cities powered. Large battery energy storage systems could provide a powerful tool for balancing the grid by charging during off-peak hours (e.g. at night when electricity is cheaper) and discharging during peak energy demand periods (e.g. during the day). More importantly, batteries constitute a flexible energy storage system solution that can be moved from one location to another and from one case use to another much more easily and more quickly than other options (e.g. pumped hydropower storage systems).

16. As with solar energy, a range of skills are needed to meet the demands related to the various components of the battery value chain, which may include expertise in research and development, in the processing of battery minerals and materials, and in the manufacturing, assembly, installation, maintenance and recycling of batteries (e.g. those used in mobility devices, electricity grids and off-grid systems and mobile devices). More specifically, important areas in which education, skills and knowledge are needed include the fields of battery minerals and chemicals processing, automation and industry 4.0 technologies, the mass manufacturing of battery components and cells, and electrical and engineering expertise related to the manufacturing, installation and maintenance of batteries in vehicles, electricity grids and other applications.[18] As noted above, key aspects to consider include costs, power

[17] European Union, Directive 2013/56/EU of the European Parliament and of the Council of 20 November 2013 amending Directive 2006/66/EC of the European Parliament and of the Council on batteries and accumulators and waste batteries and accumulators as regards the placing on the market of portable batteries and accumulators containing cadmium intended for use in cordless power tools, and of button cells with low mercury content, and repealing Commission Decision 2009/603/EC.

[18] South Metropolitan TAFE Western Australia, “Vocational skills gap assessment and workforce development plan” (Bentley, Australia, Future Battery Industries Cooperative Research Centre, 2021).

storage capacity, lifespan and space requirements. For instance, the United States Department of Energy has set a goal of reducing by 90 per cent within a decade the costs of grid-scale energy storage for systems that deliver continuous energy supply for 10 or more hours.[19] Africa will also need to set similar goals to meet its own needs or at least to keep up with developments in science, technology and industry in order to remain competitive. While this point will be addressed in detail in a subsequent section of the present report, suffice it to say that industrial alliances with leading countries and collaboration with research and development institutions will be needed if Africa is to catch up.

C. Hydrogen and hydrogen-related technologies

17. Hydrogen is an exciting renewable energy source with multiple applications in a range of sectors. First, hydrogen is a great carrier of and source of energy and it can be derived from a variety of sources. As such, the opportunities are not limited by environmental factors (e.g. sunlight exposure in the case of solar energy) or by application (e.g. batteries largely for energy storage). Second, hydrogen has a large storage capacity and can be stored and transported in gas, liquid or other chemical forms (e.g. ammonia). Finally, hydrogen can also be used as a feedstock for various industrial applications (e.g. fertilizers and electric fuels).

18. Thanks to the above-mentioned attributes of hydrogen, the global market for hydrogen energy is growing rapidly. As shown in table 3, the global hydrogen generation market is expected to grow from about $129 billion in 2022 to about $255 billion by 2030. As the world seeks to decarbonize, the market for electrolysers needed to convert water into hydrogen and oxygen is expected to rise from about $6 billion in 2021 to about $69 billion by 2030, while the market for hydrogen storage is expected to nearly double, and the market for fuel cells may grow 61-fold between now and 2030.

Table 3
Size of various hydrogen market segments

Market value	*Electrolysers*	*Storage*	*Fuel cells*	*Overall generation*
2021 or latest available	$6.0 billion	$15.0 billion	$0.7 billion	$129.0 billion
By 2030	$69.0 billion	$26.9 billion	$43.0 billion	$225.0 billon

Source: ECA estimates, which are based on various market research sources.

19. Currently, about 96 per cent of the hydrogen produced is from fossil fuels (or is grey or blue hydrogen if the carbon dioxide is captured). With regard to sources, almost 70 per cent of the hydrogen in the market is from natural gas, while 27 per cent is from coal. Only about 3 per cent is from renewable sources. Most of the pledges announced by countries in this regard (about $73 billion)[20] are aimed at accelerating the production of green hydrogen, as soaring prices for petroleum products have led to a 70 per cent rise in brown hydrogen prices.

