United Nations
Economic Commission for Africa

# EMERGING TECHNOLOGIES IN ADVANCING AFRICA'S ENERGY SECURITY SUSTAINABLY

Draft Background Note

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## 1. Introduction

The type of energy a society uses roughly reflects its stage of development. As one analyst expressed it simply: "Fire made us human; fossil fuels made us modern. Now we need a new fire that makes us secure, safe, healthy, and durable"[1]. This background note seeks 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 African must address to participate in the rapidly growing new energy economy.

Currently, Africa's energy needs are met largely by biomass (about half), fossil fuels (22%), coal (14%) and natural gas (14%), and that energy mix has not changed much in the last three decades[2]. In contrast, energy consumption in the United States is thought to have moved from about 70% biomass in 1870s to 70% from coal in 1900 to about 70% from oil and gas by 1960.[3] Each of these phases of transition represented different levels of technological learning and innovations, which created industrial opportunities and opened up new markets as well as improvements in quality of life of people around the world.[4][5] While Africa missed a good share of those opportunities, the new and emerging energy technologies present unparalleled advantages for technological learning and for leapfrogging previous energy revolutions to help the continent achieve the goals of the 2030 Agenda for Sustainable Development and Agenda 2063.

Emerging research shows that investment in increasing access to clean energy is likely to positively impact the achievement of all 17 SDGs except Goal 17 (Partnerships); and investment in decarbonization will positively affect all SDGs except Goal 4 (Education)[6]. Each of the renewable energies and their associated technologies present different opportunities, benefits, risks and challenges. For instance, biofuels have higher positive impacts on economic, technological and climate-related SDG targets but could have negative impacts on other SDG dimensions, including those related to environment (e.g. land and water use) and health targets if their use is not properly managed[7]. Solar may be cheaper, easier to deploy and could be managed by communities with wide applications for home, office and industry. Further, solar farms can be erected on wasted or unfertile lands that could recover and support or protect life. Yet, with a life span of 20-30 years and the widespread use of batteries and other potentially polluting components, solar waste could present a real risk to the environment if not planned and managed well.

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[1] Amory Lovins (2014) Reinventing Fire: Bold Business Solutions for the New Energy Era also available online at Reinventing-Fire

[2] IRENA (2020) Africa 2030: Roadmap for a Renewable Energy Future. International Renewable Energy Agency

[3] O'connor, P. A. (2010) Energy Transitions, *The Pardee Papers, No. 12*, Boston University.

[4] ECA (2021) Energy Prices in Africa: Transition Towards Clean Energy for Africa's Industrialization, United Nations Economic Commission for Africa.

[5] IFC (2019) The dirty footprint of a broken grid, International Finance Corporation, World Bank Group (Click here)

[6] Sachs, Jeffrey D., et al. "Six transformations to achieve the sustainable development goals." *Nature sustainability* 2.9 (2019): 805-814.

[7] Martinelli, F.S, Biber-Freudenberger, L., Stein, G., Börner, J., (2022) Will Brazil's push for low-carbon biofuels contribute to achieving the SDGs? A systematic expert-based assessment, *Cleaner Environmental Systems*, **5**,

**Table x Energy outputs and outcomes of SDGs**

| Output* | SDG1 | SDG2 | SDG3 | SDG4 | SDG5 | SDG6 | SDG7 | SDG8 | SDG9 | SDG10 | SDG11 | SDG12 | SDG13 | SDG14 | SDG15 | SDG16 | SDG17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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 |

*Four-point scale: 3 = output target directly SDG outcomes; 2 - reinforce the SDGs; 1 - enable the SDGs; and 0 - do not interact with the SDGs

Source: Sachs et al (2019) Six transformations to achieve the sustainable development goals. *Nature sustainability 2.9*: 805-814.

In terms of potential renewable energy, Africa has abundant sources of renewable energy: solar capacity (10 TW), hydro (350 GW), wind (110 GW), and geothermal energy sources (15 GW). A major challenge and bottleneck that many countries face is how to convert these energy resources into energy forms to power homes, transportation, businesses, farms and social amenities (e.g., schools, hospitals etc) cost-effectively, safely and reliably, given that it will require substantial investment of other resources.

Most of the gains are derived from the presence of human capital, innovations and industrial applications (e.g. electric mobility, manufacturing, electricity) that need or depend on energy. New and emerging energy technologies may rewrite the global, regional and national trade in energy and energy related products. For instance, the innovations around batteries created exciting new markets for the wired and wireless recharging stations and new generation of cars, scooters and bikes that are technological masterpieces with almost zero emissions and less noise, each with their own value chains (e.g. software, payment systems, boards, vehicles/bikes, deliveries, pickup and drop-off locations etc). It is here that new players enter the market, new industries are born, new jobs and wealth are created, and new knowledge are generated with significant consequences for the economy, social and environment.

In comparison to fossil fuels, sunlight, wind and/or water are readily accessible resources by more countries. Experiments such as those by the European Space Agency to harvest sunlight through solar farms in space and then beam the energy wirelessly to Earth or other locations in space reinforce the need for Africa to enhance its scientific, technological and innovation capabilities[8] help it reap the most benefits from its existing resources and alternative approaches. .

[8] https://www.esa.int/ESA_Multimedia/Images/2020/08/Space-based_solar_power (solar intensity is higher in space and

## 2. A glance at development and growth of emerging energy technologies

This section looks at a few emerging energy technologies that Africa should seriously consider and pursue – noting that renewable energy has lower lifecycle greenhouse gas (GHG) emissions than conventional fossil fuels, may be faster to install, easier to maintain and more adaptable to local needs than current energy technologies. For example, lifecycle GHG emissions from solar PV and wind energy are 4 per cent and 1.5 per cent, respectively, those of fossil fuels, and facilities can easily be monitored remotely and managed by local communities.[9]

While all technologies may often be studied and discussed independently to highlight their specificity, in practice, these technologies could generate better outcomes if they work in combination. In particular, hybrid systems that utilize multiple sources are needed to guarantee reliable supply in all-weather conditions. There are various emerging technologies for energy capture, conversion, storage, and use. For more targeted elaboration, we place focus on a selected set of energy technologies: solar, batteries and hydrogen in which Africa can have a good short at success or offer greater opportunities for exploiting existing resources and for technological learning.

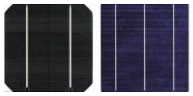
### 2.1. Solar photovoltaic technologies

Solar photovoltaics (PV) is one of the cleanest, safest and well-established renewable energy technologies for generating electricity at small and large scale and employs different type of solar cell technologies. At the heart of PV systems are solar cells – the electrical device the converts sunlight or solar energy into electrical energy and are classified into three broad generations: The first generation is composed of crystalline silicon cells (commercially produced since the 1950s); the second generation comprise thin-film technologies (commercially produced since the 1990s); and the third generation are solar cell technologies of organic materials and multi-junction cells (largely under research and development with specialized applications)[10]. The average solar cell provides about 0.5 volts – not enough to power basic devices - and thus several cells are put together to make a solar module and a series of solar modules make a solar

[9] Bruckner, Thomas et al. 2014. "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*, The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press

[10] Shubbak, M., 2019. Advances in solar photovoltaics: Technology review and patent trends. *Renewable and Sustainable Energy Reviews*, Vol. 115(Nov), pp. 109383.

