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1 Introduction

While the world market for photovoltaics has returned to double digit growth in 2019, the African continent as a whole has shown mediocre performance. Therefore, exploring the data of African countries might seem discouraging at first. However, a more in-depth analysis provides an encouraging storyline for the PV dynamics on the African continent. Overall, we expect most of the analyzed African solar PV markets to enter a phase of growth, in terms of installed capacity both on- and off-grid. While there is a mixed track record of tenders on the continent, recent tenders for utility-scale projects have led to record-low prices.

So far, and almost paradoxically, the growth of solar markets was mainly driven by countries outside the highest irradiation zones on earth. Fully exploiting the natural match of Africa and its abundant solar resources would bring enormous benefits both to the national economies and, for example, the isolated communities on the continent. Solar can contribute significantly to cover the increasing electricity demand of the continent's growing economies and to tackle global climate change. At the same time, the transition to low-carbon, fuel-less energy sources will empower nations to decrease their dependencies on expensive fossil fuels.

More than meeting growing energy demand, solar can provide the solution to many additional energy challenges in the markets covered in this report. These range from a reduction of import dependency, to the contribution to economic and social development resulting from electrification adapted to local needs. Universal electricity access to clean and reliable power is a key to positive economic development.

The scope of this year's report has been broadened in several ways. We added country-specific analyses on six more African markets: Senegal, Mali, Uganda, Madagascar, Kenya and Tunisia. You will also find an analysis of the competitiveness of mini-grids in this year's report, as it is estimated that about half the world market for these will be on the African continent. This year's report also looks at the combination of solar energy and water, a match made in heaven. The chapter "when solar met water" therefore examines the different technologies and their application in Africa. We look forward to broaden the scope to additional countries and developments in further editions.

We did find a large pipeline of projects of various sizes in Africa for both 2020 and 2021 and we have seen improvement in the managing of PV projects in all stages of their development. As we went to press, the scale of the market impact of the global COVID-19 pandemic is not finally clear. For the African continent, we believe that the positive factors driving solar installations will outweigh the negative impact of the pandemic. We hope to confirm that prediction when we present our 2021 report at The Smarter E Europe.


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2 The energy transition in Africa

The current population in Africa has surpassed 1.3 billion people. Only half the population has access to electricity, and more specifically around 79 % in urban and 35 % in rural areas [1]. The energy consumption per capita is amongst the lowest globally, with large disparities between the economically developed cities and rural areas. Despite recent improvement in electricity access, the continent struggles to keep up with the growing population and, hence, to meet the energy demand in absolute numbers. Indeed, in a special report on energy access, the International Energy Agency (IEA) expects the share of the population in Africa without access to electricity to fall to 36 % by 2030. However, due to population growth, the total amount of people without access would continue to increase [2].

Electricity demand in Africa is growing as both population and economic activities are soaring in most of the countries. Consequently, the level of investments in the power sector must be raised. According to the International Renewable Energy Agency (IRENA) [3], the continent will need to double its capacity between now and 2030 to meet the demand. The IEA seconds the statement and predicts that the capacity needed will be 497 GW in 2030 [4].

Parts of the continent can benefit from recent global progress and cost reductions in renewable power generation technologies, to leapfrog fossil fuel-based systems and move directly to a renewable-based system. Furthermore, solar PV systems in combination with batteries might be an alternative to grid infrastructure reinforcement in remote areas. Indeed, the decreasing prices for solar PV and the high irradiation on the African continent demonstrate the case to develop renewable energies and solar PV, both grid-connected and off-grid.

Despite the significant cost evolution of solar PV and its growing competitiveness in many market segments, some structural problems on the continent are holding back the expansion of renewables. The African solar energy sector suffers from the presence of fossil-fuel subsidies, weak financial strength of utilities, outdated and unstable grids and an at times unstable political environment. These factors translate into higher levels of risks for investors in the sector and make it difficult for potential investors to access needed financing. These problems are particularly relevant for investments in solar PV installations as these are characterized by higher upfront costs than fossil fuel power plants for instance.

Given the challenges cited above, most of the scenarios developed to predict long-term energy trends in Africa are quite conservative when it comes to integrating renewable energy sources. Even scenarios with higher penetration of renewable energy sources are often not in line with the Paris climate goals. The Special Report on Global Warming of 1.5 °C from the Intergovernmental Panel on Climate Change (IPCC) states that emissions of methane and black carbon must be reduced to zero in 2050 to limit global warming to 1.5 °C. After 2050, net emissions must be negative to stabilize the temperature with no or limited overshoot. Consequently, the use of fossil fuels is to be excluded by 2050 if these targets are to be met.

The scenarios that are the least in line with the climate goals are the Energy Outlook from BP [5] and the Global Energy Perspective from Mac Kinsey [6] for instance, but other studies could be cited. BP foresees a share of renewables in the African fuel mix of 16 % by 2040, while Mac Kinsey estimates that, on the global scale, fossil fuels will meet 74 % of primary energy demand in 2050.

IRENA's latest Prospect for the African Power Sector [3] is already more in line with the climate goals but not entirely, partially because it was published in 2011 and the levelized cost of electricity (LCOE) of wind and solar have decreased drastically in the meantime. According to the study, approximately 80 % of the electricity generation capacity on the continent would be renewable in 2050.

Figure 1 compares the share of solar PV in the electricity production in Africa from two major recent scientific publications: the sustainable development scenario from the World Energy

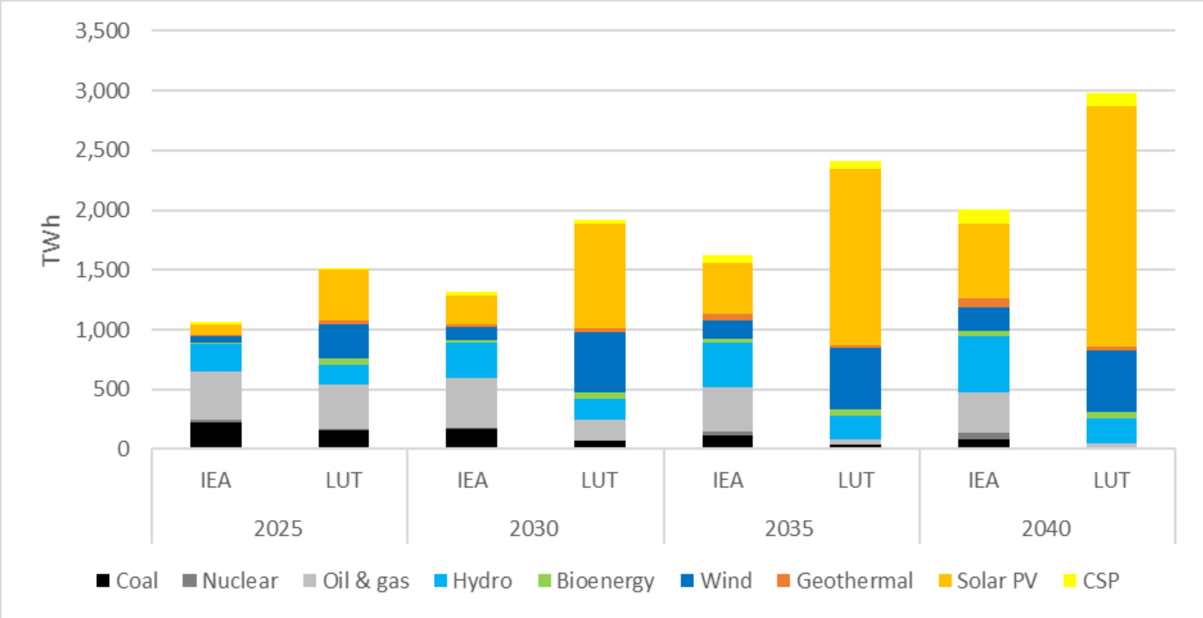

Figure 1: Comparison of scenarios of future electricity generation from different technologies in Africa [1] [7].

Outlook of IEA [1] and the Global Energy System Based on 100 % Renewable Energy study from the Lappeenranta University of Technology (LUT) [7].

The IEA scenarios map out the consequences of current energy policy and investment choices and therefore merely reflect the dynamics – or lack of dynamics – at play. The LUT scenario considers the LCOE production as well as system costs to achieve a 100 % energy transition in the power sector.

The two scenarios above differ by two main characteristics: the total electricity generation and the share of PV in total electricity generation. The difference in the total electricity generation can be explained by the total electrification of the energy system in the scenario of LUT. This electrification of the energy system is essential to fully decarbonize the energy system, transport, heating and cooling included. The higher share of PV in the LUT scenario can be explained by both economic and environmental factors. Indeed, solar is the most easily available renewable energy resource and is also the most cost-efficient. Therefore, the massive deployment of PV is required to achieve the Paris Climate Agreement [7].

Until recently, forecast scenarios involving a higher share of renewable energy were characterized by higher energy and system costs. However, the trend is reversing now, with solar PV becoming one of the cheapest production options and storage becoming more competitive at the same time. Solar PV has already achieved market competitiveness in some market segments. Its market share will continue to grow as solar PV will become even more cost competitive compared to conventional technologies [7]. Therefore, the breakthrough of solar PV on the African continent could happen sooner than expected. Even more so, if innovative business models and new ways to facilitate access to finance pave the way and allow to overcome the oftentimes higher upfront costs of solar PV.

3 Market status and forecasts

The following chapter gives an overview over the African PV market with special focus on the off-grid market, as well as in-depth analyses on 16 African countries, followed by forecasts and a ranking of countries according to attractiveness for PV.

3.1 2019 market numbers per region and country

Market numbers in Africa are in most cases estimations based on a variety of sources. Few countries follow installations with the level of detail that can be found in most OECD countries, for instance. Therefore, market data are often based on solar cell import statistics, local sources and specialized expertise.

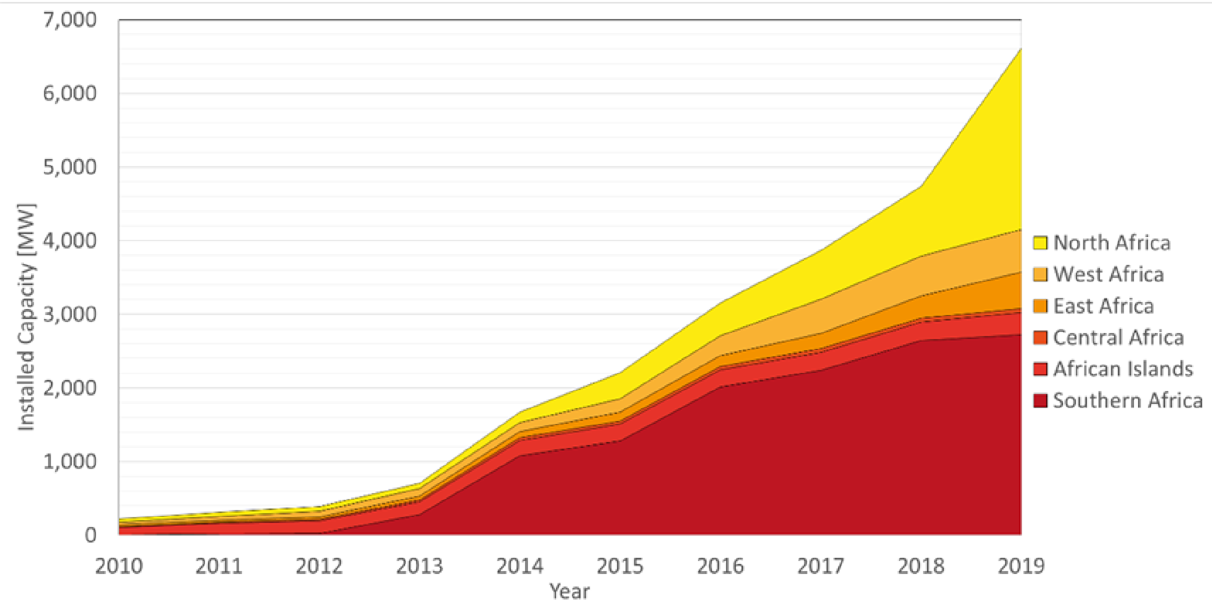

Figure 2: Evolution of the total installed PV capacity per region in Africa [8]

In general, the share of the African continent in the global PV market is still disproportionately small: In 2019, the growth of the African market amounted to an estimated 1.9 GW, while other regions of the world represented an annual market growth of 115 GW. With an estimated total solar PV installed capacity of 6,614 MW[1] [8] at the end of 2019, Africa represents a mere one per cent of the world's solar PV capacity. One of the main reasons for this low share is the difficulty for many countries to attract the needed private investments. However, the continuing introduction of supporting policies and regulations might spur the uptake of solar PV technology in the coming years. New renewable energy markets in Africa are already showing greater appeal to international and local investors and many plants are expected to come online in 2020.

The early solar PV developments on the continent were often linked to government and donor-supported rural electrification programs. However, in recent years, a transition to a more market-based diffusion has been observed. Indeed, the private sector is increasingly offering different types of PV systems for households, institutions and villages. Nowadays, solar PV is present in multiple forms in Africa, from a solar lamp over rooftop installations to utility scale PV. Various solar applications, such as street lighting, water pumping or powering hospitals, have been introduced to the market to meet the needs of the population.

In terms of volumes, large-scale installations represent the main share of total installations. Medium scale installations of ground mounted PV are probably the least represented segment. This is

[1] All the solar capacity numbers are reported in direct current (DC).

due to the lack of profitability and regulation on self-consumption – but this could shift, as discussed in chapter 5.

Although most African countries already had installations in 2010, the PV market really took off in 2014 with the first tender in South Africa, followed by tenders in several countries in the following years.

Total PV installed capacity Top 10 of the African countries	
South Africa	2,561 MW
Egypt	1,647 MW
Algeria	519 MW
Morocco	206 MW
Reunion	191 MW
Namibia	135 MW
Senegal	134 MW
Zambia	96 MW
Kenya	145 MW
Mauritania	88 MW

Figure 3: Total PV installed capacity – Top 10 in Africa [8]

The deployment of solar PV is mainly driven by Egypt (1,647 MW), Algeria (519 MW) and Morocco (206 MW) in Northern Africa and by South Africa (2,561 MW) in Southern Africa. Not surprisingly, those are the countries which combine official renewable energy targets, PV policies and supporting measures. In other regions, the most active markets were La Réunion island (191 MW), Namibia (135 MW), Senegal (134 MW), Zambia (96 MW), Kenya (145 MW) and Mauritania (88 MW).

Concerning Concentrated Solar Power (CSP), the African continent plays a more prominent role, as it represents approximately one sixth of the total capacity installed in the world. With the addition of 100 MW CSP in South Africa in 2019, the total capacity installed on the continent reached 1,076 MW at the end of 2019. The first CSP plant in Africa was built in Algeria in 2010 (25 MW). Since then, CSP has been developed mainly in Morocco (530 MW) and South Africa (500 MW). Egypt also installed some CSP (20 MW) and announced more in its renewable energy plan, as discussed in the analysis of the Egyptian market.

CSP heat can be used directly for industrial heating processes or combined with storage to deliver electricity and heat when needed. Though very promising, CSP did not follow the steep reduction of costs of solar PV, which explains its slow development as shown in the figure below. Even though recent development efforts have reduced the costs of this technology, CSP's competitiveness remains far below PV when it comes to electricity production. However, CSP can reach or even exceed 400°C and therefore could be a means of supplying medium-high temperature process heat needed by industry. Heat represents three-quarters of industrial energy demand worldwide, and half of it is of low to medium-high temperature [9].