20. There are a number of areas, the majority of which are interlinked, that need to be addressed from a technological and market-oriented viewpoint in order to increase the share of green hydrogen. The first challenge is that of reducing the cost of green hydrogen production. As can be seen in table 4, hydrogen derived from water using electrolysis costs between $5.8 and $23.3 per kg of hydrogen, while hydrogen derived from coal costs about $1.3 per kg of hydrogen. For example, the United States

[19] United States Department of Energy, Office of Energy Efficiency and Renewable Energy, "Long duration storage shot", available at www.energy.gov/eere/long-duration-storage-shot.

[20] Carbon Tracker Initiative, "Clean hydrogen's place in the energy transition: destined for dramatic growth if obstacles overcome", available at https://carbontracker.org/wp-content/uploads/2022/10/Clean-Hydrogens-Place-in-the-Energy-Transition-1.pdf.

Department of Energy is supporting research aimed at reducing the overall cost of producing hydrogen from \$5 per kg to \$1 per kg of hydrogen in one decade. Such a development would potentially curb 16 per cent of carbon dioxide emissions by 2050, while also generating 700,000 jobs and \$140 billion in revenue by 2030 in the United States alone.[21] New approaches that integrate hydrogen production into existing industrial applications have been shown to have the potential to produce green hydrogen for less than \$1 per kg.[22]

21. Hydrogen energy will require investment in infrastructure for transportation (e.g. pipelines, trucks and port terminals), storage (e.g. liquid hydrogen tanks), and use and sale (e.g. hydrogen fuelling stations and compressors), as well as in skills that, among other things, are required for the safe use of hydrogen and for maintaining competitive markets. Most African countries have neither extensive gas pipelines nor related support services or industries that can easily be repurposed. Thus, Africa may require new facilities or alternatives in order to establish competitive hydrogen energy development.

22. For example, the green hydrogen production project in Namibia, with an estimated annual output of 300,000 tons of hydrogen when fully operational, will require an investment of \$10 billion,[23] which is more than all its foreign direct investment inflows for the past decade and close to its gross domestic product of about \$12.2 billion in 2021.[24] In order to meet this investment need, Namibia is building partnerships with technology owners and engaging other stakeholders in investment and trade promotion.[25] The project is a major investment opportunity for developed countries and firms from those countries that are seeking to reduce their carbon emissions, enhance their green credentials and participate in one of the fastest growing industries. With the backing of the Government of Namibia and the Namibian Ports Authority, tracts of uninhabited land with plenty of sunshine, wind and water resources have been allocated to ensure the success of the project. Many of the hydrogen projects announced are in developing countries (e.g. Chile, Morocco and South Africa) and involve various partnerships with and interests in developed countries.

[21] United States Department of Energy, Hydrogen and Fuel Cell Technologies Office, "Hydrogen shot", available at www.energy.gov/eere/fuelcells/hydrogen-shot.

[22] Tong Wenming and others, "Electrolysis of low-grade and saline surface water", *Nature Energy*, vol. 5 (2020).

[23] Hyphen Hydrogen Energy, "Namibia announces progress with Hyphen Hydrogen Energy to unlock US\$10bn investment for first green hydrogen project to help power the energy transition", 1 June 2022.

[24] World Bank, "World development indicators", DataBank, available at https://databank.worldbank.org/source/world-development-indicators (accessed on 20 December 2022).

[25] European Commission, "COP27: European Union concludes a strategic partnership with Namibia on sustainable raw materials and renewable hydrogen", 8 November 2022, available at https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6683.