**Table XX: Market size of different PV system components**

| Market value | Cells  | Panels  | Batteries  | Inverters  | Services  |
|---|---|---|---|---|---|
| **2021 or latest** | $26 billion | $180 billion | $3.1 billion | $16 billion | $151 billion |
| **By 2030** | $37 billion | $641 billion | $9.5 billion | $34 billion | $292 billon |
| **Skills and personnel** | R&D Chemists, Physicists, Engineers, material scientists; Manufacturing, quality assurance and sales personnel etc | | | | Architects, project designers, managers, electricians, plumbers, |

*Source:* ECA estimates based on various market research sources

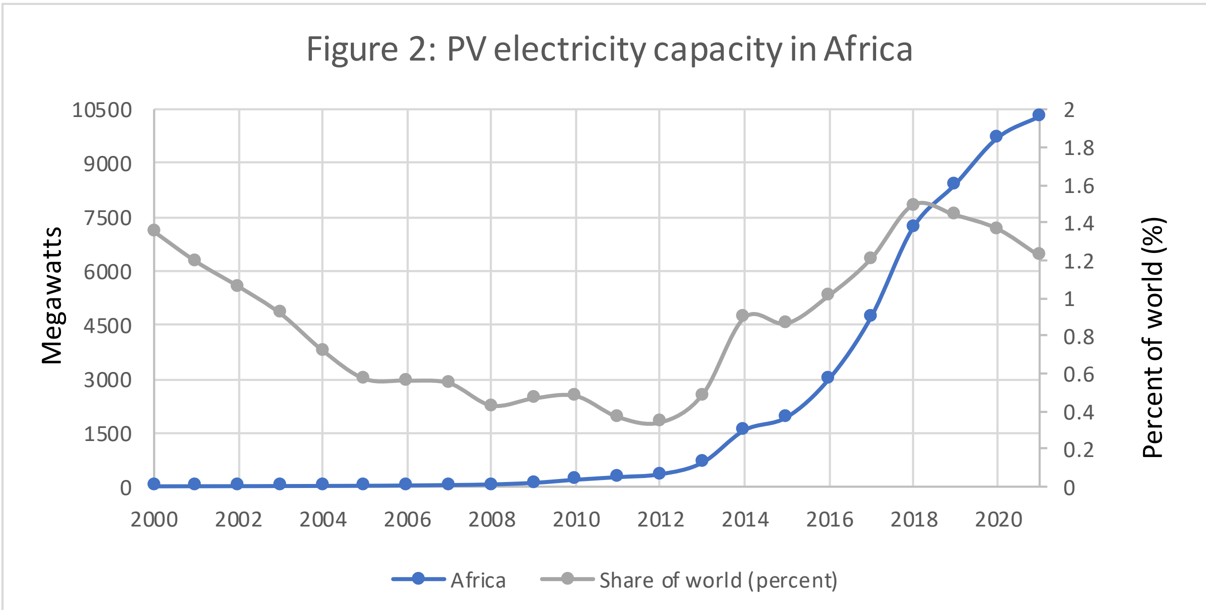
While solar panels and batteries attract most of the attention, they are not the only key components of the solar system with a significant market. Others key components such as solar inverters and electronic controllers are equally important both in monetary value and in managing and optimizing the performance of the different components of a PV system. These components manage and optimize solar energy conversion, storage and allocation – e.g., whether to store or directly use the energy, report faults, tap power from or send power to the grid etc.

In terms of market size, the global market of crystalline silicon based solar cells (first generation) accounts for about 93% and is followed by thin film (7%) of the estimated total US$26 billion in 2021[11] and this market my hit $37 billion by 2028. Similarly, the global market of solar panels was valued at $180.4 billion in 2020 and may rise to $641.1 billion by 2030[12]; and that of solar batteries was valued at US$6.8 billion in the year 2020, and is projected to reach a $18 billion by 2027[13]. The global market for solar PV inventers was estimated at $16.3 billion in 2022 and may rise to $33.9 billion in 2028.[14]

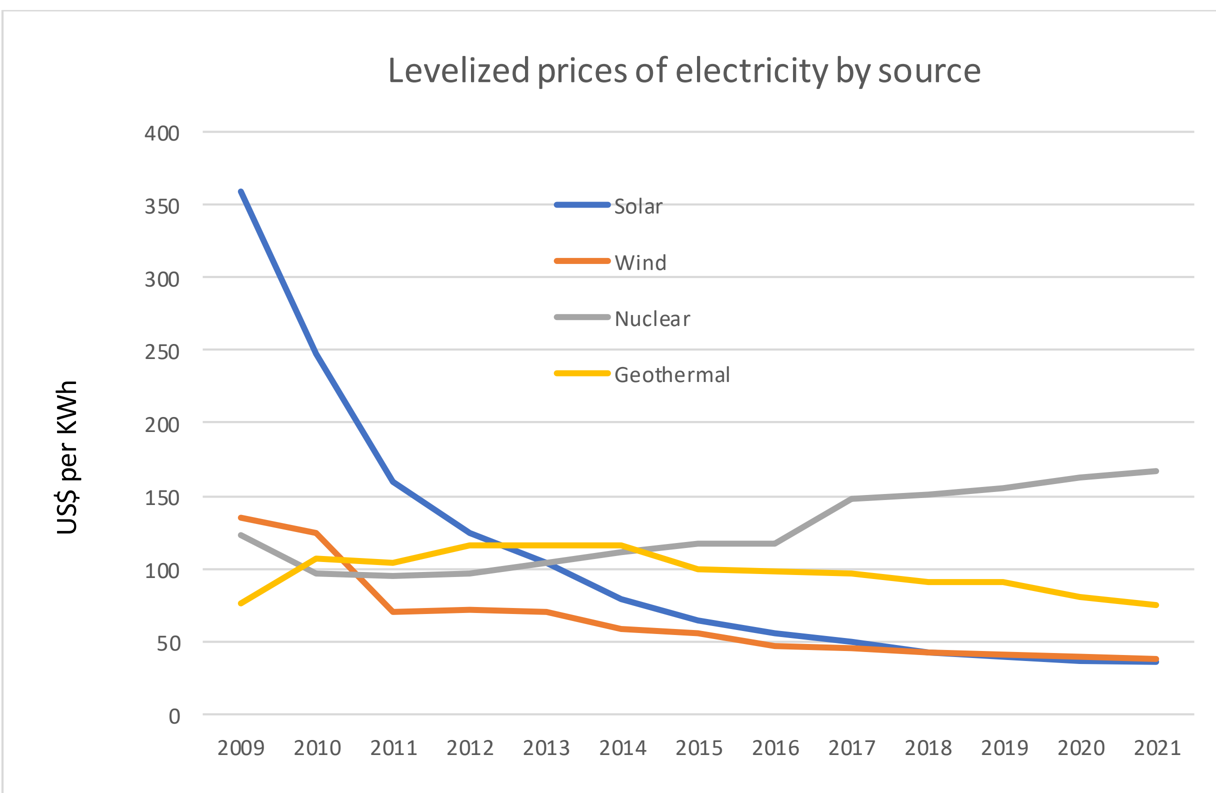
Africa needs to work hard to enter the market by supporting skills development, R&D and manufacturing capabilities. The range of skills needed include those for R&D (e.g. chemistry, physics, engineering, digital, nanotechnology etc); manufacturing of cells, modules, panels, batteries, inverters, controllers and other electronic components(e.g. production and process engineers, chemists, physicists, quality assurance and marketing managers etc) as well as for design, installation, maintenance, upgrade and safe decommissioning of solar energy systems (e.g. environmental impacts assessments experts, electricians, welders, plumbers etc). A multipronged approach may be needed where Africa encourage collaboration in the development of large grid-size plants between foreign suppliers, R&D and learning institutions and emerging knowledge intensive startups interested in growing to quickly build skills across the entire value chain. This should not be hard considering Africa's solar marketing is growing rapidly - from about 10.9