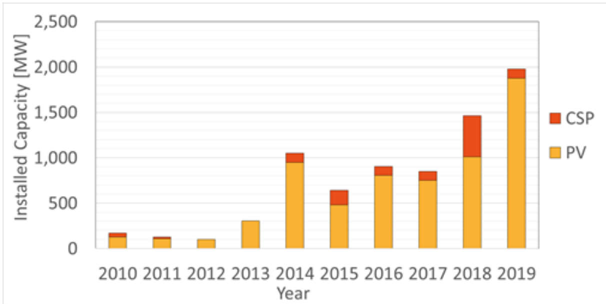

Figure 4: Evolution of the yearly installed PV and CSP capacity in Africa. [8]

3.2 Analysis of key markets

The diversity of human, social, economic and policy environments in Africa would imply to look at each country in detail to understand their complete solar development potential. The 16 countries selected below represent key examples of countries with either a significant, but untapped potential for PV development or an already existing and dynamic PV market. They also represent an interesting set of economic and policy environments. Six new countries have been added to this year's report.

Algeria

Algeria is considered to have the highest potential for solar power exploitation in the region and one of the highest in the world, as 75 % of its territory is covered with the Sahara Desert. Measurements of solar radiation reported an average annual sum of global horizontal irradiation ranging from 1,680 to 2,410 kWh/m^2 [10].

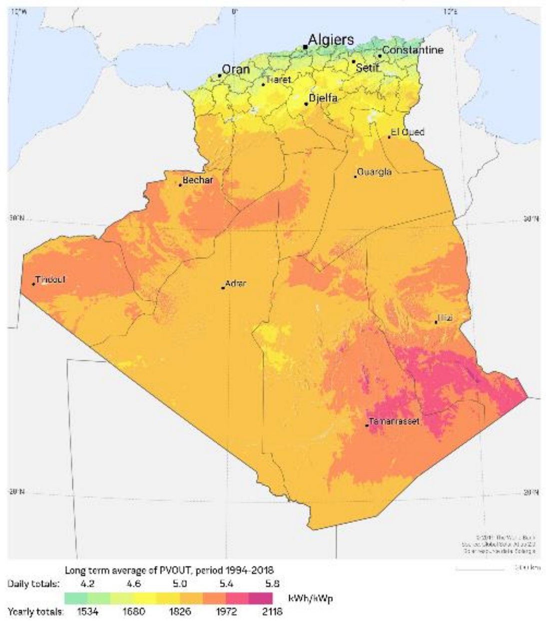

Figure 5: Photovoltaic power potential Algeria [10]

Overall, electricity access in Algeria is high, with above 95 % of the population, both in urban and rural environments, having access to electricity [11]. The high number in rural environments can be partly explained by a governmental program which provided solar electricity for over 300,000 isolated and off-grid households in the south of the country that ended in 2010 [12].

In 2011 the government of Algeria defined a Renewable Energy and Energy Efficiency Development Plan for the period from 2011 to 2030. This plan sets the ambitious target of 22 GW renewable energy installations by 2030 to satisfy local energy consumption, but also for neighboring countries, as ten GW are destined for exportation. The plan gives a preeminent role to solar energy (PV) with a target of 13.6 GW in 2030 [13].

The development of solar PV took off with increased Feed-in tariffs (FiTs) in 2015, when 48 MW were installed, followed by 180 MW in 2016, 181 MW in 2017 and 119 MW in 2018. However, no solar plants were installed in 2019 and the total capacity remained 519 MW. In May 2020, the government endorsed a plan to make solar the sole technology of a four GW renewable push from 2020 to 2024. The so-called Tafouk 1 plan foresees the investment of USD 3.2-3.6 billion to achieve its target [14].

Regulatory framework

Between 2014 and 2018, Algeria incentivized the installation of commercial PV plants above one MW with a FiT for a limited number of hours per year [15]. The renewable energy program was to be funded by a levy of 0.5 % on oil tax revenues. However, these have been decreasing in the last years and the FiT-program came to an end.

For large-scale installations, the government is regularly releasing new tenders for electricity production from renewable sources or for off-grid hybrid gas/diesel and solar projects; in the coming years the government has announced that 800 MW of capacity would be tendered annually, starting in 2020 [16]. As presented in more detail in chapter 5.2, these tenders include specific requirements concerning local manufacturing, to create more economic opportunities in the country. Selected plants sign a Power Purchase Agreement (PPA) with the regulator for a duration ranging from 20 to 25 years.

Potential for PV development

Algeria has several features which makes it attractive for the development of PV. There is a well-developed and growing local PV panel industry, the desert offers plenty of opportunities and the country shares interconnections with Morocco

(1,400 MW) and Tunisia (900 MW). After a few years of politically unstable climate, the two-decade long legislature period of the old president came to an end and gave way to a new government. The freshly elected prime minister will have to regain investors' confidence and will have to find a consistent and sustainable way to finance the energy transition. Also, in order to enable the growth of distributed PV, the nation should reduce subsidies on conventional electricity retail prices [17] as Algeria is amongst the top ten countries in the world regarding fossil-fuel consumption subsidies [18]. Over the next five years, at least four GW of PV installation should come online mainly through the above mentioned 800 MW annual tenders for the Tafouk 1 solar field [16].

Angola

Angola has several feasible options for renewable power generation: large hydropower, solar PV, solar thermal, biomass, wind and mini-hydropower. Ranging between 1,607 and 2,483 kWh/m², the average annual sum of global horizontal irradiation is very high [10], thus offering favorable conditions for the expansion of solar energy. Angola currently is the second largest oil producer in Africa.

65 % of Angola's urban population has access to electricity, leaving around seven million people in urban areas without access to electricity. In Angola's rural areas, the proportion of the population without access to electricity is 94 %, which amounts to almost ten million people with no electricity [11]. The Angolan government recognized that, especially in rural areas, renewable energy can play an important role in further electrification.

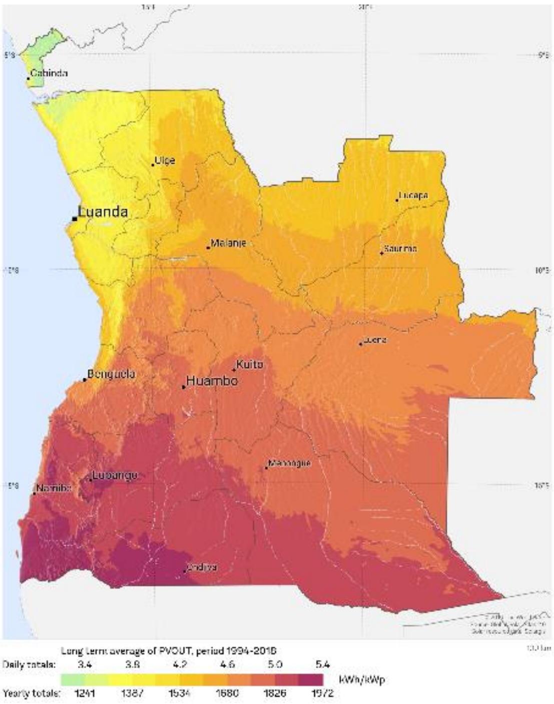

Figure 6: Photovoltaic power potential Angola [10]

Angola disposed of approximately 14 MW of installed solar capacity in 2019, including hybrid solar energy systems [19]. An updated 2018 projected energy mix for Angola consists of primarily hydro power (64 %), natural gas (12 %) and other fossil fuels (24 %) [20]. The government plans that in the future, hydro power will constitute more than 70 % of internal energy consumption in favorable years, compared to a share as low as 48 % in dry years [21], paving the way for the use of more solar energy. The Angolan Ministry of Energy and Water (MINEA) continues to estimate the potential for solar power technology at 55 GW [22].

Regulatory framework

The regulatory policies to support new renewable energy include FiTs, net metering, tenders for the construction of solar power plants and fiscal incentives [23]. The most recent national strategy "Angola Energy 2025" [21] shows a long-term vision for the energy sector of Angola from 2018 to 2025. With the government targeting an electrification rate of 60 % by 2025, as well as increased economic activity, total electricity demand is expected to rise to 7.2 GW in 2025. According to the "Angola Energy 2025" strategy, Angola will have in place 9.9 GW of installed power in 2025, compared to 5.9 GW in 2019 [24].

According to the plan, only 100 MW of solar power projects would have been installed, including 22 MW focused on rural electrification (mini-grids/off-grid systems) and 78 MW grid-connected PV. However, in September 2019, Angola's energy minister announced updated plans to increase PV capacity to 600 MW by 2022, predominantly through 30,000 individual systems build in rural areas with involvement of the private sector [22]. The "Angola Energy 2025" strategy also targets to build 500 solar villages by 2025. A concrete roadmap with the proposed locations as well as solar systems in other remote places already exists [21]. These small local grids in townships with more than 3,000 people are to be developed by private local initiatives.

Potential for PV development

As suggested in last year's report, solar energy now plays a more significant role thanks to its low costs and possible applications in rural regions. The Angolan government continues to plan to significantly increase the country's power generation capacities. The Angolan Action Plan of the Energy and Water sector (2018-2022) names solar as the main fossil fuels replacement and sees a potential of 100,000 imported and/or distributed individual solar systems [25]. Furthermore, the Angolan government continues to be in talks with the IFC to eventually join the World Bank Group's Scaling Solar Program. This could significantly increase utility-scale solar development in the coming years [23]. With view to the updated plans for off-grid systems in rural areas, a potential of additional 700 MW in the coming years seems feasible.

Egypt

Egypt is located in the northeast of the African continent and is increasingly using its immense solar energy potential [26]. Most of Egypt is desert and only 7.7 % of its land is inhabited, thus leaving plenty of space for utility-scale solar PV. All of Egypt's population has access to energy. The average annual sum of global horizontal irradiation is very high, ranging between 2,045 and 2,483 kWh/m^2 [10]. These constitute ideal conditions for the use of photovoltaic applications to generate electricity.

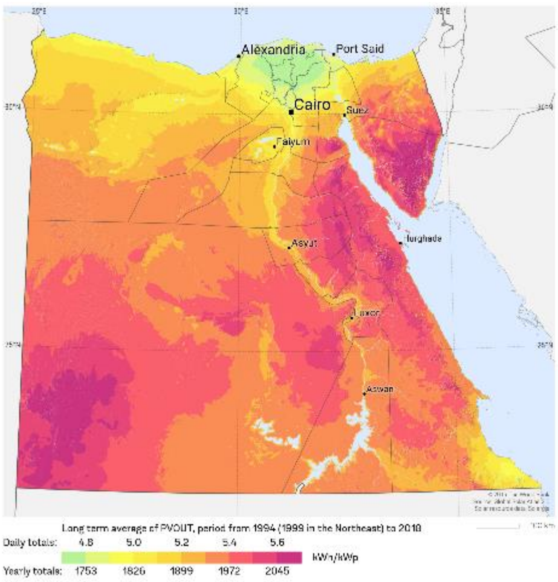

Figure 7: Photovoltaic power potential Egypt [10]

Nevertheless, at the end of 2019 around 90 % of the energy generation is covered by fossil fuels, which are limited, especially in the light of Egypt's planned significant economic development, population growth and resulting increase in energy demand. In an effort to reduce the significant air-pollution problems in Egyptian cities as well as CO_2 emissions, renewable energy sources are to become the primary fuel for the generation of electricity in the future.

By the end of 2019, the PV capacity installed in Egypt was estimated at over 1.6 GW, with the newly installed capacity during the year reaching almost one GW [27] according to IRENA, while other sources state an installed capacity of 2.3 GW and 1.6 GW added in 2019 [28]. The difference is likely due to the finalization of Benban at the very end of 2019. Benban, which is the largest solar park in Africa with a final 1.5 GW installed capacity and six million photovoltaic panels, will reduce CO_2-emissions by almost two million tons per year and has a guaranteed FiT for 25 years.

Regulatory framework

Egypt's Integrated Sustainable Energy Strategy sets out an increase in the production of electricity generated from renewable sources to 20 % of total electricity production by 2022 and 42 % by 2035, with solar providing two per cent in 2022 and 25 % by 2035 respectively [29]. As a result, an estimated total of 31 GW solar power would be added to the grid by 2035 [29][30]. In order to facilitate this growth, Egypt substantially developed its regulatory framework for solar energy over the last decade, including FITs, auctions and tenders, and allowing independent power producers to sell to consumers. In 2017, Egypt's net metering framework was updated to allow payments for surplus energy generated by net metered installations of up to 20 MW [31]. In early 2020, the Ministry of Electricity stated that further new regulations are in the works to pave the way for the establishment of renewable energy stations, as well as the direct sale of electricity to other parties under the independent power producer (IPP) system [32]. In the past years, energy prices have soared, as the state continues to cut energy subsidies.

Potential for PV Development

According to IRENA, Egypt has the potential to reach 44 GW of installed solar PV power by 2030 [33]. The Ministry of Electricity and Renewable Energy estimates a solar power potential of more than 50 GW[34]. Based on the mentioned 2035 strategy, Egypt plans to produce 31 GW solar power in 2035. In the nearer future, Egypt's Renewable Energy plan aims to install 3.5 GW solar energy by 2027, including 2.8 GW of solar PV and 700 MW of CSP[35]. At the end of 2019, The European Bank for Reconstruction and Development lent 183 million Euro to help connect further 1.3 GW of renewables into the grid [36]. In early 2020, it was announced that the Ministry of Electricity is working to formulate new incentives to further attract foreign investments in energy projects [32]. In general, the discussed set of conditions make PV applications in Egypt, both on- and off-grid solutions, economically attractive. Additionally, the exportation of renewable energy to neighboring Arab countries or even to Europe represent a conceivable option. Egypt's recent installations of solar PV show that the country can easily surpass the political goal of installing 2.8 GW of solar PV in the next seven years.

Ethiopia

Ethiopia's population of over 110 million is the second largest of Africa. While almost the entire urban population has access to electricity, around 70 % of the population (60 million people) in Ethiopia's rural areas are without access to electricity, according to the latest data available [11]. The government's target is to increase the share of population with access to electricity to almost 100 % by 2030 [37]. The average annual sum of global horizontal irradiation lies between 1,753 and 2,483 kWh/m^2 [10]. Ethiopia consequently has excellent potential for the deployment of solar energy.

Looking at installed capacity, hydropower is the main energy source in Ethiopia and covers approximately 85 % of the installed capacity of 4.5 GW in 2018 [38]. Solar PV capacity is estimated to be only 11 MW countrywide [27]. Over 90 % of the final energy in Ethiopia is consumed by domestic appliances, of which the vast majority stems from

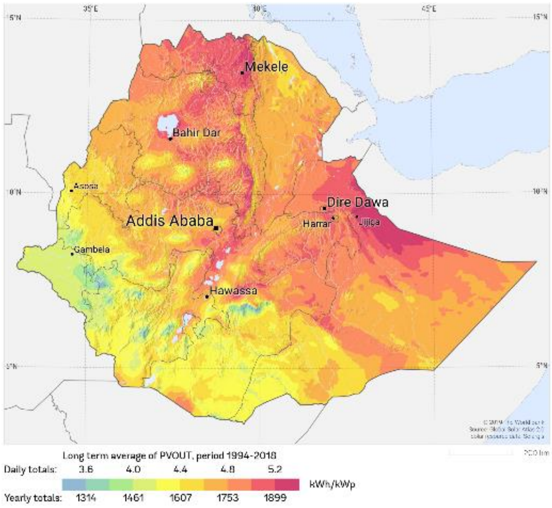

Figure 8: Photovoltaic power potential Ethiopia [10]

biomass [39]. In the past decade, electricity demand rose due to fast population growth and economic development, and it is expected to further increase 30 % per year [40]. End-consumer tariffs for energy have been among the lowest in Africa, but the Ministry of Water, Irrigation and Electricity (MoWIE) has announced gradual increases in prices in 2019.

Ethiopia is a member of the World Bank Group's Scaling Solar program, which has contributed to the government's plans to prioritize new solar capacity. The first round of the Scaling Solar program tender process for 250 MW in Ethiopia was finalized in the second half of 2019, with the winning bid of USD 0.025/kWh being among the lowest in the African continent to date [41]. In mid-2019, the second round of the Scaling Solar tenders were increased from initial 500 MW to 750 MW, which are under review at the time of writing this report. With view to mini-grids, in November 2019, the Ethiopian Electric Utility (EEU) invited bids for mini-grid solar PV projects in 25 rural towns and villages [42]. At the same time, Ethiopia has a developed pico-solar sector, which has seen a strong growth in systems smaller than 1.5 Wp [43].