Table 4
Costs of various hydrogen production technologies

Process	*Energy source*	*Feedstock*	*Capital cost (Millions of US$)*	*Hydrogen cost (US$/kg)*
Steam methane reforming	Standard fossil fuels	Natural gas	180.7	2.08
Gasification	Standard fossil fuels	Coal	435.9	1.34
Methane pyrolysis	Internally generated steam	Natural gas	..	1.59–1.70
Biomass pyrolysis	Internally generated steam	Woody biomass	53.4–3.1	1.25–2.20
Biomass gasification	Internally generated steam	Woody biomass	149.3–6.4	1.77–2.05
Photo-fermentation	Solar	Organic biomass	..	2.83
Solar photovoltaic electrolysis	Solar	Water	12.0–54.5	5.78–23.27
Solar thermal electrolysis	Solar	Water	421.0–22.1	5.10–10.49
Wind electrolysis	Wind	Water	504.8–499.6	5.89–6.03
Nuclear electrolysis	Nuclear	Water	..	4.15–7.00
Nuclear thermolysis	Nuclear	Water	39.6–2 107.6	2.17–2.63
Solar thermolysis	Solar	Water	5.7–16.0	7.98–8.40
Photo-electrolysis	Solar	Water	..	10.36

Source: Michael Ball and Marcel Weeda, “The hydrogen economy – vision or reality?”, *International Journal of Hydrogen Energy*, vol. 4, No. 25 (6 July 2015).

23. Other such projects involve the development of the infrastructure, skills, know-how and other resources needed to build a viable hydrogen value chain.[26] As in other areas, many of the skills required may be technical in nature, while others may require education at the MSc or PhD level (e.g. for research and development related to components for electrolysers, safety and standards, and infrastructure design). In other cases, minor upgrades to existing skills in industry and academia may be needed, while most of the necessary skills may have to be newly acquired, especially in countries without an existing gas industry and related infrastructure.

III. Characteristics likely to underpin success

24. As noted above, new and emerging energy technologies “encompass an array of new materials, products, applications, processes and business models [that] are interdependent, interconnected and mutually reinforcing”[27] and benefit from advances in numerous disciplines, such as in nanotechnology, material science, electrochemistry, biotech, engineering and digital technologies, among others. Accordingly, emerging technologies generate diverse opportunities for new players to enter different segments of the energy market. A small window of opportunity therefore exists for acquiring collective, technological know-how and for taking advantage of technological and market niches and, as a result, catching up and leapfrogging.

25. However, new technologies often build on existing scientific, technological and industrial knowledge bases. This suggests that countries that already have the basic infrastructure, skills, knowledge and support industries in place are better positioned to lead. For instance, manufacturers or assemblers of fossil fuel vehicles need to adjust their existing assembly platforms and acquire new resources, both

[26] Roger H. Bezdek, “The hydrogen economy and jobs of the future”, *Renewable Energy and Environmental Sustainability*, vol. 4 (2019).

[27] *World Economic and Social Survey 2018: Frontier Technologies for Sustainable Development* (United Nations publication, 2018).

tangible and intangible, to meet the manufacturing requirements for electric cars. Those that do not have experience in car assembly, however, will have to build their vehicle manufacturing capabilities and their supply and value chains from scratch, which presents a steep learning curve.

26. The case of Tesla, for instance, suggests that new entrants that possess core product knowledge (i.e. regarding electric battery technology) and skills, a unique business model that is attractive to investors and a product positioned to appeal to the market can compete even without prior experience in the industry, if they take advantage of the first-mover advantage.[28] Countries and firms in Africa that wish to enter the new energy sector may have to take similar approaches – that is, enter the market early, find a niche and build the capabilities needed to succeed. The main argument for this approach is that the cost of entry into the market increases astronomically as technologies mature, because the number of competitors rises, products become more sophisticated and consumer expectations go up. For instance, today's electric cars are technological masterpieces that come with a promise of low maintenance costs, high safety standards and good road performance compared with the electric cars produced two decades ago.