11 https://www.gminsights.com/industry-analysis/solar-cells-market
12 https://www.alliedmarketresearch.com/solar-photovoltaic-panel-market
13 https://www.researchandmarkets.com/reports/5030432/solar-batteries-global-market-trajectory-and
14 https://www.marketsandmarkets.com/Market-Reports/inverter-market-263171818.html

megawatts (MW) to 10,302.2 MW between 2000 and 2021. Most of that growth took place after 2012 (see Figure 2). However, as a share of the world's total, Africa accounts for about 1.2%.




Source: IRENA database accessed 16 April 2022.



Growing a domestic knowledge base is important as the rapid uptake of solar photovoltaics (PV) systems has been driven by solar technology improvement, reduction in manufacturing costs, increased funding for renewable energy and enabling renewable energy policies.[15] PV technologies (e.g. crystalline silicon and cadmium telluride) are now produced at an industrial scale, and many more technologies are in development.[16] As a result, the price of PV systems has decreased significantly since 2010. As of 2019, the average Levelized Cost of Generation of solar PV electricity was $51/MWh – making it the cheaper source of grid-scale electricity than coal, easier to install and cheaper to operate (i.e., low maintenance). At the heart of this trend is continuous improvement in technology for the various components and manufacturing that is likely to drive costs even lower. While Africa may not compete in R&D yet, it could exploit emerging knowledge to build capacity in design, installation, operation, maintenance to learn and generate resources and experience to enter the manufacturing stages.

### 2.2. Battery technologies for energy storage

Batteries are a critical energy solution and enablers of mobility – from the hand-help torch of a doctor, household or mechanic to mobile devices and electric scooters – mobility of these products are made possible by batteries. There are several battery technologies of which the most common and advanced include lithium-ion, lead-acid, redox flow, sodium-sulphur, 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 mobility (laptops, mobile phones, electric vehicles, scooters, bikes etc.). Developed in the 1970s during the oil crisis, it has "laid the foundation for a wireless, fossil-free society"[17] and the work won a Nobel Prize in Chemistry for 2019[18]. Rapid technological advancement has driven prices per kWh from $1,160 to $176 between 2010 and 2018, and the price is expected to drop further.[19] Lithium-ion batteries hold more charge per volume (about 126 watts per kilogramme), require less maintenance, if any, has a life span of up to 15 years. These batteries are equally accessible for small (e.g. mobile phones), and large-scale installations (e.g. power utilities) but are still relatively very expensive and pose a low but possible risk of fire.

Other batteries with high storage capacity include the Nickel-Cadmium and the Nickel-Metal Halide batteries. These batteries can hold high energy density and are capable of instantaneous and continuous high energy discharges which in important in various applications such as power tools, emergency applications (e.g. powering the emergency system of aeroplanes if engines lose power)

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[15] Wilson, G.M. et al (2020) The 2020 photovoltaic technologies roadmap, Journal of Physics D: Applied Physics **53** 493001 (https://iopscience.iop.org/article/10.1088/1361-6463/ab9c6a/pdf)
[16] NREL, 2018. *STAT FAQs Part 2: Lifetime of PV Panels*. Golden, Colorado, USA: National Renewable Energy Laboratory
[17] (The Royal Swedish Academy of Sciences 2019)
[18] https://www.nobelprize.org/prizes/chemistry/2019/popular-information/
[19] Bloomberg. 2020. *Gasoline Prices Around the World: The Real Cost of Filling Up*. New York, New York: Bloomberg

etc. While they are still in use, the cost of the metals and toxicity of cadmium has limited their applications (e.g. the EU banned cadmium-based batteries in portable devices)[20].

Lead-acid batteries are the cheaper energy storage solution for home solar systems and are used in automobiles to start and run accessories. They are easy to dispose and recycle but require maintenance (i.e., may leak), have a shorter life span (about five years with care) and are bulkier (heavy) and require more space for the same energy storage capacity as lithium. They are estimated to have a power density of about 7W per kilogram and thus are useful where space is not a major limit or small amount of power is needed (e.g. start a car).

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

Different battery technologies present varying opportunities, challenges, advantages and disadvantages. While household and office sized batteries are likely to be generic to fit general use cases of homes, grid-type of batteries are likely to be purpose-built and customized to meet the desired case in terms of amount of power they should hold and discharge to keep large business operations (e.g. mining) 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 discharge during peak energy demand period (e.g. during the day). More importantly, batteries energy storage systems are a flexible solution that can be moved from one location to another and from one case use to another much easier and faster than other options (e.g. pumped hydro energy storage systems).

As with solar, a range of skills are needed to meet the demands of different components of the battery value chain which may include: expertise for R&D, processing of battery minerals/materials; and the manufacturing, assembly, installation and maintenance as well as recycling of batteries (e.g. mobility, electricity grids and off grids, mobile devices etc). In terms of specifics, some studies skills and knowledge associated with battery minerals and chemicals processing, automation and industry 4.0, mass manufacturing of battery components and cells, electrical and engineering skills for manufacturing and installation and maintenance of batteries in vehicles, electricity grids and other applications as being important[21]. As noted earlier key aspects such as costs, power storage capacity, lifespan, space requirements are among key reasons to consider. For instance, the US Department of Energy has set the goal to reduce the costs of grid-scale energy storage by 90% for systems that deliver continuous energy supply for 10 or more hours in a decade[22]. Africa will also need to set similar goals to meet its own needs or at least keep up with developments in science, technology and industry to remain competitive. While this will be address in details later, it suffices to say that industrial alliances with leading nations and collaborations with to R&D institutions will be needed for Africa to catch up.

[20] DIRECTIVE 2013/56/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013

[21] South Metropolitan TAFE (2021) Vocational skills gap assessment and workforce development plan, Future Battery Industries Cooperative Research Centre (https://fbicrc.com.au)

[22] https://www.energy.gov/eere/long-duration-storage-shot

## 2.3. Hydrogen and the hydrogen technologies

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

It is for the above attributes of hydrogen that the global market for hydrogen is growing rapidly. As shown in table XX, 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 electrolyzers needed to convert water into hydrogen and oxygen is expected rise from about $6 billion in 2021 to about $69 billion while that of hydrogen storage is expected to almost double and that of fuel cells may grow rise 61-folds.