Regulatory framework

The development of Ethiopia's power sector is led by the second version of the "Growth and Transformation Plan" (GTP), which five years ago set an ambitious and now outdated overall target of 17.3 GW installed capacity by 2020, as well as the dissemination of off-grid solar technology, including 3.6 million lanterns/pico-PV systems and

400,000 solar home systems. In 2019, the Ethiopian government has updated its National Electrification Program (NEP), now striving to supply electricity to almost 100 % of the country's households by 2025, of which 65 % is expected to come from on-grid solutions, while 35 % of the population should receive electricity via off-grid solutions, particularly mentioning solar home systems [44]. The public share of financing for this grid and off-grid program was estimated at about 1.5 billion USD [45]. In general, the political support for renewable energy sources is growing in Ethiopia and the government aims to provide 100 % of electricity supply with renewable energies by 2050 [46].

In particular, renewable energy sources are promoted through PPAs, with the development of off-grid systems, by introducing more efficient on-grid management policies and more recently Public-Private Partnerships (PPP) to facilitate private investment in renewable energy projects [40]. To aid the dissemination of mini-grid systems and give more security to investors, Ethiopia is planning to set up a methodology for the calculation of electricity tariffs for such systems, at the time of writing this report [47].

Potential for PV Development

Ethiopia has a large potential for solar generation capacity. A study by Enel Foundation and RES4Africa estimates that taking into account optimal technical-economic levels, Ethiopia can accommodate over five GW of solar PV in ten years [48]. According to a study by the Ethio Resource Group (ERG), there is a technical potential of approximately ten million off-grid households generating energy by PV systems [49]. Given the government's intention to reduce the dependency on hydro power, solar PV can be expected to play an increasingly important role in Ethiopia's energy development endeavors. Large-scale and grid-connected solar, with the help of the World Bank, have gained momentum in Ethiopia during the last year. In the off-grid sector, the mentioned methodology for the calculation of mini-grid electricity tariffs will reduce investor uncertainty [50]. Altogether, in the next three years the installation of more than one GW seems feasible.

Ghana

With its population of 30 million, Ghana is one of the continent's smallest states. Countrywide, there is a large solar potential, with an average annual sum of global horizontal irradiation between 1,607 and 2,045 kWh/m^2 [10]. Nevertheless, currently the country is heavily relying on hydro power, natural gas and oil – with the reliance on hydro power making it vulnerable to droughts. The government stated that it realizes power sources should be diversified and has set various political targets to work towards diversification. Nevertheless, the installed PV capacity at the end of 2019 is estimated to be below 70 MW, with a 155 MW solar power station continuing to be under construction with rumored little progress made [51].

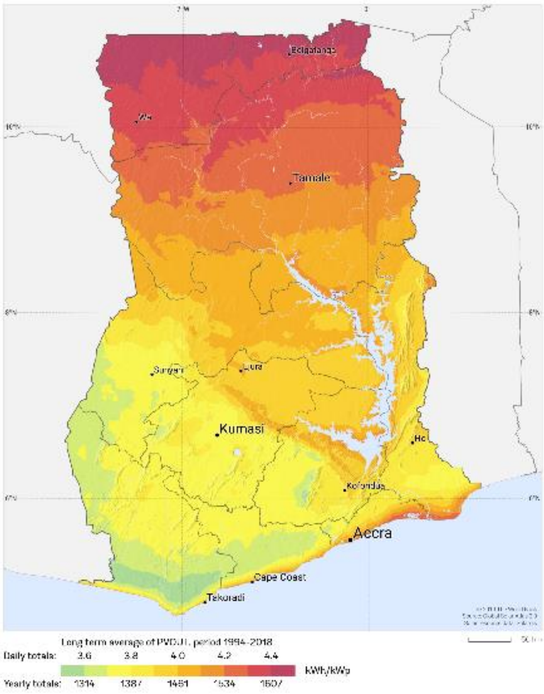

Figure 9: Photovoltaic power potential Ghana [10].

Over 90 % of the urban population has access to electricity, while in rural areas the proportion of the population with access to electricity is 73 %, leaving over three million people without electricity access [11]. According to the Ministry of Energy [52], electricity for the entire population should be available by 2020 – a plan that does not seem feasible in the meantime, but underlines that off-grid provisions are expected to be part of the solution.

Regulatory framework

Last year, Ghana reviewed its renewable energy goal of ten per cent of electricity to come from renewable sources by 2020 and subsequently extended the target period to 2030 [53]. The percentage should reach 100 % in 2050. FiTs and net metering – though the latter is not yet fully operational [54] – are predominant regulatory schemes in this context. In addition, the Ghanaian government has set a series of targets for solar technologies to be achieved until 2030: 450 MW utility scale PV, 200 MW distributed PV, 20 MW standalone PV, 55 solar mini-grids, around two million solar lanterns, 46,000 ha irrigation by PV and 135,000 solar water heaters should be installed [52][55].

Ghana's regulatory framework for enabling renewable energy include the Off-Grid Electrification Program, the Renewable Energy Master Plan, the Renewable Energy Act 2011 and the Scaling Up Renewable Energy Program (SREP). In light of Ghana's costly energy surplus in recent years [56], as well as challenges with regard to grid stability, the Ghanaian Energy Commission has stopped permitting utility-scale grid-connected solar PV plants in the past. Exceptions were made for the supply of electricity to utilities or customers with a large energy demand [54]. In early 2020, the government announced that 17 MW of utility scale solar is under construction by Ghana's largest power supplier [57]. In 2019 and 2020, several PPAs were finalized to supply solar energy to commercial customers [58][59].

Potential for PV Development

Ghana's current electricity generation capacity excess posits somewhat of a challenge to the adoption of renewable technologies [53]. However, the government has made it clear that solar PV will play an important role in electrifying Ghana's rural areas and diversifying its energy mix. In early 2020, it was announced that the Ministry of Energy is calling for consultants who will define e.g. a program to support the development of mini-grids, off-grid solar facilities and the national net metering scheme for PV [60]. The various mentioned targets with regard to e.g. solar-based mini-grids and solar home systems in rural or isolated areas underline the government's ambition in this context. In addition, roof systems up to one MW could be interesting for companies with high electricity consumption, including a storage facility to improve the power supply where feasible.

In summary, there is a large potential for solar energy, both off- and on-grid. Over the next five years, 360 MW PV installations seem possible.

Kenya

Kenya is among the most advanced economies in East Africa. Kenya has over 50 million inhabitants, of which almost the entire urban population has access to electricity, while 30 % in rural areas have not, leaving around 13 million people in rural areas without access to electricity [11]. With its average annual sum of global horizontal irradiation between 1,680 and 2,410 kWh/m^2 [10], Kenya's natural conditions for the use of solar energy are among the best in sub-Saharan Africa.

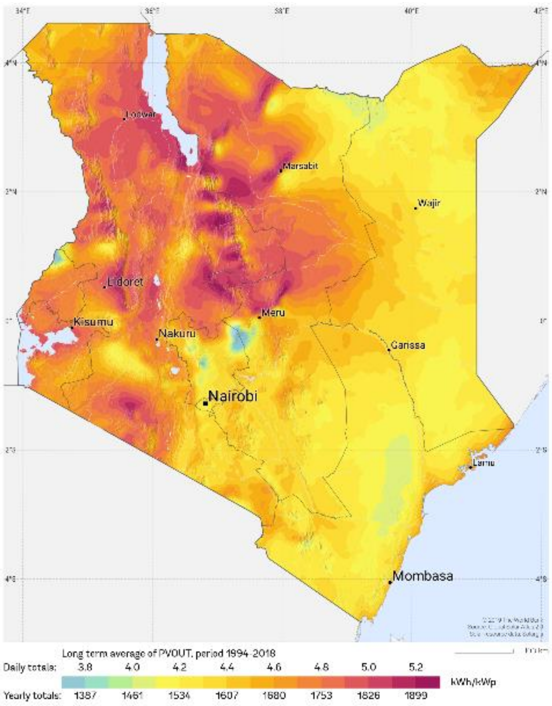

Figure 10: Photovoltaic power potential Kenya [10].

Kenya has an estimated electricity-generation capacity of 2.7 GW [61] – split almost evenly among large hydro power, fossil fuels and geothermal [62]. The country is estimated to have 145 MW of installed PV capacity at the end of 2019 [8]. Power outages have become less frequent over the last years, yet many businesses still own generators for such cases [63]. The Kenyan government expects peak energy demand to more than double by 2030. In order to meet this demand, five GW of new energy generation capacity is planned until 2024 [64].

Regulatory framework

The Kenyan government targets 100 % of electricity connectivity by 2022, as stated by the Kenya rural electrification program [62] and the Kenyan National Electrification Strategy (KNES). In 2018, Kenya's president announced plans to have 100 % of the country's energy come from green energy by 2020, going up from 70 % in 2018 [65].

In a draft regulation, the government aimed to install additional 500 MW of solar capacity and 300,000 domestic solar systems by 2030. Net Metering is expected to be implemented with the overdue passing of the 2017 energy bill [66]. Regulation for solar energy PPAs is in place and expected to be used more intensively in the future, while an auction theme is under development [67]. Different national FiTs are currently applied to solar projects below and over ten MW [64]. VAT and import duty exemption are in place in Kenya for several solar PV components [68].

In 2017, the national utility Kenya Power and Lighting Company signed PPAs for two large scale PV projects amounting to 160 MW [69]. At the end of 2019, two large scale PV projects amounting to a capacity of 80 MW received additional financing [70]. In April 2020, a 40 MW solar power project was greenlighted to start construction, under a power purchase agreement set at USD 0.075/kWh for the project, which was launched already back in 2013 [71]. In recent years, numerous renewable mini-grids have been built and diesel-based mini-grids have increasingly been transformed into hybrid diesel-solar or diesel-wind systems.

Potential for PV Development

Based on estimations in 2019, more than 500 MW of utility scale solar PV were in different stages of – at times long phases of – project development in Kenya [66]. Large scale solar will thus make a significant contribution towards the government's goal to have 100 % of the country's energy come from green energy. Given that they are considered more cost-effective than grid extension, off-grid solar PV systems in rural areas have the potential to help achieving the political target of 100 % electricity access by 2022 [68]. This is despite their low attributed budget in the investment plan according to the Kenyan National Electrification Strategy. The size of the market for solar PV home systems in Kenya was once estimated by IRENA at around six to eight MW [72]. With agriculture farms having pioneered solar PV, commercial applications have also gained momentum. If PPA projects are finished over the next five years, there is potential for additional 600 MW of installed PV capacity.

Madagascar

Located off the eastern coast of southern Africa, Madagascar is the fourth-largest island on earth. The average annual sum of global horizontal irradiation ranges from 1,680 to 2,264 kWh/m^2 and the island benefits from 2,800 hours of annual sunshine. Despite unique natural resources and a flourishing tourism industry, the country remains heavily dependent on foreign aid. However, Madagascar is recovering from the military coup of 2009 and is slowly returning to economic growth [73].

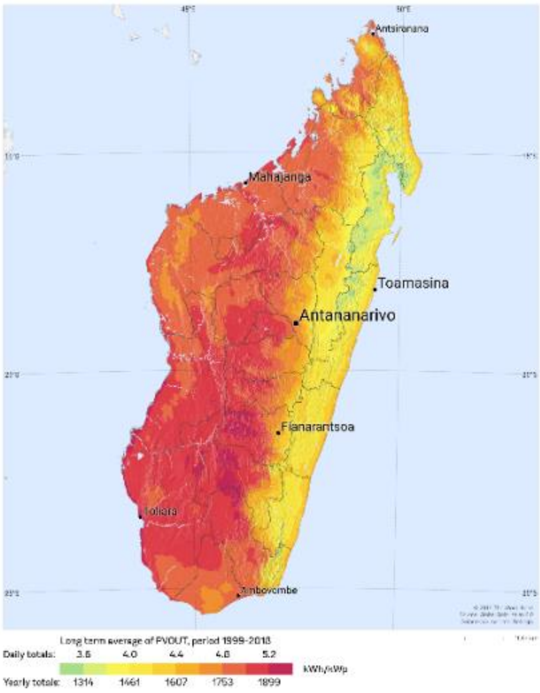

Figure 11: Photovoltaic power potential Madagascar [10]

More than half of Madagascar's urban population and over 90 % of the rural population do not have access to electricity, leaving a total of ten million people in Madagascar without access to electricity [11]. Madagascar has substantial resource potential in renewable energy, yet 50 % of Madagascar's electrical installed capacity comes from thermal energy sources, such as heavy fuel oil [74], resulting in significant costs. Recurrent power cuts hamper the economic and social development of the island. Therefore, the government decided to reform the sector and the state-owned water and electricity company (JIRAMA) with support of the World Bank. Part of that funding is dedicated to increase the use of renewable energy to provide a reliable and less expensive alternative to diesel generators. Several rural electrification programs have been launched in the past with the financial support of international organizations. The Malagasy agency for rural electrification (ADER) reports a total capacity installed of almost nine MW (mixed technologies).

In 2019, Madagascar had one large-scale solar plant of 20 MW and a total solar PV capacity installed of 33 MW [27]. A second large scale solar plant (25 MW) is expected to come online soon, thanks to the World Bank Group's Scaling Solar program, and another 50 MW has been announced via the program.

Regulatory framework

The New Energy Policy (NPE) was published in 2015 and its main target is to attain 85 % of renewable energy in the energetic mix for the year 2030 and to provide access to sustainable electricity for 70 % of the population [75]. While the lion's share of energy production will come from hydropower, solar is expected to reach a five per cent share in 2030. This solar contribution will come from grid-connected plants (about five per cent of installed capacity), solar home systems (five per cent of total households with electricity), solar lights (five per cent of households with electricity) as well as solar mini-grids (one per cent of households with electricity) [75]. The support mechanisms in place for solar energy in Madagascar are currently limited. There are however some fiscal reductions or exemptions from custom duties and VAT for solar panels and related electrical equipment.

Potential for PV Development

The government's plan is to increase the share of renewables to reduce the dependence on energy imports, which will result in significant cost reductions for the grid operation. Therefore, more public-private-partnerships can be expected in the coming years, firstly to hybridize existing thermal plants and in a second step, to achieve higher autonomy in combination with batteries. Given the dynamic market development observed over the last years, the PV potential for the next five years is estimated at 150 MW.

Mali

Mali is located in Western Africa and, with large parts of the country situated in the Saharan Desert, one of the hottest countries in the world. Measurements of solar radiation reported an average annual sum of global horizontal irradiation ranging from 2,118 to 2,337 kWh/m^2 [10].

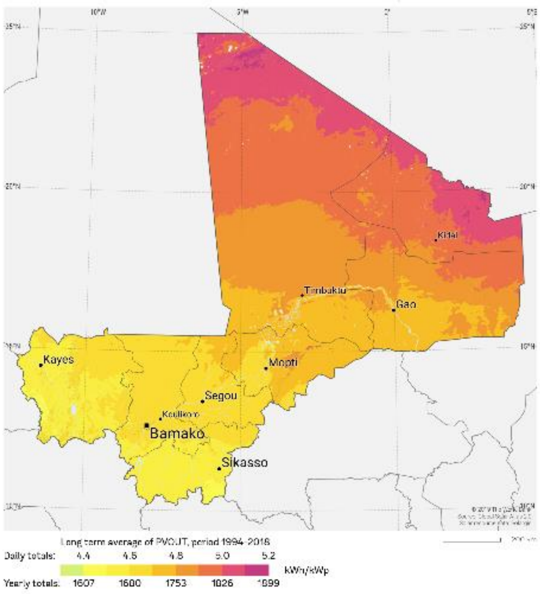

Figure 12: Photovoltaic power potential Mali [10]

Despite steady economic growth since 2013, Mali remains among the world's poorest countries. Less than 70 % of the urban population has access to electricity and less than 80 % of the rural population, leaving almost nine million people in rural regions of Mali without access to electricity [11]. Biomass, mainly wood and charcoal, represents around 76 % of national primary energy supply, with petroleum products amounting to 20 % and electricity making up four per cent [76].