27. Another key element underpinning success in the development of new emerging technologies is the continuous, active acquisition of technological know-how,[29] irrespective of the industry in question. All energy technologies – from those involving solar cells to batteries – will continue to evolve at a rapid pace. Countries will have to continuously learn to keep up with new advances in the relevant sector. This will be true at the energy conversion technology level (e.g. solar cells and electrolysers for hydrogen production), the energy storage level (e.g. batteries and pumped hydropower) and the application level (e.g. solar-powered products).

28. As the technologies mature, public sector research and development investment in renewable energy is likely to be surpassed by private sector investment. By that point, the protection of intellectual property as it relates to key technologies will make it more difficult and more expensive to gain access to new knowledge. Countries seeking to corner a portion of the emerging renewable energy market may therefore wish to get in early and learn together with the rest of the world.

IV. Carving out a stake for Africa in emerging energy technologies

29. The market for renewable energy products is growing rapidly, both in Africa and around the world. For example, between 2000 and 2019, the total energy supply in Africa grew by 75 per cent, while the renewable energy supply grew by 1,740 per cent (see figure III). The question is therefore not whether there is an appetite for renewable energy in Africa,[30] but rather whether the current approaches and business models[31] are likely to help Africa reduce its dependence on traditional fossil fuels and biomass. For African countries, high energy prices and a lack of alternative, modern energy sources to meet their energy needs may be other key factors, in addition to falling prices, business opportunities and environmental concerns.

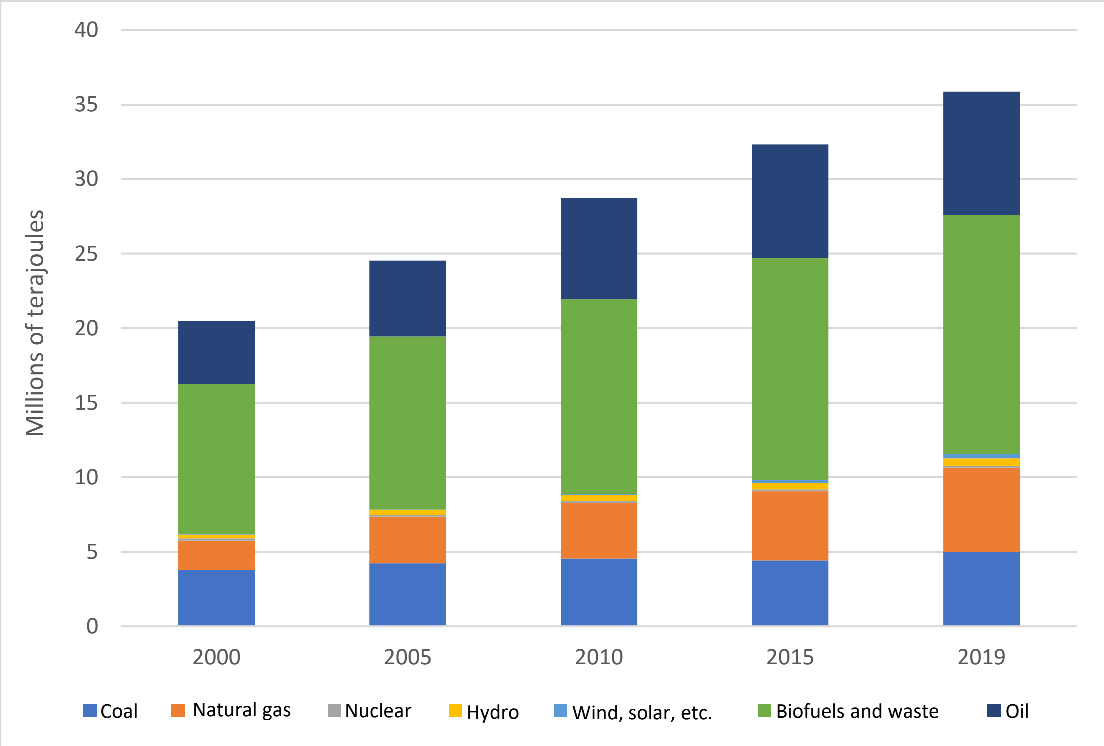
[28] Forbes, "Tesla notches first full-year profit, aided by $270 million fourth-quarter net income", 27 January 2021.