**Table XX: Market size of some hydrogen market segments**

| Market value | Electrolysers | Storage | Fuel cells | Overall Generation |
|---|---|---|---|---|
| **2021 or latest** | $6 billion | $15 billion | $0.7 billion | $129 billion |
| **By 2030** | $69 billion | $26.9 billion | $43 billion | $225 billon |

*Source:* ECA estimates based on various market research sources

Currently, about 96% of the hydrogen is produced from fossil fuels (or is grey or blue hydrogen if the carbon dioxide is captured). It terms of sources, almost 70% of the hydrogen in the market is from natural gas and 27% is from coal. Only 3% or so is from renewable sources. Most of the pledges seeks to accelerate the production of green hydrogen which has received a $73 billion[23] boost in investments as prices for petroleum products have soared, resulting in a 70% rise in brown hydrogen prices.

There are a number of areas that need to be addressed technologically and market wise in order to increase the share of green hydrogen, majority of which are interlinked. The first challenge is to reduce the cost of green hydrogen production. As can be seen from table xx, hydrogen derived from water using electrolysis costs between $5.8 and $23.3 per kg of hydrogen while that from coal is about $1.3 per kilogram of hydrogen. Reducing the cost of green hydrogen production from renewable resources ia a key R&D and manufacturing goal for it be more competitive and accessible.

For example, the United States Department of Energy, for instance, is supporting research to reduce the overall cost of producing hydrogen from $5 per kilogram to $1 per kilogram of

[23] https://carbontracker.org/wp-content/uploads/2022/10/Clean-Hydrogens-Place-in-the-Energy-Transition-1.pdf?lang=ja

hydrogen in 1 decade (a strategy commonly referred to as 1.1.1) and such a development would potentially curb 16% of carbon dioxide emissions by 2050, as well as generate 700,000 jobs and $140 billion in revenues by 2030 in the US alone[24]. New approaches to integrate hydrogen production in existing industrial applications and designs of electrolyzers may have been shown to lower cost. Advanced Ionics, a US Start-up, claims to have developed electrolyzers that utilizer water vapour (100-650 degrees Celsius) to produce green hydrogen for less than $1 per kilogramme and the electrolyzer can be integrated in existing industrial production. There are also research efforts to build electrolysers that can use salty water[25] to eliminate the desalination step which would reduce costs.

Besides production, hydrogen will require investment in infrastructure for transportation (e.g. pipelines, trucks, port terminals etc), storage (e.g. tanks of liquid hydrogen,)and use and sale (e.g. hydrogen fuelling stations, compressors etc) as well as in skills, among others, is required for safe use and maintenance of competitive markets. Most African countries do not have extensive gas pipelines and their support services and industries that can easily be repurposed and thus may need new facilities or alternatives to build competitive hydrogen development. .

For example, Namibia green hydrogen production project with estimated annual 300,000 tons output of hydrogen will require investment of $10 billion[26] – more than its foreign direct investment inflows for the last decade and close to its gross domestic product of about $12.2 billion in 2021[27]. To meet this investment need, Namibia is building partnerships with technology owners, infrastructure, investment and trade promotion and funding partners or owners (e.g. the European Union and Namibia signed agreement at COP 27 that includes Green Hydrogen[28]). The project is a major investment opportunity for developed countries and their firms seeking to reduce carbon emissions, enhance their green credential and participate in the one of fastest growing industries. With the backing of the Government of Namibia and port authorities, tracks of uninhabited land with plenty of sun shines, wind and water resources, the potential success of the project is high.

Huge sums investment should not scare Africa. Ethiopia has successfully mobilized domestic resources to partly fund the $5 billion Grand Ethiopian Renaissance Dam even with limited access to international investors. For hydrogen, the opportunities to attract both domestic and foreign investors is very high. Many of the hydrogen projects announced in developing countries (e.g. Chile, Morocco and South Africa) include various partnerships and interests in developed countries.

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[24] https://www.energy.gov/eere/fuelcells/hydrogen-shot

[25] Tong, W., Forster, M., Dionigi, F. *et al.* (2020) Electrolysis of low-grade and saline surface water. *Nature Energy*, **5, pg** 367–377

[26] https://hyphenafrica.com/news/namibia-announces-progress-with-hyphen-hydrogen-energy-to-unlock-us10bn-investment-for-first-green-hydrogen-project-to-help-power-the-energy-transition/

[27] See World Development Indicators 2022, World Bank.

[28] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6683

**Table xxx: Cost of different hydrogen production technologies.**

| Process | Energy source | Feedstock | Capital cost (M$) | Hydrogen cost ($/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 |
| **Direct bio-photolysis** | Solar | Water + algae | 50 $/m$^2$ | 2.13 |
| **Photo-fermentation** | Solar | Organic biomass | – | 2.83 |
| **Solar PV electrolysis** | Solar | Water | 12–54.5 | 5.78–23.27 |
| **Solar thermal electrolysis** | Solar | Water | 421–22.1 | 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 | 39.6–2107.6 | 2.17–2.63 |
| **Solar thermolysis** | Solar | Water | 5.7–16 | 7.98–8.40 |
| **Photo-electrolysis** | Solar | Water | – | 10.36 |

*Source:* M. Ball, and M. Weeda, (2016) The hydrogen economy - Vision or reality? Editor(s): Michael Ball, M., Angelo Basile, A. and T. Nejat Veziroğlu, T. N. In Compendium of Hydrogen Energy, Woodhead Publishing, Vol 4, Pages 237-266,

A second component is efficient hydrogen industry support infrastructure. Hydrogen gas produced may have to be converted into a liquid, ammonia or other forms for easy transportation and storage, safe use at fuelling station of vehicles etc.

Countries may choose to either have distributed hydrogen production facilities placed close to the sites/localities of use (e.g. cities or major corridors) or centralized systems especially for those targeting export markets[29].

[29] F.G.N. Li, W. McDowall, P. Agnolucci, O. Akgul, L.G. Papageorgiou (2016), Designing optimal infrastructures for delivering hydrogen to consumers, Editor(s): Ram B. Gupta, Angelo Basile, T. Nejat Veziroğlu, In Woodhead Publishing Series in Energy, Compendium of Hydrogen Energy, Woodhead Publishing, Vol 2; pages 345-377,

A final component is skills, knowhow and other resources needed to build a viable hydrogen value chain.[30] Like in other areas, many of the skills required may be at technician and trades level while other may require skills at MSc and PhD levels (e.g. R&D components for electrolysers, safety and standards, infrastructure design etc). For instance, hydrogen fuelling station managers, technicians and attendants are unlikely to need PhDs to perform their jobs but system designers and R&D performers may need Masters degrees or higher qualifications. Some of them may require minor upgrade of existing skills in industry and academia while most may be new especially in countries without existing gas industry and infrastructure.

## 3. Characteristics likely to underpin success

New and emerging energy technologies "encompass an array of new materials, products, applications, processes and business models, [that] are interdependent, interconnected and mutually reinforcing".[31] For instance, battery technologies range from Lead-acid to Lithium and Cadmium, among others. They employ a range of technologies (e.g. smart lithium batteries capable of plug and play with inbuilt Bluetooth etc), and have a wide range of applications in electronics, mobility, infrastructure, and so forth. Emerging technologies benefit from advances in numerous disciplines such as in nanotechnology, material science, electrochemistry, biotech, engineering, and digital technologies, among others. Accordingly, generating diverse opportunities for new players to enter different segments in the energy market.