Solar photovoltaic capacity has been increasing over the years, mainly through solar-diesel hybrid plants but also through small-scale decentralized installations. However, the share of solar energy remains marginal when compared to hydropower and thermal plants [27]. At the end of 2019, only 20 MW of solar PV were installed in Mail [27], yet more are expected to come online in the coming years based on the project pipeline and due to the funding described below.

Regulatory framework

Mali is a member of the Economic Community of West African States (ECOWAS), which agreed to stronger regional cooperation and integration to accelerate the adoption of renewable energy and energy efficiency [77]. The ECOWAS Renewable Energy Policy aims to increase the share of renewable energy in the region's overall electricity mix and has been translated into the National Energy Efficiency Action Plan [78]. The Malian government has set an official target of 61 % rural electrification rate by 2033 while increasing the share of renewable energy in the national energy mix to 25 % during the same period, which accounts to around 1,4 GW in 2030 [79]. The country has also set a target to build 6,657 km of power lines and to reduce the losses on the electric grid [80].

The government increased the budget allocated to renewable energy, however, the budget remains low in face of the country's challenges. In order to attract more foreign investment, the government adopted an investment code in 2012, which provides some benefits and security to private investors to develop the electricity sector [78]. For instance, permits and other request are being handled in five days by the investment promotion agency and solar panels have been exempted from VAT and import duties [79].

Potential for PV Development

According to IRENA, the solar potential of Mali's southwestern regions alone amounts to 53 GW and would suffice to cover the energy demand of the entire country [81]. In 2019, the World Bank approved a funding of USD 22.7 million for Mali [82]. The funds will support the country's efforts to promote the use of renewable energy and improve access to quality electricity services in rural areas [82]. According to the official targets, the capacity of grid-connected solar plants should significantly increase in the coming years. Several Build Own Operate Transfer (BOOT) agreements have been signed, with one contract alone signed in June 2020 to develop 500 MW solar PV [83]. Over the next five years, a potential of over 500 MW PV installations seems realistic.

Morocco

As most of its surface is covered by deserts, Morocco has very high levels of solar resources: about 3,000 hours per year of sunshine and an average annual sum of global horizontal irradiation ranging from 1,753 up to 2,264 kWh/m^2 in the desert [10].

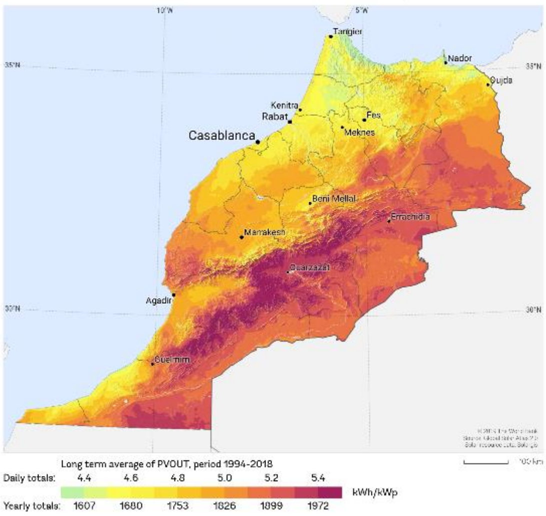

Figure 13: Photovoltaic power potential Morocco [10]

In 2015, Morocco increased its official target to have more than half of its energy coming from renewables by 2030, which translates into a target of 4.5 GW solar [84]. In 2018, the total installed capacity reached 206 MW due to the construction of several utility-scale plants, mostly around Noor (combination of solar PV and CSP plants). No new installations were added in 2019 [27].

Morocco installed more than 70,000 solar kits for households between 1998 and 2017 by means of its rural electrification program [84]. Hence, the electrification rate is very high and over 95 % of the population has access to electricity, both in rural and in urban environments. Morocco has two energy interconnections with Spain and the two nations have signed a memorandum of understanding to build a third power link [85]. In addition, Morocco has two interconnections with Algeria and is also looking for opportunities to connect with Portugal and Mauritania [84].

Regulatory framework

Morocco's regulatory framework for solar PV includes tenders linked to specific projects and net metering for renewable projects that connect to the high voltage grid. The legislation on net metering is expected be updated to expand net metering for projects connected to the medium voltage grid, and this could increase the growth of decentralized installations [86]. Injection of solar electricity on the low voltage grid is partly allowed since 2016 and net metering should be applied [49]. However, it is the grid operator ONEE which decides the price for the electricity surpluses injected into the grid, which reduces the security of investments.

Potential for PV development

In line with the continuous and stable economic growth, the electricity demand in Morocco is growing by five per cent per year, thereby creating opportunities for investment in new production facilities. To curb energy imports, the country wants to invest more in renewable energy sources and energy efficiency measures. The government announced that a budget would be available in 2021 for solar installations in agriculture [87], mainly for powering water pumping installations. However, official plans have not been published yet. The "Noor Solar Plan" will result in a combined solar capacity of about 2,000 MW, together with storage in the form of heated molten salt [87]. In the first three phases of the plan, Morocco invested in CSP (160 MW in 2016, 200 MW in 2018 and 150 MW still to be build). The next phases of the plan should be dedicated to solar PV, in 2019 a first tender of 200 MW has been launched and others are planned to complete the project [88]. Over the next five years, there is an estimated potential for up to two GW of PV installation.

Namibia

Based on natural conditions, the opportunities for solar energy in Namibia are vast. Namibia has a high average annual sum of global horizontal irradiation between 2,118 and 2,447 kWh/m^2 [10]. Of its population of over 2.5 million, roughly half live in urban areas. 65 % of the population in rural areas do not have access to electricity, compared to 22 % without access to electricity in urban areas [11].

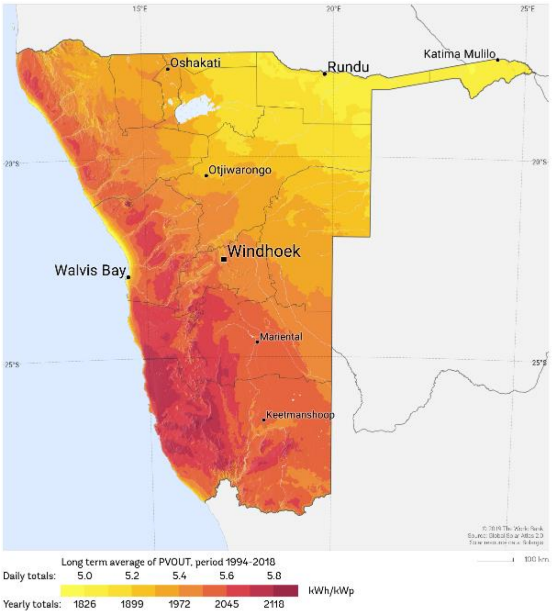

Figure 14: Photovoltaic power potential Namibia [10].

The Namibian government has specified a Renewable Power Target of 70 % by 2030. Currently, Namibia's installed electrical generation capacity does not meet electricity demands, making the country strongly dependent on electricity imports. Over 60 % of the total energy consumption consists of electricity imports, mainly from South Africa [89], with one large hydro power plant and coal amounting for the rest. 135 MW solar PV exist nationwide [27]. Excluding hydro power, the share of RE in the electricity consumption is approximately four per cent.

Regulatory Framework

In its National Integrated Resource Plan (NIRP), the Namibian Energy Ministry projects future electricity demand and the cheapest and most reliable options for electricity generation. According to the plan, Namibia's energy peak demand will rise to 930 MW in 2025 and reach more than 1,300 MW by 2035, and Solar PV (not including installations with net metering) is expected to grow significantly [90]. As part of the national renewable energy policy, the government also laid out a solar thermal technology roadmap with sector targets until 2030. The Ministry of Mines and Energy also targeted an increase in the rural electrification rate to 50 % by 2020 – though this might no longer be feasible, it illustrates the intention to improve access to electricity in rural areas via off-grid solutions [91].

The Namibian government is increasing its efforts to generate electricity from renewable sources via public-private partnership (PPP) with independent power producers (IPPs). To that end, 17 IPPs were contracted by Namibia's state-run utility to supply 171 MW of renewable energy. Renewable energy sources are also promoted by net metering (self-consumption systems up to 500 kW and in the past over 500 kW when agreed upon with the local electricity supplier) and by the FiT-Program (systems between 500 kW and five MW) and tenders for large grid connected RE systems larger than five MW [92]. Net metering licenses have been issued reluctantly at some point in the past [92], while installations for self-consumption < 500 kW can be installed without a license. The current regulations provide for FiTs for systems of up to five MW. The Namibian government limits the licenses and thus controls the number of FiT-projects. Currently, a 45 MW and a 50 MW solar plant are under construction [93][94]. In 2019, Namibia's state-run utility announced plans to build two 20 MW solar PV installations until 2023, as part of a portfolio of renewable energy power plants totaling in 220 MW, in a further effort to diversify the energy mix and loosen the dependence from energy imports [89].

Potential for PV Development

Given the low population density in many areas, an extension to the grid is not feasible in many rural areas. This opens up large opportunities for mini-grid PV solutions to lower the rate of people without access to electricity in rural areas [95]. According to the Namibian government, around 100,000 households in approximately 4,300 villages are considered being "off-grid". If negotiated as financially feasible, there are consequently large potentials for mini-grid PV solutions in Namibia [96]. Additionally, there are around 22,000 industrial and commercial electricity consumers in Namibia to which PV self-consumption systems are becoming increasingly interesting, due to the reducing costs of solar PV. A conservative estimate assumes that there are at least 5,000 potential industrial customers for PV self-consumption systems [92]. Namibia is also in early talk with the World Economic Forum's (WEF) Global Future Council on Energy, to develop five GW of solar capacity together with Botswana over the next two decades [97]. Over the next three years, a potential of 150 MW new PV installations seems realistic.

Nigeria

With its average annual sum of global horizontal irradiation between 1,534 and 2,264 kWh/m^2 [10], Nigeria has good natural conditions for the use of solar energy. Nigeria has around 200 million inhabitants, thus representing the country with the largest population in Africa. Almost 90 % of the urban population has access to electricity, while almost 70 % in rural areas have not, leaving around 65 million people in rural Nigerian areas without access to electricity [11].

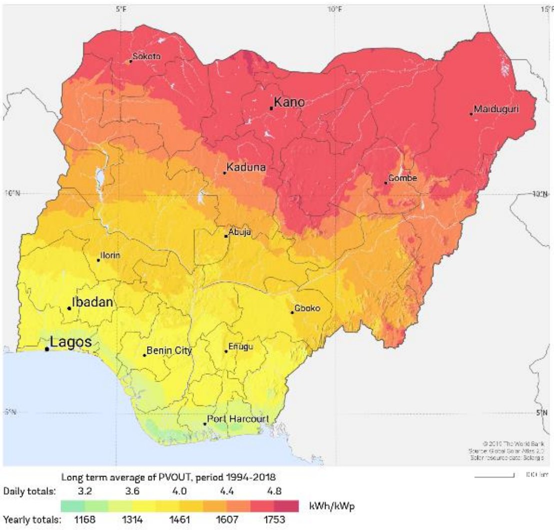

Figure 15: Photovoltaic power potential Nigeria [10].

While Nigeria currently has an estimated electricity-generation capacity of between 13 and 18 GW – mostly from gas and hydro power – electricity service delivery is often below five GW/hour [98][99]. Biomass is the dominant energy source consumed in Nigeria due its use for cooking and heating in rural areas, followed by oil and gas. Power cuts are frequent and considered an obstacle by businesses [100]. It is assumed that in the future, electricity demand will continue to surpass supply due to the rapidly growing population and economy. In light of these challenges, renewable energy sources, especially PV energy, offer immense potential and opportunities.

Regulatory framework

The Nigerian government targets a cumulative installed capacity of 30 GW by 2030, and at the same time to cover 30 % of the country's energy needs with renewables. The National Renewable Energy Action Plan (NREAP) [101] created the framework for the use of renewable energy. The installed capacity of grid-connected PV is expected to reach around five GW in 2030 and solar thermal around one GW. An estimated total of 28 MW PV capacity existed in Nigeria in 2019 [27]. Feed-in-tariffs exist for solar power plants up to five MW [102], as well as regulation for PPAs. However, in 2016 Nigeria signed PPAs for 14 utility scale PV projects with a combined capacity of over one GW, of which in light of attempts to reduce agreed tariffs, so far none has been finalized [99].

The government's plan anticipates the share of the rural population served by renewable energies and hybrid mini-grids to reach ten per cent by 2030. Targets for solar water heaters also exist. Furthermore, more than five GW installed capacity of mini-grids powered purely by renewables is planned [101]. Mini-grids are defined as self-contained electricity systems of less than one MW [103] and tariffs are calculated using a dedicated methodology designed for mini-grids. Nigeria's Rural Electrification Agency recently issued various tenders under both, the Mini-Grid Acceleration Scheme (MAS) and Interconnected Mini-Grid Acceleration Scheme (IMAS) [104].

Potential for PV Development

Renewable energy sources, especially PV systems, are an important pillar to solve Nigeria's energy problems. In many rural areas without access to electricity, PV systems and captive diesel-PV hybrid systems are a cost effective and safe solution to reach governmental renewable energy goals. In many cases, the integration of a storage facility makes sense or is necessary. The Rural Electrification Agency (REA) of Nigeria estimates that the Nigerian mini-grid and solar home systems market can easily reach a level of more than nine billion dollars a year [105]. Backed by a 550 million USD World Bank loan, the "Nigeria Electrification Project" is currently under way to provide electricity for 2.5 million people and 70,000 micro to medium-sized enterprises [106]. With the support of the project, the REA of Nigeria plans to install 10,000 mini-grids, which will cover about 30 % of the expected demand in the country [107]. Next to households, commercial and industrial as well as agricultural electricity consumers in Nigeria can benefit from PV applications. According to Bloomberg, Nigeria has the largest potential for commercial and industrial solar on the African continent due to the opportunity for diesel replacement [108]. The country's potential for solar generation capacity is estimated to be 427 GW [109]. If PPA projects are finished over the next five years, there is potential for up to 3.5 GW of PV installation.

Senegal

Senegal is located in West Africa and has abundant natural conditions for solar energy. The average annual sum of global horizontal irradiation is steadily high throughout the entire country, ranging only between 2,045 to 2,191 kWh/m^2 [10]. Fossil fuels and biomass are still the main contributors to the energy mix of Senegal. Fossil fuels contributes almost 50 % of the total primary energy consumed in Senegal, with high costs of oil imports making the country very vulnerable to oil price fluctuations. Biomass accounts for almost the other half of Senegal's energy consumption. The use of biomass for e.g. cooking is in large parts responsible for the depletion of Senegal's forests [110]. Only half of the rural population in Senegal has access to electricity, leaving around five million people in rural regions without electricity access [11].

The government has been looking to develop and promote solar and wind energy to curb oil imports since 2010. Solar PV is the renewable source that has experienced the most sustained development in Senegal in the last years [27]. In 2019, the total capacity installed reached 134 MW [27]. More is expected to come online in the coming years, as a 60 MW tender achieved record-low prices in 2018,

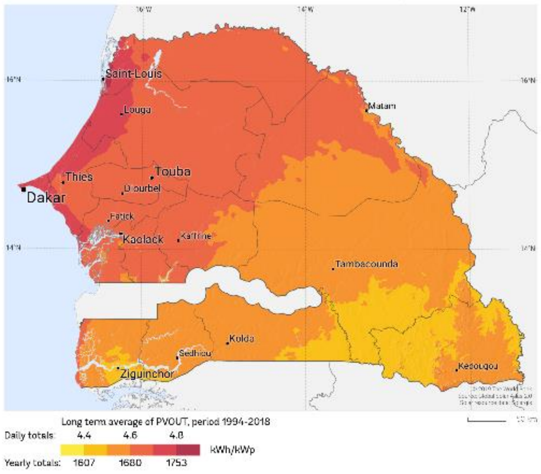

Figure 16: Photovoltaic power potential Senegal [10]

with winning bids below EUR four cent/kWh [111]. Senegal has joined the World Bank Group's Scaling Solar program in 2016. With regard to PV projects in the pipeline, in total 200 MW are expected to come online soon [111]. With regard to off-grid, Senegal invested in off-grid hybrid plants in remote villages, sometimes also in combination with batteries [112].