[29] Eduardo B. Viotti, "National Learning Systems: a new approach on technological change in late industrializing economies and evidences from the cases of Brazil and South Korea", *Technological Forecasting and Social Change*, vol. 69, No. 7 (September 2002).

[30] Anders Ellegård and others, "Rural people pay for solar: experiences from the Zambia PV-ESCO project", *Renewable Energy*, vol. 29, No. 8 (July 2004).

[31] Velma Mukoro, Maria Sharmina and Alejandro Gallego-Schmid, "A review of business models for access to affordable and clean energy in Africa: do they deliver social, economic, and environmental value?", *Energy Research and Social Science*, vol. 88 (June 2022).

Figure III
Total energy supply of Africa



Source: ECA data, which are based on the International Renewable Energy Agency database.

30. What can Africa do to carve out a decent portion of the future global market for renewable energy? Until a few decades ago, the production and export of solar photovoltaic industry products was an exclusive club made up of advanced countries in Europe and the United States. Today, however, China and India are producers of solar energy components and systems, and Viet Nam is also emerging as a producer of solar energy products. China, for instance, has supported innovative, private start-ups,[32] which are often attracted by ambitious, long-term government investment programmes, human capital development[33] and investment in research and development infrastructure. China boasts entire universities and numerous schools and academic programmes specialized in energy, thereby providing the talent and knowledge necessary for energy development planning at the industry and national levels.[34] Similarly, Viet Nam attracted foreign and domestic investors to develop local production and exports through its ambitious programme that saw installed solar energy grow from 105 MW in 2018 to 16,660 MW in 2020.[35] African countries need similarly ambitious plans. Highlighted below are a few steps that African countries could pursue to compete successfully.

[32] Matthew Hopkins and Yin Li, "The rise of the Chinese solar photovoltaic industry: firms, governments, and global competition", in *China As an Innovation Nation*, Yu Zhou, William Lazonick and Yifei Sun, eds. (Oxford, Oxford University Press, 2016); and Ping Huang and others, "How China became a leader in solar PV: an innovation system analysis", *Renewable and Sustainable Energy Reviews*, vol. 64 (2016).

[33] David Cyranoski and others, "Education: the PhD factory", *Nature*, vol. 472 (2011).

[34] Sarah O'Meara and Yvaine Ye, "Four research teams powering China's net-zero energy goal", Nature, 23 March 2022.

[35] Van Nguyen, "Vietnam: foreign investors in dire need of incentives for renewable energy", Energy Monitor, 1 September 2022.

A. Adopting an integrated approach to human capital development

31. New and emerging energy technologies encompass a range of skills, knowledge sets and technologies drawn from various disciplines and sectors, making it relatively difficult to determine entry points. One option is for countries to encourage their institutions to set up interdisciplinary training and research centres in collaboration with existing energy firms that teach, undertake research and develop products for or with related industries. They can be designed around existing skills that can easily be upgraded, a given energy technology, existing training centres, specific renewable energy suppliers and operators, or any combination that may fit national contexts.

32. For instance, the Geothermal Training and Research Institute at Dedan Kimathi University of Technology in Kenya offers a BSc degree in geology, a postgraduate diploma in geothermal energy technology and an MSc degree in geothermal energy technology for students, as well as for teams that may include members of academia, industry and regulators interested in developing the geothermal energy industry.[36] The programmes were jointly designed with industry experts who have helped to make Kenya the eighth-largest geothermal energy producer in the world and the top producer in Africa.[37] A similar approach could be used in designing training and skills development programmes in relation to other renewable energy industries.