Emerging energy technologies have the potential to disrupt exiting energy production and supply value chains and current industries by reallocating economic, social and environmental value from some players to others. For instance, some of the skills, knowledge, infrastructure, applications and markets required for new energy economy are likely to differ from those for the fossil fuel energy economy. A small window of opportunity thus exists for collective technological learning all countries, irrespective of their levels of development, for exploiting technological and market niches and, as a result, for catching up and leapfrogging.

For instance, Namibia has set its goal to become a producer and exporter of hydrogen to Europe. Namibia has already identified land, location and mobilized technical and financial resources, and signed MoU with the EU at COP 27 for integration of renewable hydrogen in the EU value chain and promotion of trade and investment.[32] Namibia, which is currently a net importer of hydrocarbons and electricity could become a net exporter of hydrogen. More importantly, the project, once fully realized could transform a remote area into a cosmopolitan area along its long coastline. .

However, new technologies often build on existing scientific, technological and industrial knowledge base. This suggests that countries that already have the basic infrastructure, skills, knowledge, and support industries in place is are better positioned to upgrade or repurpose these existing assets to meet the preconditions for the development and diffusion of new energy technologies. For instance, , manufacturers or assemblers of fossil-fuel vehicles need to make

[30] Roger H. Bezdek (2019) The hydrogen economy and jobs of the future, *Renew. Energy Environ. Sustain.* 4, 1 pp1-6

[31] E/2018/50/Rev.1. ST/ESA/370 (Executive summary).

[32]

adjustments to their existing assembly platforms and acquired both new tangible and intangible resources to meet the manufacturing requirements of electric cars. Those that do not have experience in car assembly will have to build the vehicle manufacturing capabilities and their supply and value chains from a scratch..

For instance, Tesla was founded by a team of engineers that wanted to prove electric cars could be as competitive or even better than fossil fuel-powered ones. Tesla adopted the Silicon Valley approach of continuous updates on-the-go rather than the industry approach of delivering near perfect products to market. Despite not having prior car manufacturing experience, Tesla is perhaps the most globally recognized leader in electric car segment[33][34]. The main point here is that new entrants with core product knowledge (i.e. electric battery technology) and skills, and a unique business model that was attractive to investors and a product that appeals to the market could compete even without prior experience in the industry especially if they are set out to be the first movers. Countries and firms in Africa that wish to enter the new energy sector may have to take similar approaches – enter the market early, find a niche and build the capabilities needed to succeeds.

The main argument is that the cost of entry into the market increases astronomically as the technologies mature because the number of competitors rise and products become more sophisticated and consumer expectations goes up. For instance, if Tesla was entering the market now, it would face a much larger number of competitors with well-established manufacturing plants, more refined electric vehicles and consumers demanding more sophisticated vehicles than in the early 2000s. Today's electric cars are technological masterpieces that come with a promise of low maintenance costs, high safety standards and good road performance. The number of models entering the market is also growing fast across the world. The main aspect of the tale is that African countries should not wait until the technology has matured but rather seek areas where they can learn or even lead the rest of the world.

Another key element underpinning success in the development of new emerging technology is continuous active technological learning[35], irrespective of the industry in question. All energy technologies – from those of solar cell to batteries – will continue to evolve at a rapid pace. Countries will have to continuously learn in order to keep up with new advances in the respective sector. This will happen at both at the energy conversion technology level (e.g. solar cell, electrolyzers for hydrogen production etc), energy storage (e.g. battery, pumped hydro etc) as well as the application level (e.g. solar-powered products have continued to multiply and become increasingly technologically complex but easy to use).

As the technologies matures, R&D investment by the public sector in renewable energy is likely to be surpassed by the private sector. By this time, intellectual property protection on key

[33] See www.tesla.com for details

[34] https://www.forbes.com/sites/alanohnsman/2021/01/27/tesla-notches-first-full-year-profit-aided-by-270-million-fourth-quarter-net-income/?sh=3373689a22f6

[35] Eduardo B. Viotti, E.D. (2002) 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, pg 653-680,

technologies will deepen making access to newer knowledge difficult and expensive. Therefore, countries seeking to corner a portion of the emerging renewable energies market may wish to get in early and learn together with the rest of the world. As the sector consolidates, R&D investment by the private sector will deepen in order to keep up with competitors and may relegate countries that have not built the necessary human and intellectual capital and businesses to the periphery of the industry (e.g., suppliers of raw materials and distributors of final products developed by others).

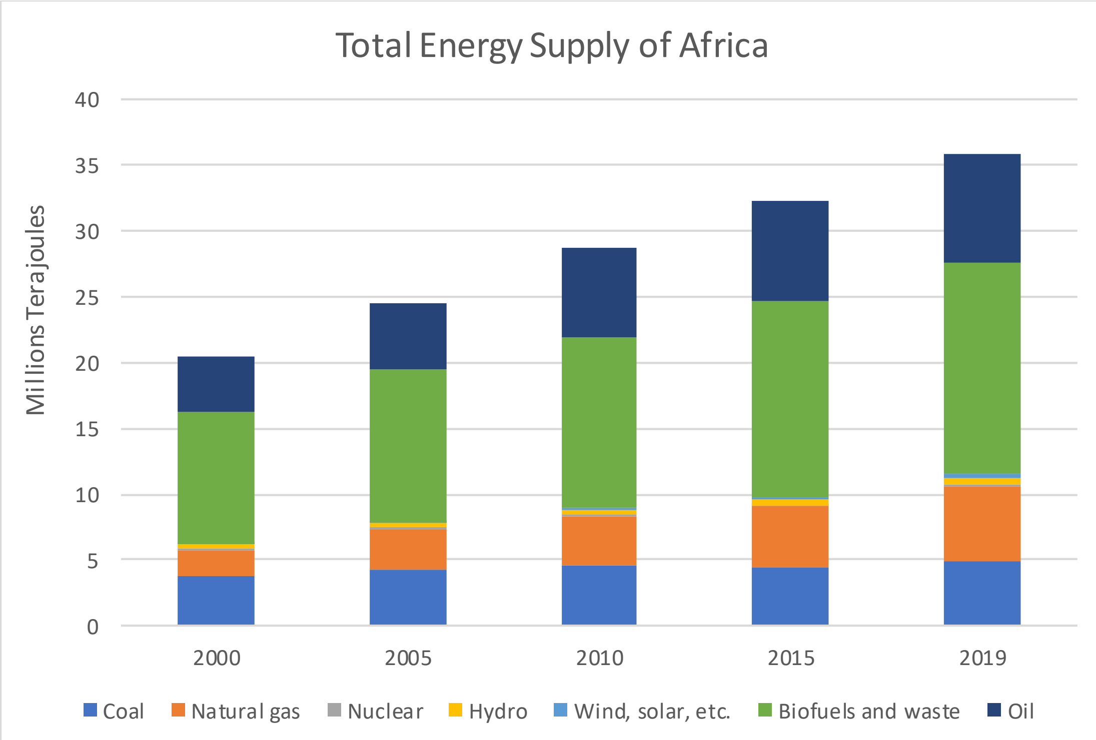
Therefore, each country may have to assess its own resources, skills and industrial base as well as demand for energy in order to make strategic decisions on areas of focus and interest. This can take into consideration the characteristics and maturity the emerging technologies and their needs. In emerging fields, countries can push their education and research institutions to build the necessary skills and knowledge as well as partnership with R&D institutions with more advanced research and training facilities elsewhere in the world. In areas that are mature, joint-venture and public contracts that offer markets could help boost R&D and manufacturing know-how.