Regulatory framework

The development of the power sector is a key component of the country's strategy to make Senegal an emerging economy by 2025 [113]. The main priority is to lower the cost of generation, therefore the government's goal is to reduce fossil fuel imports by developing solar and wind power and increasing electricity access in rural areas [113].

In September 2018, the Regulatory Commission of the Electricity Sector (CRSE) set rates for excess electricity injected to the grid for installations intended for self-consumption: installed capacity cannot exceed 120 % of the peak consumption for residential customers and 110 % for commercial customers [114]. Based on the profitability of the defined market segments, the CRSE calculated differentiated tariffs around EUR eight cents/kWh, which amounts to approximately half of the retail electricity price [114]. These tariffs are applied for 20 years and will be revised every three years to consider price developments [114]. With regard to large-scale solar PV, the CRSE is responsible to issue tenders and to select the investors that will sign a PPA with Senegal's national utility.

Potential for PV Development

Next to financial resources, grid capacity and human resources with the needed technical capacities constitute the main bottlenecks when it comes to the development of large-scale solar PV installations in Senegal [115]. The above-mentioned introduction of the tariff for injection of excess energy is expected to trigger growth in the decentralized market segment in the coming years. Given the high rate of rural population without access to electricity and the government's political target of universal electricity access, there should be large opportunities for mini-grid PV solutions in rural areas in the coming years. There is an estimated potential of 300 MW of solar PV installations in the next five years.

South Africa

Situated in the Southern Hemisphere's subtropical zone, South Africa has a wider variety of climates than most other countries in sub-Saharan Africa. Consequently, the average annual sum of global horizontal irradiation ranges rather widely between 1,534 and 2,264 kWh/m^2 [10]. Almost the entire urban population in South Africa has access to electricity, while roughly eight per cent – or 1.5 million people – of the rural population is without access to electricity [11].

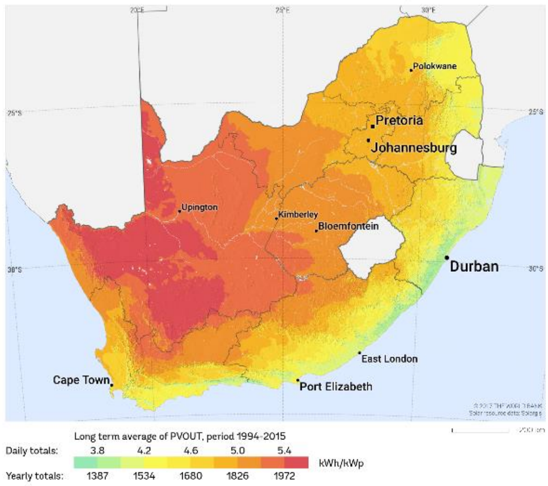

Figure 17: Photovoltaic power potential South Africa [10]

South Africa promulgated the Integrated Resource Plan (IRP) in March 2011, which has last been updated in 2019. The updated plan sets a more ambitious target of 17,800 MW of renewable energy to be achieved by 2030, of which 7,958 MW come from solar power [116]. The implementation of the plan has been effective, as the installation rate of solar PV has been accelerating since 2013 and reached 2.5 GW in 2019 [27].

Initially, the development was mainly driven by utility-scale installations within the framework of official tenders. However, as the economic feasibility of distributed solar installations improved in recent years, rooftop installations started to take off. The high retail electricity prices in combination with the frequent power shortages and consequent load shedding are driving households to look for backup solutions. Hence, solar home systems are increasingly finding their way to South Africa.

Regulatory framework

The IRP is the electricity infrastructure development plan which sets the goals for the power sector and is revised regularly to adapt to cost and demand evolutions, taking into account the security of supply and the environment [116]. Large-scale renewable energy power plants are being financed through PPAs concluded with Eskom, the national company for electricity generation, transmission, trading and distribution. Eskom has organized six solar tenders since 2011. In 2016, the government introduced a tax incentive for the installation of PV systems. Depending on the size, a tax shield is available through accelerated depreciation of the commercial tax paying entity. PV systems greater than one MW are depreciated with the scheduled 50 %, 30 %, and 20 % in the first years respectively [117].

Potential for PV development

In the upcoming years, the impressive growth is expected to continue as the political target for solar energy of almost eight GW has not been realized yet [118]. Furthermore, a third of Eskom's aging coal-fired plants will be at end of their lifespan by 2023. Replacing the current generating capacity is urgently needed, given the rising energy demand in South Africa and the fact that more plants will reach retirement age after 2030 [118]. However, despite the reaffirmed and even boosted ambitions in terms of renewable energy, South Africa's energy mix will still be dominated by coal in 2030 if the IRP is not revised [116]. As electricity prices have risen, the distributed segment is likely to grow as well as the business case for small-scale solar installations further improves. The growth of distributed PV will likely be linked to storage systems, even more, if the cost of storage also further decreases. Over the next five years, there is potential for up to three GW of PV installation.

Tanzania

With its population of over 58 million, Tanzania is one of the largest East African countries. Just over 70 % of the urban population has access to electricity, while more than 80 % in rural areas have not, leaving more than 30 million people in rural Tanzanian areas without access to electricity [11]. With its average annual sum of global horizontal irradiation between 1,753 and 2,337 kWh/m^2 [10], Tanzania offers vast natural resources for solar PV. The use of Tanzania's renewable energy potential in general however, remains in its infancy with the exception of hydropower.

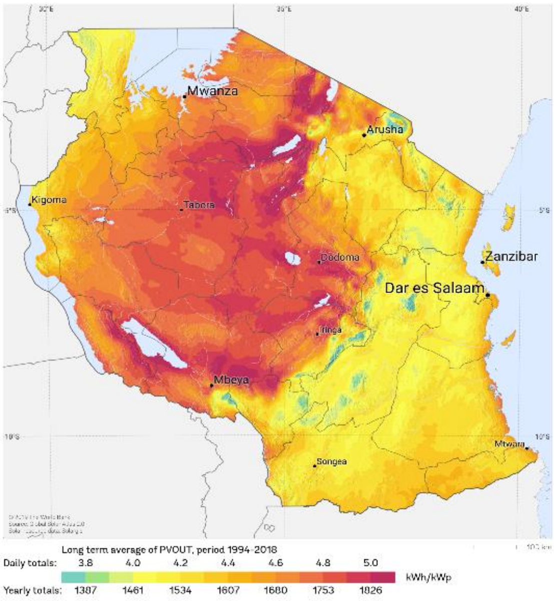

Figure 18: Photovoltaic power potential Tanzania [10].

Countrywide, the installed capacity is 1.6 GW [119], around 40 % of which is covered by hydro and more than 55 % by fossil fuels. The government intends to six-fold this installed capacity until 2025 [119]. An estimated 26 MW of installed solar PV capacity exists in Tanzania [27]. Due to its use for cooking, biomass makes up close to 90 % of the total primary energy consumption in Tanzania. In rural areas, off-grid solutions like diesel-powered electricity generation are common. Tanzania's energy prices are very high and power outages are frequent and considered a problem for businesses. 30 % of all energy is consumed by the county's mining industry. A positive GDP growth rate over the last decade stimulated growing demand for electricity.

Regulatory framework

Tanzania wants to reduce its dependency on fossil fuels and hydropower, the latter due to frequent droughts. Solar and wind represent perfect alternative energy sources. The government's target is to achieve at least a 75 % national electrification rate by 2035 [120] with 100 % of energy from renewable power in 2050 [46]. In terms of capacity, the government aims at ten GW of installed electrical generation capacity by 2025, with 50 % coming from renewable energy by 2030. However, the government at one point stated its plans to install as little as 100 MW of solar energy capacity by 2025 [62]. Thus, solar energy, both on- and off-grid, does not play a sufficiently important role in the regulatory framework. With regard to off-grid solar PV capacity, more than 500 kW were installed between 2016 and 2019 [62].

Tanzania has put in place regulations for auctions to determine FiTs for solar PV [23] and lowered the VAT and import duties on PV equipment to stimulate investments. On-grid projects with a total capacity of over 200 MW are on their way [23] [62]. A one MW utility-scale PV power plant has already been installed, but uncertainty and a lack of confidence in long-term payments from utilities put a damper on further installations in this segment [62]. Off-grid and mini-grid investments have grown in the past years with e.g. 60 new mini-grids financed in 2019 to be built in the next two years [121].

Potential for PV Development

The off-grid market as well as mini-grids continue to show huge potential in Tanzania. The Rural Energy Agency (REA) and other donors have already begun to support several solar PV expansion programs. With view to large scale solar, there is untapped potential with regard to the mining industry and the manufacturing sector. Solar power plants could also be combined with new rural hydro projects, to mitigate seasonal shortcomings in times of droughts. Over the next five years, there is an estimated potential for over 200 MW of PV installations.

Tunisia

With its average annual sum of global horizontal irradiation between 1,607 and 2,191 kWh/m^2 [10], Tunisia has very good natural conditions for the use of solar energy. Tunisia currently has around 11 million inhabitants, with almost all of the urban and rural population having access to electricity and the national grid [11].

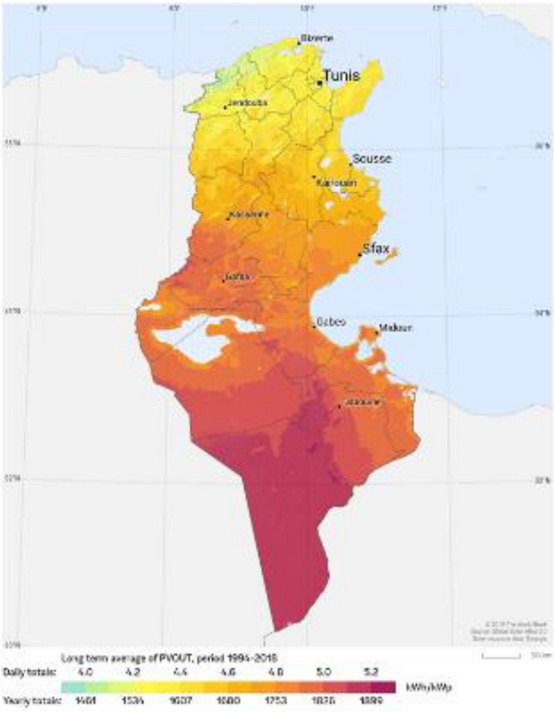

Figure 19: Photovoltaic power potential Tunisia [10].

Tunisia was almost energy independent a decade ago, but is currently highly dependent on energy imports from its neighboring countries, resulting in the energy deficit making up one third of the Tunisian commercial deficit [122]. Energy production in Tunisia has decreased by six per cent between 1990 to 2018, with final consumption of electricity rising by 240 % during the same period [123]. Electricity demand is expected to double again in the coming 15 years [124].

In the first quarter of 2020, more than 96 % of Tunisia's produced electricity came from natural gas, and less than four per cent from renewable energy sources. Less than 0.01 % of electricity production came from solar PV [125]. In the 20 years preceding 2019, Tunisia only built around 300 MW of renewable energy capacity [126]. The installed solar PV capacity is estimated to be 62 MW at the end of 2019 [27]. In In the light of Tunisia's energy deficit and expected rise in electric demand, solar PV offers immense potential and opportunities.

Regulatory framework

In 2015, the Tunisian Solar Plan set the goal to reach 30 % of the country's energy production via renewable energy by 2030. This is estimated to amount to 4.7 GW of installed renewable energy generation [127], with much of the investment coming from the private sector. The Tunisian Solar Plan enhanced the existing regulatory framework, especially with view to large-scale renewable energy projects. Tunisia has a differentiated electricity tariff system, with tariffs depending e.g. on time of day and customer, which is heavily subsidized [122]. In 2017, FiTs were introduced for solar installations under ten MW including possible net metering and net billing for selected grids [128]. Since early 2020, a new regulation for net metering allows renewable power companies to produce and sell more excess power, including bilateral PPAs [128]. Tax benefits, such as VAT exceptions on selected components, are available for renewable energy projects [122].

Starting in 2017, several large-scale solar power tenders have been announced [124]. In 2018 the Ministry of Energy and Mines published a call for 500 MW of private solar PV projects. In July 2019, five bids, all below USD three cent/kWh, were received. In early 2020, the Ministry of Energy and Mines and the Tunisian Company of Electricity and Gas approved an IPP project for a 120 MW PV power plant with a PPA valid for 20 years [129].

Potential for PV Development

Solar energy has strong potential to drecrease the energy deficit and improve Tunisia's energy security, while lowering Greenhouse gas emissions. Large scale solar PV will play an important part in this process – even though the bankability of PPAs has been criticised by international investors due to the lack of governmental guarantees [122]. Nevertheless, the Tunisian Solar Plan is in full force to increase the installed solar PV capacity rapidly. Over the next three years, if large-scale projects from tenders are realized, there is an estimated potential for over 700 MW of PV installations.

Uganda

Uganda is located in East Africa and offers very good natural conditions for solar PV, with the average annual sum of global horizontal irradiation ranging from 1,753 to 2,264 kWh/m. The current level of electrification in Uganda is significantly low: 63 % of the urban population has access to electricity and only 11 % of the rural population, leaving 30 million people in rural Uganda without access to electricity [11].

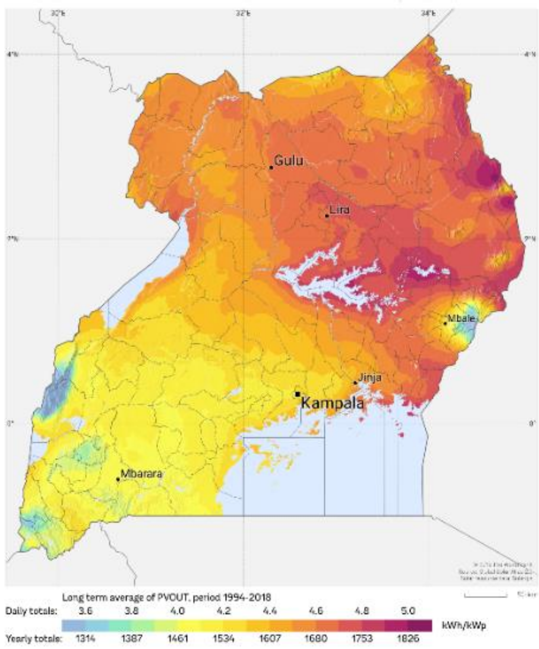

Figure 20: Photovoltaic power potential Uganda [10]

As of 2019, biomass contributes 88 % of the total primary energy consumed, mainly through firewood, charcoal and crop residues. Fossil fuels account for ten per cent of the national energy mix [130]. There is about one GW of installed hydropower capacity in Uganda and as little as 82 MW of solar PV [27].

Three per cent of Uganda's rural population have a solar home systems, while almost a third rely on solar lighting systems or solar lanterns [130]. In the coming years, 2.5 MW representing 17,500 off-grid solar home systems are expected to be installed thanks to nine million USD funding obtained by domestic installer SolarNow [131].

Concerning large-scale installations, four power plants were installed since 2015, reaching a capacity of 50 MW and at least five other sites, totaling 150 MW, have been identified for the coming years [27][132]. Furthermore, a Chinese state-owned energy conglomerate has secured contracts to deliver 500 MW of solar generation capacity in Uganda [133].

Regulatory framework

Rural electrification is an integral component of the government's overall policy and program to promote national economic and social development. The official goal is to achieve a rural electrification access of 51 % by 2030 and universal access in 2040 [134].