33. Regional blocs of countries could also build on existing programmes to create specialized capacity in specific energy technologies. For example, the Kafue Gorge Regional Training Centre in Zambia is overseen by a regional board of trustees from Eswatini, Malawi, Uganda, the United Republic of Tanzania, Zambia and Zimbabwe and offers training in hydropower. Based in the same location as the Kafue Gorge Hydropower Station, it offers hands-on training to graduates from engineering schools and workers in the energy sector. With the growing number of renewable energy firms, a similar approach could be used to upgrade skills and generate new ones.

B. Expanding research and development in renewable energy

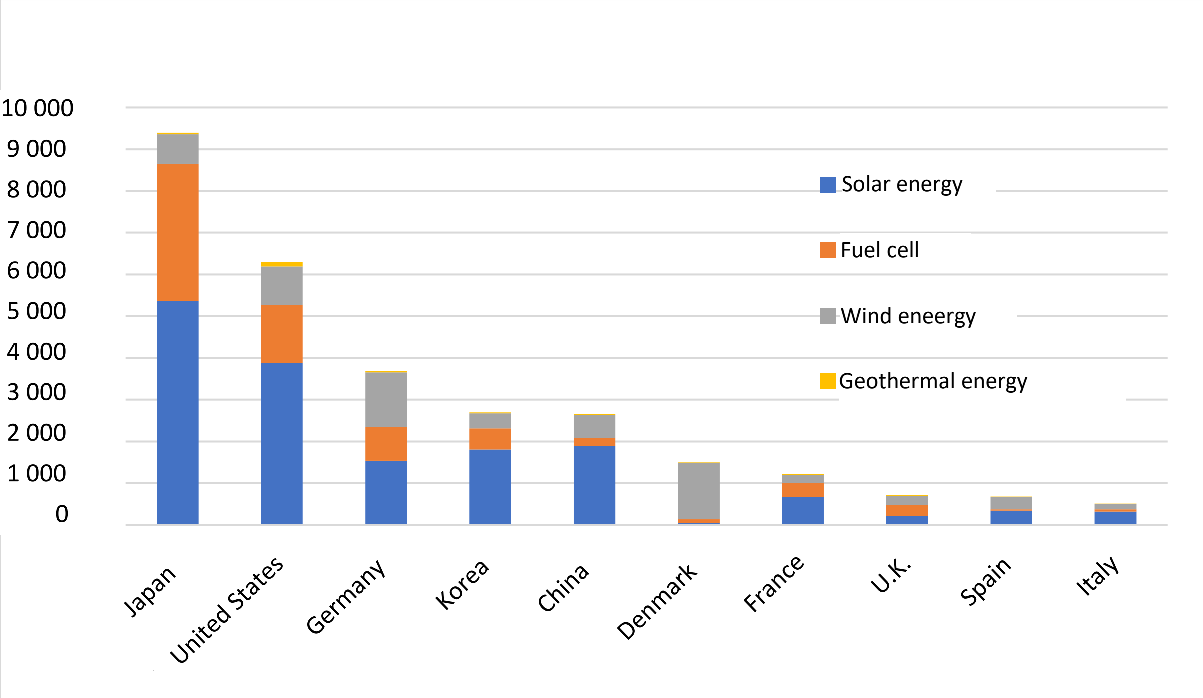
34. Globally, in 2019 alone about $6.7 billion was invested in research and development for solar energy, $2.7 billion for wind energy, $1.8 billion for biofuels energy, $1 billion for biomass energy, $0.7 billion for small hydroelectric power and $0.2 billion each for geothermal energy and marine energy. Similarly, the top 20 automobile manufacturers spent $97.5 billion on battery research and development between 2019 and 2020.[38] These investments are focused on the technology value chain (materials, production, integration and recycling) with the aim of optimizing performance, costs and durability so as to meet environmental and economic growth objectives.

[36] Dedan Kimathi University of Technology, "Programmes", available at https://getri.dkut.ac.ke/programmes/.