## 4. Carving a stake for Africa in emerging energy technologies

Africa is home to most of the key materials such as copper, cobalt nickel, magnesium and lithium that are needed in development of renewable energy products and the market for renewable energy products is growing rapidly both in Africa and around the world. For example, between 2000 and 2019, total energy supply in Africa grew by 75% while that of renewable grew by 1,740%. Therefore, demand for renewable energy is growing rapidly but its share in total energy supply of the continent is very low (about 1% or 2.2% if one includes hydropower). The question, therefore, is not whether there is appetite for renewable energies in Africa[36] but rather are the current approaches and business models[37] likely to help Africa reduce its dependence on traditional fossil fuels (currently 53% of total energy supply) and biomass (about 45%)? As noted earlier, the main drivers of the rapid growth in renewable energy supply include improved performance (life-span, storage capacity, energy conversion efficiency etc), rapidly falling prices, easy of installation and maintenance (almost approaching plug and play), and faster deployment time). For Africa, high energy prices and lack of alternatives modern energy sources to meet their personal and institutional needs may be other key drivers as well.

[36] Anders Ellegård, Anders Arvidson, Mattias Nordström, Oscar S Kalumiana and Clotilda Mwanza, (2004) Rural people pay for solar: experiences from the Zambia PV-ESCO project, *Renewable Energy*, Volume 29, Issue 8, Pages 1251-1263

[37] Mukoro, V., Sharmina M. and Schmid A. G. (2022) A review of business models for access to affordable and clean energy in Africa: Do they deliver social, economic, and environmental value? *Energy Research & Social Science*, Volume 88, 102530, pages 1-12




Source: ECA based on International Renewable Energy Agency database

What can Africa do to carve a decent portion of the future global market for renewable energy? Until a few decades ago, the production and export of solar PV industry products was an exclusive club of advanced nations in Europe and the United States. Today, China and India are now to producers of solar energy components and systems. Vietnam is also emerging as a producers of solar energy products. China now accounts for about 80% of the solar cells manufacturing and controls about 64% of the materials for making solar cells (i.e. polysilicon material which is needed to produce Ingots and later wafers used to make solar cells).[38] This has achieved through support to innovative private start-ups[39] often attracted by ambitious long term Government investment programmes and support to enter export markets, ramping up human capital development[40] and investment in R&D infrastructures. For instance, China boast entire universities and numerous schools and academic programmes on energy, including renewable energies, providing the talent and

[38] CPA white paper 2022 available at https://prosperousamerica.org/wp-content/uploads/2021/03/210309-CPA_WP-Solar_Supply_Chain.pdf

[39] Hopkins, M. and Li, Yin (2016) The Rise of the Chinese Solar Photovoltaic Industry: Firms, Governments, and Global Competition. In: China As an Innovation Nation (pp.306-332), Chapter: 12 Oxford University Press (Editors: Yu Zhou, William Lazonick, Yifei Sun)
Huang, Ping & Negro, S.O. & Hekkert, M.P. & Bi, Kexin. (2016). How China became a leader in solar PV: An innovation system analysis. Renewable and Sustainable Energy Reviews. 64. 777-789. 10.1016/j.rser.2016.06.061.

[40] Cyranoski, D., Gilbert, N., Ledford, H. *et al*. (2011) Education: The PhD factory. *Nature* **472,** 276–279.

knowledge for industry and national energy development planning[41]. Similar, Vietnam attracted foreign and domestic investors to develop local production and exports through its ambitious programme that saw installed solar grow from 105 MW in 2018 to 16,660MW in 2020 (more than Africa's installed capacity of 10,200 MW in 2021[42]. African countries need similar ambitious plans and here we highlight a few steps African countries can pursue to compete successfully and win.

### 4.1. Integrated approach to human capital development

As noted earlier, new and emerging energy technologies encompass a range of skills, knowledge sets and technologies drawn from different disciplines and sectors – each of technology with its own value and supply chains. The questions therefore is how to design new or enhance existing human capital development efforts that reflect the need to urgently build a wide range of skills and talent; which institutions or institutional arrangement may be best placed and what support measures are needed? This could be achieved in various ways and each country or groups of countries can employ.

One option is for countries to encourage their institution to set up interdisciplinary training and research centres in collaboration with existing energy firms. These 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 combinations that may fit national contexts. For instance, existing skills in mining, petrochemical and energy industries can be employed to support practical training programmes for the development of batteries, solar products and handling of hydrogen as well as installations and maintenances of home and commercial solar and wind energy systems.

Depending on comparative advantages, countries may also choose an entry point that exploits existing natural resources. For instance, the Geothermal Training and Research Institute at Dedan Kimathi University of Technology offers BSc in Geology, Post Graduate Diploma in Geothermal Energy Technology, and MSc in Geothermal Energy Technology for students as well as industry and countries teams interested in developing geothermal energy industry[43]. The programmes we co-designed with industry that have made Kenya the eight largest geothermal energy producer in the world (number 1 in Africa)[44]. In this case, existence of geothermal resources and firms in the emerging sector played a role in getting academia and industry to support design of geothermal training programmes. A similar approach could be used in designing training and skills development programmes in other renewable energy industries.

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[41] O'Meara, S. and Ye, Y. (2022) Four research teams powering China's net-zero energy goal. *Nature* Spotlight https://www.nature.com/articles/d41586-022-00801-4

[42] https://www.energymonitor.ai/finance/vietnam-foreign-investors-in-dire-need-of-incentives-for-renewable-energy

[43] https://getri.dkut.ac.ke/programmes/

[44] https://www.unesco.org/reports/science/2021/sites/default/files/medias/fichiers/2022/03/central-east_africa_Box-19-1.pdf

Regional blocks could also build on existing programmes to create specialized capacity in specific energy technologies. For example, the Kafue Gorge Regional Training Centre (KGRTC) is overseen by a regional Board of Trustees from Malawi, Eswatini, Tanzania, Uganda, Zambia and Zimbabwe and offer training in hydropower. Such entities provide a model for building regional training centres in specific energy technologies. Based in the same location as the Kafue Gorge Hydropower Station, if offers hands-on training to graduates from engineering schools and workers in the energy sector. With the growing number of renewable energy firms, similar approach can be used to upgrade skills as well as generate new ones.