In April 2014, the national Electricity Regulatory Authority (ERA) approved the introduction of FiTs for electricity generated by renewable energy systems of up to a maximum capacity of 20 MW [135]. A ceiling price and maximum return on equity level were set, the current FiT is fixed at USD 7.1 cents per kWh for grid connected PV installations [135].

By means of its Rural Electrification Strategy and Plan 2013-2022, the government wants to increasingly fund the transition in the power sector through the wholesale rate charge instead of public funds. Furthermore, capital recovery on the realized investments will be collected by the Rural Electrification Fund (REF) for reinvestment in the future [134].

Potential for PV Development

Despite the early unbundling of the energy sector, Uganda faces some major challenges when it comes to grid reliability and flexibility [67]. However, the government addresses these issues in the latest Draft National Energy Policy and wants to tackle them with investments in transmission lines for instance [130]. Concerning flexibility, the country's important hydropower capacity should provide enough back up for large-scale solar power installations through adequate energy management.

Despite ambitious programs, the country's target to achieve universal access has been delayed mainly because of funding reasons [134]. The decreasing costs of solar PV installations and storage should allow a faster deployment of mini-grids in the coming years, especially in combination with innovative financing mechanisms to extend credit to people without access to electricity. The potential for PV development in Uganda in the next five years is of about an estimated 700 MW new capacity.

3.3 Regional PV development forecast

Forecasting PV development is a difficult undertaking in all countries and even more so in a continent as diverse as Africa. Nevertheless, forecasting is an enlightening exercise to compare current trends with the goals to be achieved. This section presents four original scenarios for PV development in African sub-regions with a critical perspective.

The four scenarios present vastly different evolutions of the PV market in African countries for the coming decade and include all market segments (utility, commercial and residential scale, and off-grid developments as well). A key element is the start of growth from 2019 onwards, which is expected in the coming years. The policy-driven scenario is based on the official national goals at the scale of the continent, while the three other scenarios offer perspectives based on the analysis of potential future African needs and the Paris Climate Agreement.

The four scenarios are built as follow:

The **Policy-Driven scenario** is based on official roadmaps and announcements made by policymakers in key African countries. Several countries in Africa have political energy roadmaps and targets, which include set targets for installed PV capacity for different years. For the countries that have set a target of installed PV capacity by a certain year, a value of installed PV capacity per capita has been derived from that goal and the UN's world urbanization prospects. In each region, an average PV capacity per capita has been calculated based on the countries that have official goals or roadmaps in that region.

The **Business as Usual scenario:** This scenario envisions some market development driven by existing policies (or the lack of policies), in a realistic and conservative way. It assumes the existing constraints for PV development in Africa will not be lifted simply and immediately, and that existing constraints in many countries that delayed the development of the energy sector will remain in place. In the medium term, it assumes that the targets from the policy-driven scenario described above will be reached progressively.

The **Solarize Africa Accelerated scenario** assumes that the continent will experience the same kind of PV development as the rest of the world. With declining PV prices, the question of policies becomes less important in Africa and the intrinsic competitiveness of the technology will allow for a PV breakthrough in all segments. The scenario is based on a methodology developed by Becquerel Institute, Chris Werner and Alexander Gerlach [136] and considers that in an environment without specific financial incentives, a competitive technology can be developed according to logistic curves until it reaches market saturation. Market saturation has been evaluated in this case according to IEA energy consumption scenarios for the African continent. This comprises the shift to electricity for industrial applications, transport and heating (when applicable), while it is assumed that a complete electrification of the continent will be achieved in 2050. Consumption levels rise to comparable levels in other world regions with similar patterns. With 30 GW installed per year in whole of Africa, the path to electrification would remain relatively slow and leaves the door open to a more ambitious scenario.

The **Solarize Africa Paradigm Shift scenario** assumes a much faster market development, driven not only by the increased competitiveness of PV but also by a fast unlocking of policies and finance to ensure a massive roll-out of PV in the continent. With a total of 600 GW installed at the end of 2030, Africa would become a hub for clean energy production and a major region within the global PV market, delivering clean electricity to Africa but also producing green hydrogen for export. To reach this Paradigm Shift scenario, policymakers should start to allow PV installations in the distributed grids immediately for all power levels, allow massive utility-scale PV development, possibly with embedded storage to ease grid integration and develop rapidly and massively high-voltage interconnection lines inside the continent and with neighboring regions, starting with Europe. Fossil-fuels should be abandoned rapidly and leapfrogged to electric mobility (with or without hydrogen) to ensure a faster development of PV. Once the barriers are lifted, the PV market development could rapidly skyrocket.

The business-as-usual scenario would imply 65 GW of cumulative PV installations in Africa at the horizon 2030, a level slightly below the 70 GW of the policy-driven scenario. In the Solarize Africa Accelerated scenario, 170 GW which could be installed while the installed capacity would be of about 607 GW in the Solarize Africa Paradigm Shift scenario.

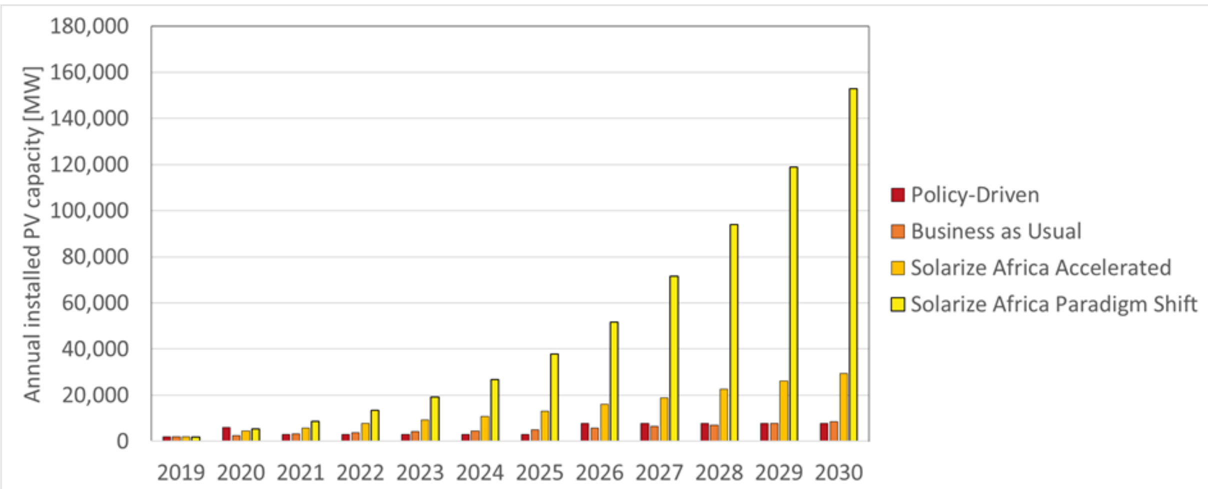

Figure 21: Solarize Africa original PV development scenarios for Africa [260]

Policy driven

The policy-driven scenario represents in a way the development of solar PV in the African continent according to the willingness of policymakers. However, some of the national goals and roadmaps have been set a few years ago and have underestimated the full potential of future PV installations as price developments have not been fully considered. This leads to goals and targets that can be considered quite conservative. Therefore, there is a good chance that long-term installation numbers (65 GW cumulative capacity by 2030) in the policy driven scenario will be overshot.

Business-as-Usual

Despite the challenges for PV developments on the continent, recent and short-term future market developments seem to indicate that the business-as-usual scenario has the lowest chance to occur. Indeed, the combination of immature policies with the lack of reliable infrastructure, political instability and other national specific constraints will delay the massive development of PV in Africa, however, the growing competitiveness of PV will contribute to overcome these challenges. Countries experiencing heavy political instability or even civil unrest are the least likely to develop in

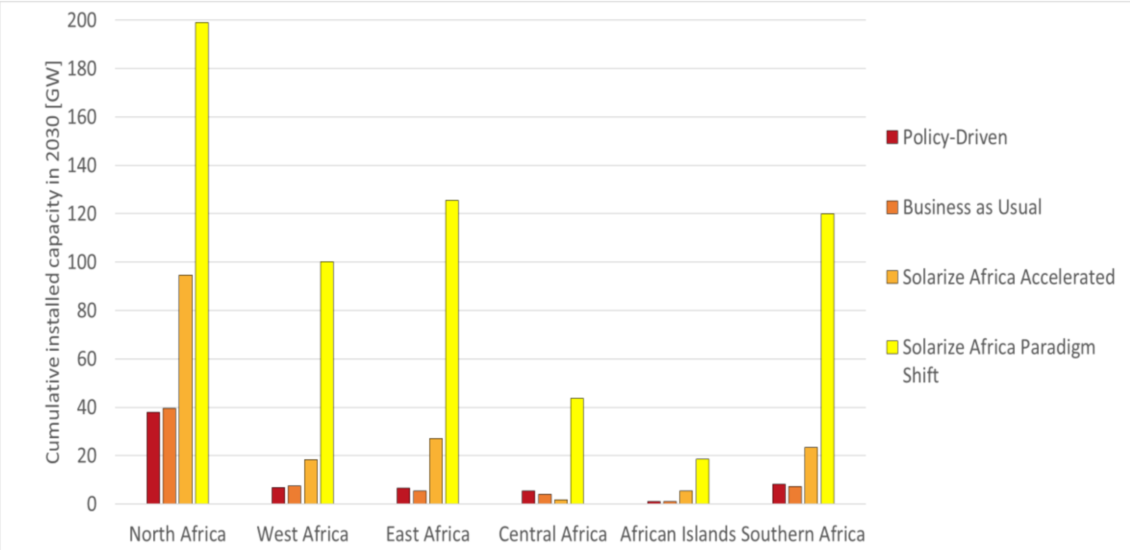

Figure 22: Solarize Africa scenarios for regional PV development in Africa for the year 2030 [260]

In the policy driven scenario, the yearly installation rate is three GW until 2025. After 2025 the yearly installation rate will accelerate again with an average of 7.6 GW per year. As mentioned above, these fluctuations can be attributed to the limitations of the approach chosen in this scenario, which is based on national goals and roadmaps: Governments tend to define policies towards appealing deadlines, most of the time far forward in time, such as the year 2030. Despite the apparent incoherences linked to the discrepancies between some intermediate targets, accelerated-decreased-accelerated market developments are possible until 2030 for the African PV market as investments in infrastructure are needed. Building electricity grid lines, substations, etc. can in many cases take longer than installing PV systems and might constitute a limiting factor.

the short term and might therefore probably follow this scenario in the coming years. In the other countries however, opportunities will continue to develop PV based on international funding and increasingly private investments. In this scenario, the market will be mainly driven by countries in North Africa and would reach two to three GW until 2025 and continue growing slowly to achieve more than seven GW a year towards 2030. Since this scenario combines pessimistic outlooks for all regions, its general probability of occurrence is relatively low and should be considered as a bottom line.

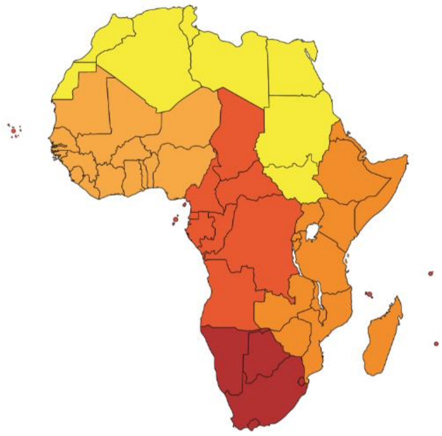

Figure 23: Regional segmentation applied to the Solarize Africa scenarios [260]

Solarize Africa Accelerated

In this scenario, the increased competitiveness of PV will unleash the development of solar PV applications first in the off-grid and in the utility segments in the short term, as well as in other segments such agricultural PV. Floating PV and special off-grid applications such as PV for water pumping will also be developed in this scenario. This scenario is more realistic than the two previous ones as low system prices already available in many countries are unlocking markets and projects are popping up all over the continent. However, technical and funding barriers must be lifted rapidly for PV to develop according to its potential and the continent's needs. The short-term strategy will be based on solar to support or progressively replace diesel generators in major cities, and increasingly in combination with batteries to achieve full autonomy in off-grid sites for instance. To achieve this, an annual market of four to six GW until 2025 is requested, then reaching more than ten GW a year from 2025 and up to 29 GW a year in 2030. There are also reasons to believe that the market could develop faster and reach these levels expected in 2030 earlier but this would require significant policy developments which are not often visible yet. This scenario appears to be the most probable after 2021-2022 and will lead to significant installation levels in the coming decennia.

Solarize Africa Paradigm Shift

While this scenario might seem out of proportion at first sight, one should keep in mind that in the rest of the word the early development of solar PV has been greeted with great skepticism, not to say resistance, at first but managed to find its way through, and became the most competitive technology in a growing number of market segments.

Similarly to the Solarize Africa Accelerated scenario, this scenario also assumes a fast transition to electric mobility in the densely populated cities and the massive use of PV with battery storage in suburban areas. The latter will simplify grid developments and reduce the costs to bring power to remote areas as well as to densely populated areas lacking basic infrastructure. In most places, solar in combination with storage will progressively replace diesel generators. All the relevant market segments such as PV for water desalination and for water pumping, agricultural PV and floating PV will be exploited to their maximum to reach the illustrated 607 GW level of PV development in 2030.

Even though this scenario is the only one in line with the Paris Climate Agreement, significant international efforts and coordination are needed to leverage the development of PV to that level. Several initiatives already exist to enhance cross border collaboration between the countries, these initiatives are paving the way for an integrated large-scale PV development on the continent as it will not happen overnight without a vision and a strong commitment. This is also true for the development of electric mobility, national and international grid infrastructure, and large-scale storage.

3.4 Ranking of countries according to attractiveness for PV

PV development comes from a combination of drivers, which ultimately translates into policy decisions and private or public investments. Africa does not escape that reality. This section proposes an analysis of the factors driving PV investments to predict which markets are likely to continue to grow or to likely to break through. The methodology used below was initially developed for the "Unlocking the Potential of PV in Sunbelt Countries" report published in 2011 [137]. It was further developed since then and continues to position countries according to the attractiveness of PV in the country and the attractiveness of the country for PV investments. The combination of both can lead to a conclusion where a PV market could most likely develop particularly well.

The attractiveness of a country is defined by its economic development and stability, a business-friendly environment, the regulatory quality and reliability and the political stability, to name a few. For the PV market, the attractiveness of a country is among others determined by its renewable energy policies, level of energy access, electric power consumption per capita. Each of these elements is quantified using international indicators, weighted to provide a unique value per country. Political and economic stability play a key role while the competitiveness of PV increases the chances to see a rapid and sustainable development. Below, an analysis of both indicators is provided.

Some countries are both attractive for PV and for business in general. These countries are often more stable, both politically and economically, and most of these countries also already implemented some renewable energy policies and targets. These countries are also characterized with higher energy access rates and higher electrical consumption per capita, which creates a higher demand for large-scale projects for instance. Among these countries, Ghana, Mauritius, Namibia, Rwanda, Senegal, South Africa and Zambia can be cited.

Other countries such as Benin, Egypt, Ivory Coast, Kenya, Tanzania, Tunisia and Uganda are quite attractive for the PV industry as most of them have enough flexible generation assets to integrate solar PV on a large scale as well as a high electric power consumption. However, doing business is not especially being facilitated for foreigners and investors in these countries, which cost them slightly, but they are still quite attractive. Egypt experienced some political instability in recent years, which explains the relatively lower ranking than one might expect for this country.