[37] United Nations Educational, Scientific and Cultural Organization, "Kenya now eighth in the world for geothermal power", available at www.unesco.org/reports/science/2021/sites/default/files/medias/fichiers/2022/03/central-east_africa_Box-19-1.pdf.

[38] Binder Dijker Otte (BDO) UK, "Top 20 global carmakers spend another £71.7bn on R&D as electric vehicle rollout gathers pace", 26 July 2021.

Figure IV
Top patenting countries in renewable technology (2010–2019)



Source: James Nurton, "Patenting trends in renewable energy", World Intellectual Property Organization, March 2020.

35. Evidence suggests that investment in renewable energy in Africa is limited. There is no African country among the top renewable energy patenting countries (see figure IV above). As a first step towards changing this situation, African countries should aim to create renewable energy research and product development centres in universities and in research and development institutions. Models could include the National Renewable Energy Laboratory of the United States Department of Energy, which has 3,227 staff and various research centres and laboratories specialized in solar energy, wind energy and bioenergy. Its business volume in 2022 was $671 million, and it has been awarded 688 patents and is involved in 1,046 active collaborations with academia, industry and not-for-profit and government entities.[39] Such entities can lead national or regional efforts in training, research and support to related industries.

36. Expanding the research and development base creates immediate jobs for some of the brightest and most creative minds in Africa, which are currently being lost to emigration; gives Africa a stake in generating knowledge that will drive the future of renewable energy industries; and helps Africa develop the skills and industries needed to install, maintain, upgrade and design its renewable energy technologies, products and infrastructure. Expanding research and development also helps to bring together top research teams[40] and industries for close collaboration, which traditionally has been seen to speed up the growth of industries in emerging technologies.[41,42] Very few African countries today can boast the capacity to design, install and maintain grid-scale renewable energy installations.

[39] National Renewable Energy Laboratory, "About NREL", available at www.nrel.gov/about/.

[40] The Hamilton Project, "Most investors have graduate degrees", 13 December 2017.

[41] Lynne Zucker, Michael Darby and Marilynn B. Brewer, "Intellectual human capital and the birth of U.S. biotechnology enterprises", *American Economic Review*, vol. 88, No. 1 (1998).

[42] Reddi Kotha and Gerard George, "Academic entrepreneurs: the role of star scientists in commercialization of radical science", *Frontiers of Entrepreneurship Research: Proceedings of the 30th Annual Entrepreneurship Research Conference*, vol. 30 (2010).

C. Actively seeking strategic research and industrial alliances

37. African countries should take the lead in identifying areas in which strategic alliances may be of greater value. Research alliances will be important in acquiring and developing a national research base in renewable energy. They may include twinning training, teaching and research institutions of interest, the exchange and hosting of top researchers and students, and joint research facilities at home and in partner countries. Such alliances must have a clear goal of helping African countries move up the technological ladder in order to avoid perpetual dependency.

38. Industrial alliances are largely formed between firms for a range of reasons that may include combining unique knowledge, intellectual assets and experiences in research and development, manufacturing or production, distribution, marketing and sales. Africa may need to: entice or incentivize its largely vertically integrated energy utilities and private firms to seek partnerships that could lead to the formation of joint ventures; form start-ups in given technology segments; or gain access to skills, gain experience or jointly develop research and development, manufacturing and production platforms for renewable energy technologies or products.

D. Developing and upgrading transmission infrastructure

39. As investment in renewable energy increases, the number of projects aimed at connecting to national grids is likely to grow rapidly. The current electricity grids in Africa, which serve about half of the population, may be inadequate and possibly ill prepared to meet a surge in the supply and demand of energy. Countries must therefore anticipate this surge and undertake the necessary upgrades to ensure that the electricity grid will be safe, stable and reliable if or when the load is increased. Even countries with extensive and well-developed grids will face challenges in bringing more electricity from renewable sources online.[43] Issues such as connection to the grid and feed-in tariffs will become key in encouraging investment in the rapid growth of energy access and affordability in Africa. Other infrastructure for electric mobility, hydrogen storage and distribution will have to be built on the basis of anticipated demand and supply needs.