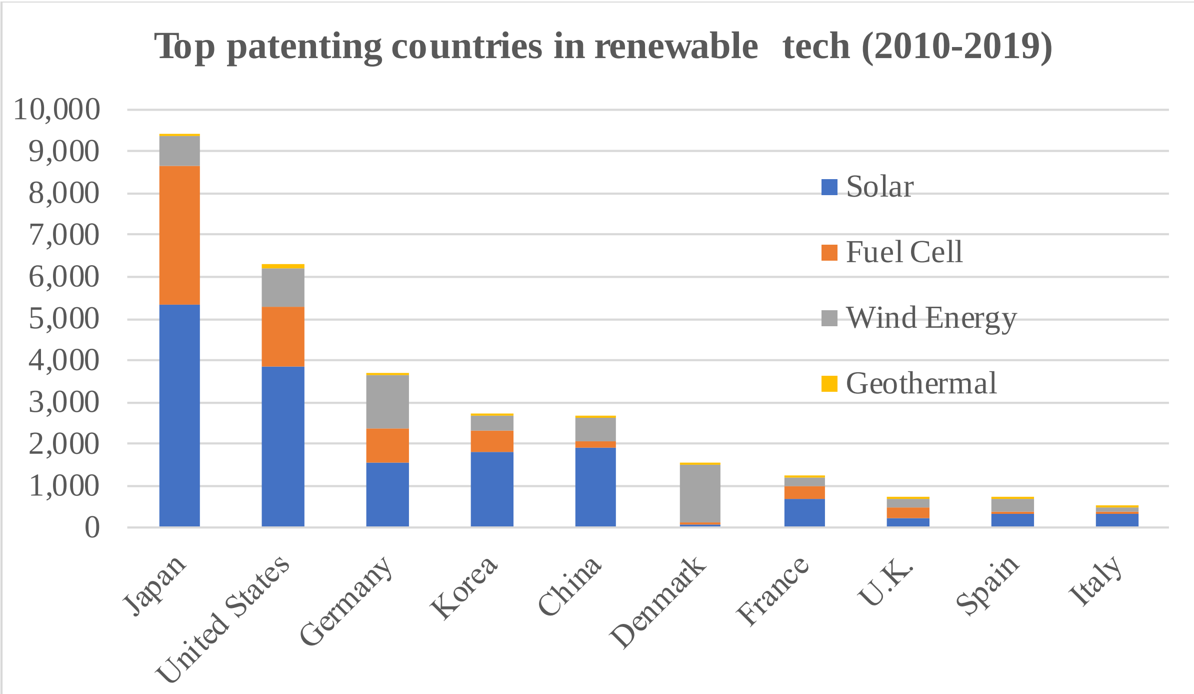
Countries with greater ambitions may have to go a step further and build interdisciplinary centres in universities or colleges that teach, undertake research and develop products for and with industry. These centres can benefit from the specialized courses in biology, chemistry, physics, engineering and others with a focus on energy. For instance, ECA and its partners have designed BSc and MSc programmes in material sciences with a focus on energy, water, health and agriculture that are advance an interdisciplinary and entrepreneurial approach.

### 4.2. Expanding the research and development in renewable energy

Emerging technologies are driven by research and development in the materials needed to produce the various technological productions, basic science that underpin the advances in scientific understanding and improvements in product performance, and the design, application and manufacturing processes that enable industrial scale production. For example, research in advanced materials and nanotechnologies are the heart of design and development of high energy storage batteries, membrane for electrolysers for hydrogen production and seawater desalination, and high efficient solar cells among others. Fundamental research is also needed to inform the manufacturing and deployment of renewable energy technologies in an inclusive and sustainable manner.

Globally, about $6.7 billion in R&D investment was spent on solar systems, $2.7 billion on wind, $1.8 billion on biofuels, $1 billion biomass, $0.7 billion in small hydropower, and $0.2 billion each for geothermal and marine energy in 2019 alone. Similarly, the top 20 automobile manufacturers have spent $97.5 billion (£71.7 billion) on battery R&D between 2019 and 2020.[45] These investments are focusing on the technology value chain (materials, production, integration and recycling) with the desire to optimize performance, costs and durability to meet environmental and economic growth ambitions.

[45] Top 20 global carmakers spend £71.7 billion on R&D battery technology




Source: Economics and Statistics Division, WIPO

Evidence so far suggest that Africa has limited investment in renewable energy. There is no African country among the top renewable energy patenting countries (see figure above). Patenting trends reveal areas of national interest. China, for instance, has applied for more patents in solar technologies than in all other renewable technologies combined. It is thus not surprising that China "added 55 GW of solar installations in 2021 and module exports surpassing 100 GW"[46]. The same can be said of Denmark where Siemens and Vestas account for a third of the global wind turbine installation in 2018.[47]

As a first step to change this picture, African countries should aim to create renewable energy research and product development centres in universities and R&D institutions that can support both product and skills development. Such university research programmes or even schools can be co-designed, supported and managed with industry (e.g. energy utilities), government departments and/or partners with established programmes. These could take similar models such as the National Renewable Energy Laboratory of the US Department of Energy with 3227 staff, various research centres and laboratories in solar, wind and bioenergy, $671 million in business volume in 2022 and has been awarded 688 patents and 1046 active collaborations with academia, industry, not-for-profit entities and government[48]. Such entities can lead national efforts by keeping researchers and industry abreast with emerging trends as well as help in design national

[46] https://mercomindia.com/china-exports-modules-2021/
[47] https://denmark.dk/innovation-and-design/clean-energy
[48] https://www.nrel.gov/about/

energy development plans and strategies through social science research, and in seeding and nurturing start-ups.

Expanding the R&D base creates immediate jobs for some of the brightest and creative minds Africa loses to the world; gives Africa a stake in generating knowledge that will drive 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 R&D also helps bring top research teams[49] and industry to work closely which traditionally has been observed to speed up growth of industries in emerging technologies (Zucker et al, 1998[50]; Kotha and George, 2010)[51]. Very few African countries today can boast capacity to design, install and maintain grid-scale renewable energy installations.

### 4.3. Actively seek strategic research and industrial alliances

Strategic alliances are intended to develop specific set of skills and complementary knowledge base, reduce the time and risk of developing and bringing a technology or technology products to market, and gain access to vital resources (e.g. land, water, minerals, facilities, infrastructure, intellectual assets etc) and/or markets. This will require African countries to take a lead in identifying areas where such alliances may be of greater value.

Research alliances will be important in acquiring and developing national research base in renewable energy. These may include twinning training, teaching and research institutions of interest, exchange and hosting of top researchers and students and joint research facilities in a developed country partner. Such alliances must have a clear goal to help move up the technological ladder to avoid perpetual dependency.

Industrial alliances are largely formed between firms for a range of reasons that may include combining unique knowledge, intellectual assets and experiences in R&D, manufacturing or production, distribution, marketing and sales. Africa may have to entice and/or incentivize its vertically integrated energy utilities to seek partnerships that may lead to formation of joint-ventures or form start-ups in given technology segments or to access skills, gain experience or codevelop R&D, manufacturing and production of renewable energy technologies or products. It may require governments to entice energy utilities to create opportunities for private sector participation in the energy sector.

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[49] https://www.hamiltonproject.org/charts/most_inventors_have_graduate_degrees

[50] Zucker, L.G., Darby, M.R., and Brewer, M.B. (1998) Intellectual human capital and the birth of U.S. biotechnology enterprises," *American Economic Review*, *88*, 290-306.

[51] Kotha, R. and George, G. (2010). Academic entrepreneurs: The role of star scientists in commercialization of radical science. Frontiers of Entrepreneurship Research: Proceedings of the 30th Annual Entrepreneurship Research Conference. 30, 5-1-5-1.