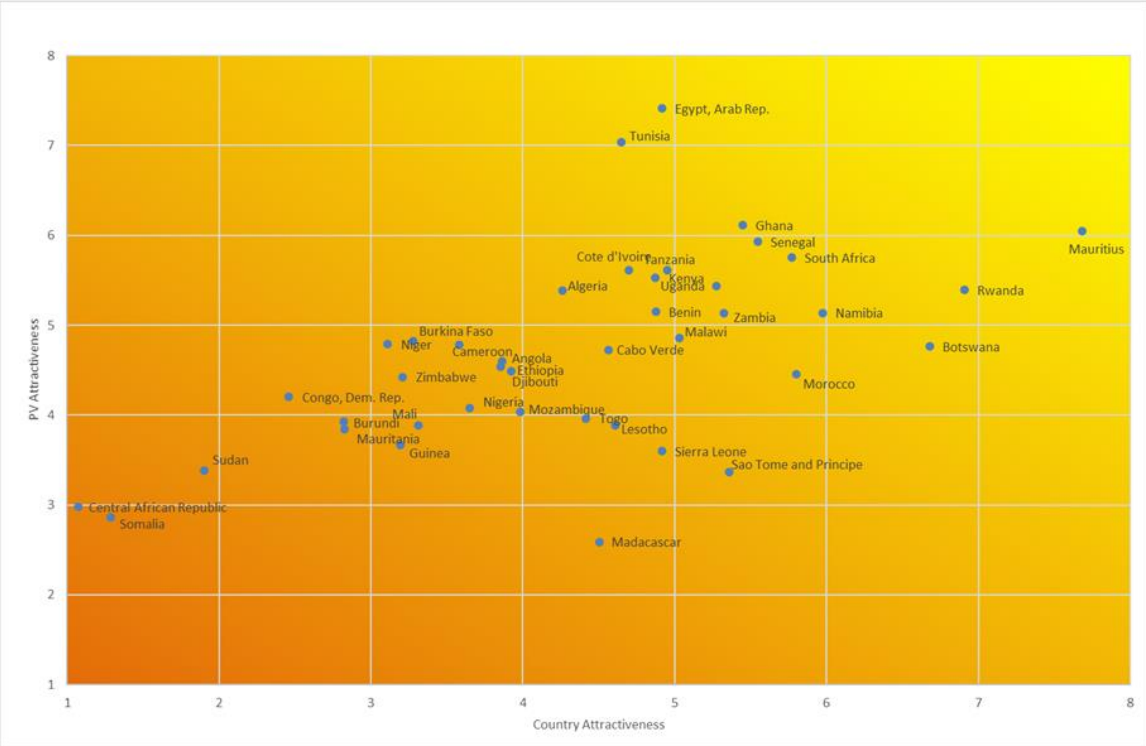

Figure 24: African countries scoring for PV attractiveness [8]

Morocco and Botswana are attractive countries, mainly because of the ease of doing business and political stability. Botswana lacks some flexible capacity to be more attractive for the PV market, while the energy mix in Morocco is more balanced. However, the lower energy consumption per capita makes it less attractive for the development of PV.

As for now, many African countries show a low score with regard to PV attractiveness and country attractiveness. These countries include Algeria, Angola, Burkina Faso, Cabo Verde, Cameroon, Djibouti, Ethiopia, Lesotho, Malawi, Mozambique, Sao Tome and Principe, Sierra Leone and Togo. All these countries experience some level of corruption, political instability or administrative complexity when it comes to doing business. Most of these countries have not installed much solar PV yet and have not yet implemented sufficient renewable energy policies. The electric power consumption per capita in these countries is also very low. This reflects the reduced grid access, which is key to develop large-scale solar PV. This analysis is even more valid for Burundi, Congo (RDC), Guinea, Madagascar, Mali, Mauritania, Niger, Nigeria, Zimbabwe. However, concerning Algeria, the score does not reflect the recent positive developments in the country and might therefore evolve in the coming years.

Countries, such as the Central African Republic, Somalia and Sudan, which recently experienced political instabilities, are the least attractive for PV and for business in general. However, even in times of civil war, solar PV might prove to be a possibility to deliver much needed improvements of the living conditions for a country's population. At the same time, it could result in short-term cost savings as electricity generation is one of the highest recurring costs in humanitarian budgets [138].

3.5 Specific market conditions

Many countries on the African continent rely heavily on fossil fuels and suffer from a lack of grid infrastructure. Therefore, these specific market conditions are briefly highlighted below.

Dependence on fossil fuel and subsidized electricity price

It is estimated that 80 % of Africa's electricity is generated from fossil fuels [139]. The low costs of solar attract many African countries to increasingly build systems on- and off-grid [140], but even in light of this higher competitiveness, the historical reliance on fossil fuel technologies, which are often imported and expensive, appears to continue [67]. The continuing dependency on fossil fuels is, among the various other factors discussed throughout this report, caused by the fact that most African countries still heavily subsidize electricity from fossil fuel. Subsidizing fossil fuels hinders investment in energy efficiency and the renewable energy sector, and at the same time imposes a significant burden on government budgets [141]. For example, South Africa spent around USD eight billion on fossil-fuel subsidies in 2017, compared to just over USD five billion spent in Germany [142]. By region, sub-Saharan Africa amounts to two per cent of global energy subsidies. On a global scale, coal is the largest source of subsidies (44 %), followed by petroleum (41 %) [143].

The reduction of subsidies remains politically challenging and is often met by strong resistance from politically influential groups and the population – even though low-income consumers are typically not the main beneficiaries of subsidies [144].

Need for grid upgrade and strengthening

Grid infrastructure remains a core challenge for African power utilities and the population, especially in sub-Saharan Africa [144]. As discussed in depth in the next chapter, the proportion of the rural population with access to electricity is below 20 % in several African countries [145]. However, studies also find that one out of six people in Africa without electricity access lives in very close proximity to existing grid infrastructure [146]. When connected to the grid, power outages are frequent in Africa. In fact, 77 % of firms in sub-Saharan Africa experienced electrical outages in 2019. On average, a firm in sub-Saharan Africa suffered from 8.5 power outages per month in 2019 [147]. In many African countries back-up diesel generators are used to generate the needed energy in times of power outages – according to studies increasing the cost of electricity up to three times [148].

There is a lack of investment and financial creditworthiness of power utilities to maintain operations, as well as to invest in an upgrade of grid infrastructures [149]. In order to increasingly attract foreign investors to develop renewable energy, the African continent will require extensions and upgrades of outdated grid infrastructure to connect new power plants, improve power supply reliability and reduce electricity losses.

3.6 Off-grid market including distributed storage solutions

Electricity access has arrived at the forefront of the development agenda. Emerging and developing countries support the deployment of distributed renewable energy solutions in order to increase electricity access in rural areas. At the same time, commercial and industrial users are increasingly interested in off-grid solutions to insulate themselves from at times unstable grids.

Distributed generation to contribute to universal energy access

While the population in Northern Africa has nearly universal access to electricity, other regions on the African continent are lacking behind. In sub-Saharan Africa, 573 million people do not have access to electricity [150]. Historically, the dominant solution for providing electricity access has been through grid extensions. However, considering that the majority of those lacking access to electricity live in rural areas, it is estimated that 40 % of installed capacity covered by mini-grids is needed to reach universal access to electricity by 2030 [151]. In fact, half of the mini-grids in planning stages globally in 2019 were planned to be installed in Africa [151]. Most mini-grids were planned in Senegal and Nigeria, where currently less than every second person in rural areas has access to electricity [145].

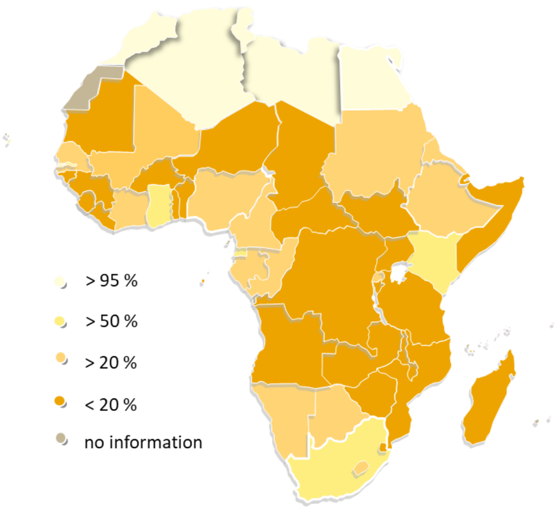

Figure 25: Proportion of the rural population with access to electricity [145]

Solar can dramatically improve energy access on the African continent, given the high irradiation and the decline in technology costs. This is all the more true for rural off-grid areas, where off-grid solar PV solutions have enormous potential. For example, the Ethiopian government strives to supply electricity to almost 100 % of the country's households by 2025, of which 35 % of the population will receive electricity via various off-grid solutions [38]. PV systems and captive diesel PV hybrid systems represent feasible solutions in many regions, where there is no access to the grid, and can be combined with a storage facility.

In rural areas, distributed generation is often the most cost-effective option. It is estimated that the annual off-grid solar market has grown to USD 1.75 billion and currently serves more than 400 million people [152]. As rural households often do not dispose of the financial capacity to pay for RE applications themselves, many governments on the African continent offer subsidies for the installation of off-grid systems. At the same time, decentralized systems can also be attractive in areas with grid access but unreliable power supply [153]. Among off-grid systems we distinguish:

- **Mini-grids**, also termed as isolated grids, involve small-scale electricity generation with a capacity between ten kW – ten MW. This grid uses one or more renewable energy sources to generate electricity and serves a limited number of consumers in isolation from national electricity transmission networks. Back-up power can be batteries and/or diesel generators. Batteries balance out fluctuations between electricity supply and demand.
- **Stand-alone systems**, i.e. solar home systems (SHS) or pico systems, are not connected to a central power distribution system and supply power for individual appliances, households or small (production) business. Batteries are also used to extend the duration of energy use.

SHS or pico-solar appliances continue to represent the bulk of distributed solar, thanks to the significantly lower system prices. In recent years, unit sales of larger SHS kits increased by over 70 % every year [152]. In the future, the role of mini-grids is expected to increase. However, to further grow and attract investments, mini-grids need a supportive enabling environment, including policies and regulations on how to integrate mini-grids, tariffs and licensing [151] [153].

Distributed generation for commercial and industrial buildings

Developers on the African continent are increasingly interested to invest in distributed solar installations for commercial and industrial (C&I) buildings. This is due to the fact that solar energy allows companies to insulate themselves from unreliable grid power and, in some markets, is becoming cheaper than the electricity tariffs that the C&I customers would buy from the grid. The latter is already the case for some countries such as Ghana, Senegal and Kenya, where the C&I market was expected to grow significantly in the last year [154]. In 2020, a Wood Mackenzie report estimated that in sub-Saharan Africa, more than 500 MW of C&I solar was under development [155].

In general, C&I off-grid energy access is expected to grow rapidly well throughout the 2020s [155], with solar PV combined with battery storage playing a prominent role. This expectation can be attributed to the fact that C&I consumers using solar PV with a storage solution can bypass many of the challenges linked to the grid connected solar market, such as frequent power outages and instability of the transmission grids. So far, the alternative for such C&I users was using diesel generators for back-up power – or alternately loose sales or manufacturing output [154]. While the number of countries allowing to sell excess solar power back to the grid and introducing net metering or FiT schemes is overall growing in Africa, in many countries a solar system has to be designed to maximize self-consumption. This can be achieved by adding a storage facility. Alternatively, distributed solar installations coupled with diesel generators can be an interesting alternative especially for the mining industry in Africa [156] which is often located far off the main grid.

4 Specific business models paving the way for energy transition in Africa

Access to finance is often the main barrier to the adoption of solar energy on the African continent. Indeed, despite the competitivity of solar solutions, the higher upfront costs are an issue especially for populations with little access to banking services or savings perspectives.

The following chapter covers some of the specific business models that emerged in this challenging context, and that develop new commercial market segments as well as want to reach people in remote areas. Mobile phone payment plans have been adopted in many African countries, special crowdfunding schemes are now making their way and adapted solar applications are likely to play a growing role in the coming years. Given that they are particularly interesting to the business models discussed in this chapter, an analysis of the competitivity of solar PV in mini-grids is also provided.

4.1 Mobile phone payment plans

Mobile payment arrangements such as the now famous "Pay-As-You-Go" models have been popularized by the Kenyan company M-KOPA Solar. Since the broader introduction of Solar Home Systems (SHS) in the early 2010s, companies have found innovative ways to give the African residential market access to SHS, even though customers have limited means to pay for their electricity. In the meantime, several companies developed similar approaches. The underlying principle is that the customer typically makes an initial payment for the basic home system, then, mobile money transfers give the possibility to also pay a small amount each month for the solar system. If the customer stops paying, the system is switched off until the customer pays the remaining credit. Customers are typically charged per unit of time, not per kWh consumed, however, pricing formats can differ substantially.

Payments are often made via mobile money, additionally there are also alternative payment methods like scratch cards, direct cash payments, or mobile phone credit. The home system is usually enabled to operate by instructions received via built-in GSM chip or after the customer enters a code received via text message.

Off Grid Electric developed a similar approach: Their customers pay a monthly fee of six USD and Off Grid Electric installs the solar panel and a meter to monitor their energy usage, along with LED lights, a radio, and a phone charger. Since 2012, the startup already provides a solar power solution to thousands of households in Nigeria, Tanzania, Rwanda, Ghana and Ivory Coast. Off Grid Electric provides a system that includes a solar panel installed on a roof and a lithium-ion battery. This provides households with the advantage of an environmentally friendly alternative to handle their lighting, cooking, and mobile phone charging needs without being connected to the grid.

The German company Mobisol, which is mainly active in Rwanda but also Kenya and Tanzania, offers customers mobile phone payment plans and has already installed more than 12 MW solar home systems. Mobisol's solar home systems provide enough electricity to power a variety of household and consumer appliance systems. Its systems come in varying sizes, from 80 to 200 Wp, to match the various energy needs of differing households or even small businesses.

This model relies on the recently increased penetration of mobile use and is in direct continuation of the introduction of mobile payment services introduced by African phone companies. Indeed, most of the phone companies offer payment services linked to a mobile phone account, without the need to open a bank account and accessible even to the poorest in sub-Saharan African countries [157]. Following the introduction in early markets such as Kenya, Namibia and South Africa, the mobile money usage penetration is soaring in most of the countries in Africa, suggesting a bright future for business models connected to this type of payment.

4.2 Crowdfunding

The possibilities for funding PV installations in Africa depend on the size of the project. On one hand, very small solar systems are relatively covered by mobile payment plans, or by associations and micro-credit companies. On the other hand, very large projects are handled by development banks and/or international institutions. It is however for projects that fall in between these two categories that funding opportunities are rather limited in Africa. The main reason is the fixed transaction cost that cannot be reduced. Therefore, financial institutions give priority to bigger projects despite the promising prospects for the medium segment.

Some cost reductions can be achieved by internalizing as many parts of the project value chain as possible, and with the digitalization of e.g. payment processes. Most importantly, however, financing costs can be limited by funding the projects directly through crowdfunding. Ecoligo launched a crowdfunding specialized platform and managed to collect enough funding for their first two projects (EUR 107,000 and EUR 153,000) with an interest rate of over five per cent for five years. They plan to open the project financing platform to institutional investors. By bundling projects, they hope to reach the segment that investors are interested in.

Since 2018, six pilot solar mini-grids give 15,000 people access to reliable electricity in Nigeria. To overcome the financial barriers to realize this project, the project partners found two innovative solutions which could be applied elsewhere: Firstly, they worked with a so-called split asset model by separating the distribution and generation components. Secondly, they decided to collaborate with the German crowdfunding platform Bettervest with the aim of entering the Nigerian market. The combination of the solutions to cover the financial aspect for this project allowed to lower the risk faced by its investors. Such financial models could be replicated elsewhere to improve access to finance in countries with higher investment risks.

Energise Africa is an initiative that provides working capital to businesses that sell SHSs and is the result of a link-up between Ethex, a UK-based ethical investment platform, and Lendahand, a Dutch-based crowdfunding platform. Sweden-based Trine is another crowdfunding solar energy platform that connects international investors with solar power entrepreneurs in East Africa; as of December 2016, the company had raised over USD 32 billion invested in solar energy projects in Kenya, Tanzania, Uganda and Zambia. Other crowdfunding platforms include Kenya's M-Changa, where entrepreneurs and their teams can easily start fundraising projects via text message.