E. Creating a renewable energy technology and innovation road map

40. Several issues discussed in this section of the present report could inform national and regional renewable energy road maps. A detailed plan may address the issue of how countries will transition towards a clean, accessible, competitive, secure, safe and affordable energy supply for all. Policymakers and emerging industrial entities in Africa need to develop clearer strategic plans that guide the behaviour of all stakeholders and inspire hope of a better future among the population. For example, they need to consider questions such as how many jobs would be created, how many communities would be connected, how affordable energy would become and how stable the power supply would be. While plans do not necessarily work out as written, they do inspire academia, industry, government agencies and society at large to work towards a common future.

41. While each country may employ different tools and approaches, they should all take into account, among other things, the technological, industrial, trade, employment and investment requirements and merging regulations and practices, as well as the costs and benefits and the potential losers and winners. For instance, of

[43] Joseph Rand and others, "Queued up: characteristics of power plants seeking transmission interconnection as of the end of 2021" (Berkeley, United States, Lawrence Berkeley National Laboratory, 2022), available at (https://escholarship.org/uc/item/38m4d192).

the jobs created by utilities and photovoltaic systems for communities, about 75 per cent are in manufacturing and 25 per cent are in construction and installation,[44] while two thirds of jobs in green hydrogen are in renewable energy production and one third are in hydrogen production, transmission and storage.[45] As such, the choices countries and their firms make will have an impact on employment, accessibility, affordability and overall future demand, depending on the sector and use cases. Clearer road maps could help to guide national policies, investments and human capital development, minimize the creation of losers and optimize benefits, and encourage healthy competition and collaboration at the national, regional and global levels. The road maps should include clear implementation and investment plans.

V. Conclusion

42. The main purpose of the present report is to highlight some of the emerging technologies and the opportunities they present for Africa and to showcase some trends and ways in which Africa could fully participate in the emerging energy technology industries. It is also hoped that the present report will stimulate research, debate, policy development, collaboration and partnerships between and among countries to advance the development, production and manufacture of renewable energy products in Africa, so as to enable the continent to sustainably produce renewable energy that is useful, accessible and affordable.

43. Thus far, Africa seems to be doing very well in the acquisition and deployment of solar and wind energy and is poised to be one of the key players in the trade in and production of hydrogen. The rapid uptake of renewable energy in Africa is driven by the steep drop in prices and the improved efficiency of various components, such as batteries,[46] solar panels and wind turbines,[47] with a focus on bringing electricity to those who do not have any or who have an unstable power supply. The next step is to move beyond being a user and consumer of energy products designed elsewhere for different environments.

44. Concerted efforts by Governments, academia, industry and not-for-profit organizations are needed to enable Africa to become a key player in the research into, development, production and manufacturing and use of, and trade in, renewable energy products. Clearer policies can help to drive such development and address many of the issues raised in the present report.

[44] Georgeta Vidican Auktor and others, *Achieving Inclusive Competitiveness in the Emerging Solar Energy Sector in Morocco*, study No. 79 (Bonn, German Development Institute, 2013).

[45] Sonja van Renssen, “Hydrogen tests climate policymakers with its job potential”, Energy Monitor, 6 May 2021.

[46] Sustainable Truck and Van, “Price of lithium batteries -97% in 30 years. And by 2050 an extra -68%”, 20 May 2021. www.sustainabletruckvan.com/price-of-lithium-batteries-fall/.

[47] United States Department of Energy, “2020 sees record for land-based wind generation, 24% increase in pipeline of offshore wind energy – laying the foundation for rapid growth in years to come”, 30 August 2021, available at www.energy.gov/articles/doe-releases-new-reports-highlighting-record-growth-declining-costs-wind-power.