### 4.4. Develop and upgrade transmission infrastructure

As noted earlier, renewable update in Africa is growing rapidly and that trends are likely to continue especially if the energy infrastructure is reliable and secure. For instance, the number of projects that will seek connection to national grids is likely to grow rapidly. The current electricity grids that serve about half of the population may be inadequate and possibly ill-prepared to meet a surge in supply and demand of energy. This requires that countries anticipate and undertake the necessary upgrades to ensure the electricity grid will be safe, stable and reliable if or when new load is taken up. Even countries with extensive and well-developed grids will face challenges to bring more electricity from renewable sources online

For example, data from the United States suggests that the number of projects applying to connect to the grid have a combined 930 gigawatts of generation capacity and 420 gigawatts of storage capacity as of 2021 - about 80% of the electricity capacity the US needs to meet its 2030 target of clean energy targets- but the waiting time for approval has increased from 2.1 years between 2000 and 2010 to 3.7 years between 2011 and 2021 largely blamed on the infrastructure[52]. Issues such as connection to the grid and feed in tariffs will become key in encouraging investment and rapid grow of energy access and affordability in Africa.

As discussed earlier, infrastructure for electric mobility, hydrogen storage and distribution are other cases that will require governments and industry to anticipate demand and supply needs. Electric cars may already be entering the market but charging points remain few or lacking in most places.

### 4.5. Supporting new and innovative business models

New and innovative models are needed not just in technologies for converting, storing and transporting renewable energies but also in its applications and consumption. As renewable energy technologies become affordable, such as solar-powered microgrids, a $1 million investment could power a rural community of tens of households[53]. It is a lot simpler and faster to build and could be maintained by the local community. In a way, it makes Africa the perfect place for distributed or decentralized energy systems and microgrids.

There is a rapid expansion of pay-as-you-go and mini-grid business in Africa. For instance, ENGIE Energy Access[54] offers off-grid, Pay-As-You-Go (PAYGo) solar and mini-grid solutions to over 1 million customers Benin, Cote d'Ivoire, Kenya, Nigeria, Mozambique, Tanzania, Uganda and Zambia while Sun King[55] designs its own lighting and solar home systems that may include a TV that can be purchased or paid off through PAYGo in a year – with over 2000 employees and 15,000 field agents in India, Kenya, Nigeria, Myanmar, Mozambique, Tanzania, Uganda and Zambia. Senegal's Oolu[56], founded in 2014 has since raised $8.5 million in investment and has offices Mali, Burkina Faso, Niger and Senegal and with operations in Nigeria offers both solar home systems

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53 Singh, Rajesh Kumar. 2019. "Tata, Rockefeller Foundation Plan 10,000 India Microgrids." *Bloomberg*

54 https://www.engie-africa.com/

55 https://sunking.com/

56 https://oolusolar.com/

and micro-grid development. Many such firms are groping up across Africa and the developing world largely responding to the unmet energy needs of the urban and rural poor.

While these models may be currently viable, they need support to grow and evolve with the technology to remain competitive. The case of digital technology offers a few examples. The community information centres and internet cafes as well as independent internet service providers were viable innovative business models were key in narrowing the digital divide between the rich and the poor, urban and rural, among others, in both developing and developed countries through most of the 1990s and 2000s. The advances in wireless technology and their rapid uptake made most internet cafes, community information centres and independent internet service providers irrelevant.[57] As such, both the governments and firms have to keep up with trends in emerging energy technologies and changing expectations of users.

### 4.6 Renewable energy technology and innovation roadmap

Several issues discussed in this section could inform national and regional renewable energy roadmaps. A detailed plans may address how countries will transition towards clean, accessible, competitive, secure, safe and affordable energy supply for all. Policy makers and emerging industrial entities in Africa need to develop clearer strategic plans that guide the behaviour of all players and inspire the populous of better future. For example, how many jobs would be created, how many communities will be connected, how cheap would energy get, how stable will be the power supply etc. While plans do not necessarily work out as written, they inspire academia, industry, government agencies and society at large to work towards a common future.

While each country may employ different tools and approaches, they could look at technological, industrial, trade, employment, investment requirements and merging regulations and practices etc, as well as the costs and benefits, losers and winners among others. For instance, different components of energy technology sectors present different employment opportunities. The PV systems for communities and utilities create about 75% of the jobs in manufacturing (e.g. wafers, solar cells, panel, batteries, inverters etc) and 25% in constructions and installation[58] while two-thirds of the in employment in green hydrogen are in renewable energy production and a third in hydrogen production, transmission and storage[59]. As such, the choices countries and their firms make will have an impact on employment, accessibility, affordability and overall future demand by sector and use cases (e.g. heating, cooling, transport etc). Clearer roadmaps could help guide national policies, investments, human capital development, minimise creating losers and optimise benefits, and encourage healthy competition and collaborations at national, regional and global level. The roadmaps should include clear implementation and investment plans.

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[57] Desmond Frimpong, Internet cafes in Accra are quickly becoming a thing of the past, Business Insider, September 28, 2017;

[58] Vidican Auktor, Georgeta; Böhning, Matthias; Burger, Gina; de Siqueira, Elisa; Müller, Sandra and Wendt, Susanne. (2013). Achieving Inclusive Competitiveness in the Emerging Solar Energy Sector in Morocco. Technical Report, German Development Institute

[59] https://www.energymonitor.ai/tech/hydrogen/hydrogen-tests-climate-policymakers-with-its-job-potential

**Conclusion**

The main purpose of this background note was to highlight some of the emerging technologies and the opportunities they present to Africa and show case some of trends and how Africa could fully participate in the emerging energy technology industries. It is also hoped that it will stimulate research, debate, policy development, collaboration and partnerships between and among countries to advance development, production and manufacture of renewable energy products in Africa to enable the continent to sustainability bring renewable energy that is useful, accessible and affordable.

So far, Africa seems to be doing very well in acquisition and deployment of solar and wind energy, and is poised to be one of the key players in hydrogen production and trade. The rapid uptake of renewable deployments in Africa is driven by the rapid falls in the prices and efficiency of various components such as batteries,[60] solar panels and wind turbines [61] with a focus on bringing electricity to those without any or with unstable power supply. The next step is move beyond being a user and consumer of energy products designed elsewhere for different environments.

This will require countries to stimulate the emergency and growth of existing energy technology firms offer decent employment and compete in the global market for emerging energy products. For that to happen, concerted efforts by governments, academia, industry and not-for-profit organization to become players in technology research, development, production and manufacturing will be needed. The burgeoning domestic demand for renewable energy products could serve as the target market and basis for supporting nascent and existing firms to learn and grow.

Clearer policies are needed to drive such development and address many of the issues raised in this note. The ECA science, technology and innovation development and implementation policy guide offer numerous examples that countries can use to develop their roadmaps for renewable energy. Furthermore, the science, technology and innovation roadmap for the sustainable development goal developed by the UN Inter-Agency Task Team on STI is another tool that can also be used to support countries seeking to develop their own roadmap, strategies and policies.

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[60] https://www.sustainabletruckvan.com/price-of-lithium-batteries-fall/

[61] https://www.energy.gov/articles/doe-releases-new-reports-highlighting-record-growth-declining-costs-wind-power