Crowdfunding, like any other investing activity, comes with certain risks. There are few reported instances of fraud, however, attempts to circumvent regulations and to defraud investors cannot be completely excluded. Despite this, the biggest concerns regarding risk are business failure and execution or fulfillment challenges [158]. However, next to the examples mentioned above, there are many other examples of projects successfully financed through crowdfunding. Crowdfunding expands at a rapid pace in Africa; the World Bank estimates that by 2025, it will be a USD 2.5 billion business in Africa.

4.3 Adapted solar applications

Access to energy is still a challenge in many African countries, especially in rural areas, and user needs differ greatly. Therefore, several adapted solar solutions are emerging to respond to these diverse needs. From solar cooking to solar water purification, the potential applications of solar energy are as diverse as the needs are.

One example for such a need is Mobile Solar Cell Phone kiosk, which is a solar-powered mobile kiosk that charges phones and connects communities in Rwanda. It was founded by Henri Nyakarundi, who noticed that even though many people had cell phones, they faced a challenge with charging their devices. It is estimated that over 70 % of the population in Rwanda own a cell phone. However, at the same time, the World Energy Outlook of the IEA [1] estimates that less than 76 % of the Rwandan population has access to electricity in cities and less than 44 % in rural settlements. Prompted by this need, the solar-powered kiosk can be towed by a bicycle and provides concurrent charging for up to 80 phones. The Mobile Solar Cell Phone Kiosk uses a franchise model. Micro franchisees earn money from mobile charging and selling add-ons such as mobile credit, government certificates and prepaid electricity.

Another similar example is a multi-purpose solar-powered vehicle to supply cheap energy to Kenya's rural homes and to ease transport as well. The bike was invented and designed by three young Kenyans under the name Solar e Cycles, it can easily carry weights of up to 150 kg and travels at 50 km per hour. The bike can also be used to store electricity to use it for lightning for instance.

Solar lights are an easy solution to provide access to safe light. SunnyMoney is one of the main sellers of solar lights in Africa and its unique community distribution model uses teachers to raise trust and build awareness of solar. SunnyMoney also supports local shops and independent agents by providing marketing campaigns, training and shipping of products. This creates the market conditions required to be able to sell a range of solar lights profitably, to create new sources of income and enable people to improve the life quality of other people.

4.4 Mini-grids: Analysis of solar PV competitiveness

In Africa, mini-grids using diesel generators are often powering entire villages, companies or sites far off the grid. The addition of solar PV to these systems allows to reduce the fossil fuel consumption by 20 to 50 % depending on the site and the operating conditions [159]. Initially, solar PV was simply considered a marginal add-on to these generators, because of technical constraints (the generators cannot stay idle below a certain power output). However, with high oil prices and the simultaneous drop in prices of solar panels and batteries, opportunities for new business models to hybridize diesel generators have opened up.

This section provides an analysis of the main factors influencing the competitiveness of solar PV in mini-grids and an indicative LCOE comparison for different cases based on the Micro-grid Tariff Assessment Tool from the National Renewable Energy Laboratory (NREL) [160].

The main factors influencing the competitivity of solar PV in mini-grids in Africa are the costs of fuels and the costs of solar PV and batteries. The cost of fuel is determined by several factors, most importantly international barrel prices. However, some local factors can play a crucial role as well, such as subsidies for fossil fuels, which have an adverse effect on the profitability of PV (see chapter 3.5 on Specific Market Conditions). However, this section on mini-grids will focus the impact of remoteness and location. As a matter of fact, for remote sites fuel must be transported via roads – often in poor conditions – by trucks – often old and not fuel-efficient –, and both factors result in higher fuel consumption for transport [161]. For instance, considering around half a liter of diesel must be burnt to transport one liter of diesel from the closest city or port to a remote site, it can be estimated that the actual local price for diesel would be 50 % more expensive. Solar irradiance is also affecting the competitiveness of solar PV, as the differences between sites can have a decisive impact on the size and design optimization of the solar PV and battery installations. Despite the high global average solar irradiance on the African continent, there are some local disparities that can significantly affect solar power output.

The Micro-grid Tariff Assessment Tool from NREL was used to provide a meta-analysis of these factors influencing the competitivity of solar PV and batteries of mini-grids in Africa. The tool allows a better understanding of mini-grid in sub-Saharan countries depending on the respective technical and economic assumptions. The principal parameters of the LCOE calculation are summarized in the table below. The fuel cost was set at USD 1.16 per liter for remote sites and USD 0.85 for connected sites. The analysis was conducted twice to compare the impact of a solar irradiation of 5.3 and 6.1 kWh/m^2/day. The load profile is an average profile where 90 % of the load is served.

The results are merely indicative of the impact of the remoteness of a site on the competitive advantage of solar PV. The main trend that can be drawn from this analysis is that both solar and battery solutions are competitive when fuel prices are high (remote sites). Conversely, when fuel prices are low (connected sites), diesel generators - possibly in combination with a reduced amount of solar PV to lower the LCOE - could stay an economically preferred option. The solar irradiation also significantly impacts the LCOE, i.e. higher solar irradiation leads to lower LCOE.

In remote sites, the costs of transport of fuel strongly influences the LCOE from diesel generators. Therefore, the business models might encourage producing electricity with PV, store it in the batteries and keep the generator in reserve in case of a lack of production from PV during several days. From a practical point of view, diesel generator hybridization is rather complex. For instance, diesel generators must always operate at a capacity factor of minimum 20 to 30 % and thus are highly inefficient at low loads, which escalates the cost of producing electricity at low electrical output. Operation of diesel generators in combination with PV and battery requires specific management tools and knowledge to avoid suboptimal use of the coupled installations. Depending on the relative size of the diesel generators and the PV installation and on the weather forecast, the optimal management mode will be different to optimize energy storage and reduce fuel consumption.

As the costs of solar PV and batteries are still decreasing, there is no doubt that solar PV and batteries will play an increasing role in off-grid mini-grids in Africa in the coming years. This development might however take longer in countries that are still strongly subsidizing fossil fuel prices.

LCOE calculation assumptions	
Installed PV cost [USD/kW]	1,400
PV O&M [USD/kW]	28
Useful life	20 years
Battery storage cost [USD/kWh]	300
Battery useful life	7 years
Inverter and BOS costs [USD/kW]	600
Inverter replacement cost [USD/kW]	300
Battery O&M [USD/kWh-installed]	20
Inverter useful life	10 years
Diesel genset cost [USD/kW]	400
Useful life	10 years
Fuel consumption rate [kWh/gal]	10
Fuel escalation rate	3 %
Total distribution system costs [USD]	20,000
Pre-operating soft costs [USD/kW]	1,200
Annual labor costs [USD/year]	3,000
Annual land lease costs [USD/year]	800

Table 1: Overview of the LCOE calculation assumptions

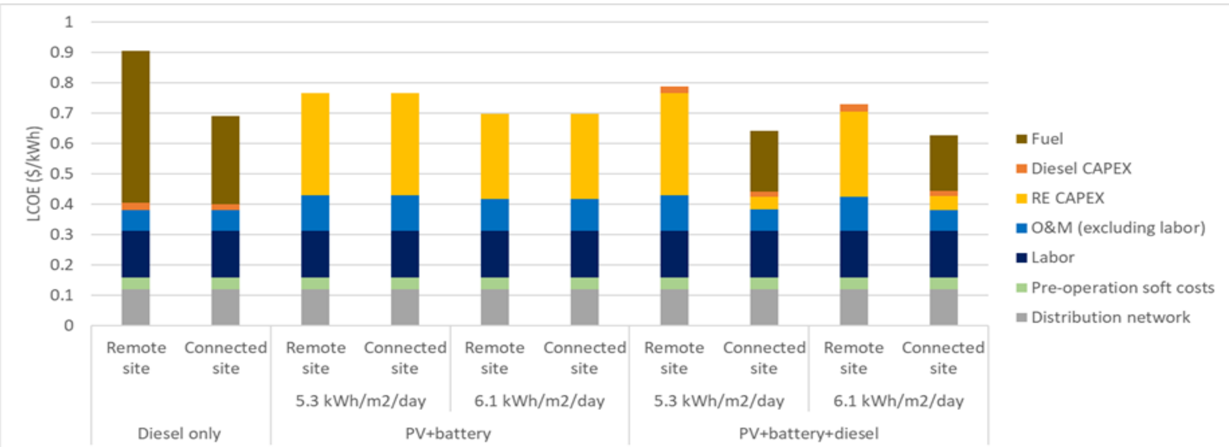

Figure 26: Comparison of the factors influencing optimal LCOE in remote and connected sites [8]

5 Policies and Support

As solar systems have relatively high upfront investment costs, the introduction of support policies is still crucial to ensure their deployment in Africa, both on- and off-grid. This chapter will provide an overview of such support policies, as well as policies to foster local economies and the support through funding organizations.

It is important to mention that while not detailed in this chapter, support measures should be accompanied with adequate grid codes and simplified administrative procedures to accelerate investments in renewable energy. In addition, clear allocation of property rights is needed to shape clarity during the otherwise time-consuming negotiations.

5.1 Analysis of key supporting policies

Most African nations have introduced support instruments for the development of renewables. Key policies for on-grid and distributed generation encompass:

- **Renewable energy targets and national commitments,** which are still one of the main means for policymakers to express political will to renewable energy deployment and give a signal to the market. These targets are increasingly linked to climate targets.
- **Financial and fiscal incentives** in the form of tax incentives, rebates, grants, performance-based incentives, concessional loans and guarantees as well as measures to mitigate risks, which are used to catalyze private investments, reduce the high upfront costs or the production costs of renewable energy projects.
- **Regulatory and pricing policies** such as FiTs, auctions, and net metering.

Renewable energy targets exist in almost all African countries. Tax reductions are also a common instrument and many countries support renewables via direct public investments, loans or grants. The measures having the most impact on the development of solar installations are undoubtedly pricing policies. The two main schemes applied to provide financial support are tariffs and self-consumption policies (for small scale installations). However, as the price of solar installations further decreases, it is likely that the market will more and more shift towards PPA or self-consumption without any state intervention.

FiTs and **feed-in premiums (FiPs)** have been instrumental in encouraging renewable energy projects worldwide, since they provide a stable income to generators and help increase the bankability of projects [162]. FiTs and FiPs have been adopted by at least ten African countries, among them Egypt, Uganda and Zambia. In the past, some FiT-schemes in Africa worked out poorly because of unfavorable institutional design, insufficient level of FiT rates or obstacles in the process of implementation [163].

Self-consumption policies target embedded power systems in the residential and the commercial segments. Despite the advantages of embedded production such as the decreased energy losses and the reduction in peak demand, many countries still seem reluctant to incentivize PV systems through self-consumption schemes [164]. However, the need for grid reinforcement and the frequent loss of loads experienced in many countries might increasingly drive the growth of the self-consumption segments, even without additional incentive from the governments. Among the first countries to introduce compensation schemes self-consumption, the following can be cited: South Africa, Cabo Verde, Egypt, Ghana, Kenya, Lesotho, Morocco, Namibia, Senegal, Tanzania and Zimbabwe.

Auctions or tenders remain a key driver for PV development especially for utility scale projects [162], this is also true for new African emerging markets. Auctions allow to grant a FiT or to settle PPAs with the power producer, based on the most competitive bids. Auctions or tenders are being introduced in a growing number of countries on the continent and have contributed to the recent reduction of renewable energy prices. When thoughtfully implemented, tenders can lead to cost effective and stable market development. However, implementation mistakes can make potential investors more reluctant. Recently, some tenders for small projects in African countries with immature energy markets are considered to have sent wrong price signals, thereby limiting market access to just a few large companies, and thus eventually hindering the development of PV in these markets [165]. Often, tenders are coupled with support instruments to increase social economic benefit, such as local content requirements, or to facilitate access to finances, i.e. financial guarantees backing contracts to increase investor confidence [162].

5.2 Local manufacturing policies to foster local economy

The energy transition requires significant investments. To create economic opportunities along the way, some emerging markets implemented Local Content Requirements (LCR). LCRs allow to foster local manufacturing, local supply chains and innovative industries. However, to develop several key industries, countries must have a solid industrial and technical background. Moreover, a stable and visible pipeline of solar projects is a key element to create a sustainable solar component industry [166]. Despite the competitiveness in labor costs, main barriers with regard to qualified labor are the lack of technical knowledge related to component design and manufacturing, the absence of specialized training centers and low productivity.

The World Bank conducted a competitiveness analysis and identified Egypt as a serious candidate to develop a local solar industry [166]. According to the analysis, Egypt's key strengths for solar industrial development are production factors such as low cost of labor and low cost of energy for industrial consumers, availability of material for solar industries (particularly glass, steel and stainless steel), and strong manufacturing capabilities. Egypt plans to increase the total installed power by 2,800 MW of PV and 700 MW of CSP by 2027 [35], which provides some good perspectives to develop a local industry.

Algeria has already started setting domestic content requirements as part of tender rules for a few years. The requirements compel developers to construct PV component manufacturing facilities in the country. Consequently, Algeria has a well-developed local PV panel industry. According to official sources, the module industry capacity has reached the milestone of 500 MW of annual production [167].

South Africa is an interesting example for a fast-growing market with local initiatives to promote the industry. Through its Industrial Policy Action Plan, the Government identifies local content as a strategic industrial policy instrument. Since December 2011, the department of Trade and Industry (DTI) is empowered to designate industries, sectors and sub-sectors for local production at a specified level of local content. Within the framework of the Renewable Energy Independent Power Producer Procurement Program, the DTI developed a table of socio-economic output to be met or exceeded to become a "preferred bidder" in the tender [168]. Each renewable energy project requires a minimum of 40 % participation by a South African entity, a minimum ownership by black South Africans of 12 % and a minimum ownership of a local community of 2.5 %, where the community lives within a 50 km radius [168].

Tenders in Morocco are also set up to favor the local industry indirectly through the Moroccan Agency for Sustainable Energy (MASEN). MASEN is currently responsible for managing the solar auction scheme to install 2,000 MW across five sites. To link the development of solar PV to local manufacturing, MASEN operates a two-phase auction process: a pre-qualification phase and an evaluation phase [169]. In the evaluation phase, the selection is based on price. MASEN also sets a condition on local requirement: 30 % of the plant's capital cost (local equipment manufacturing, operation and maintenance, R&D) must come from local industry [169].

5.3 Implication of international organizations

Despite the growing number of companies expanding the cleantech market to the developing world, much financial aid is still required to help the poorest people in the world to gain access to electricity. Indeed, donors' active involvement is still crucial to ensure the technological transfer and financial support for renewable energy projects and programs in Africa, both large and small-scale, on- and off-grid [170].

All major bilateral and multilateral donors made the promotion of renewable energy an important element of their international climate and development policies [171]. This is a direct consequence of the impulse provided by the UN Sustainable Energy for All (SE4ALL) initiative and its three central objectives of ensuring universal access to modern energy services, doubling the global rate of improvement in energy efficiency as well as doubling the share of renewable energy in the global energy mix.

The support through donor organizations can take many possible forms: concessional loans by Development Finance Institutions (DFIs), grants offered by bilateral foreign aid agencies, direct subsidies, technical assistance for policy support and institution building or for example project management capacity development and training. In addition to these, non-governmental organizations (NGOs) and private charities can have diverse goals and objectives.

The three major multilateral donors in the energy sector in Africa are the World Bank, the EU and the African Development Bank. While the three of them participate and manage various multi-country programs, a large role is given to local organizations and national governments through multilateral lending via loans and grants [172]. More specifically related to the renewable energy sector, the Global Environment Facility (GEF) and the Green Climate Fund (GCF) can be cited.

Next to traditional development cooperation, both bilateral and multilateral donor agencies have launched a significant number of new initiatives at the regional and sub-regional level. These initiatives aim to support the energy sector and it can be distinguished between high level Initiatives supporting political dialogue between African countries, high level initiatives with an operative program, as well as operative programs and delivery mechanisms providing different forms of technical assistance and financial support.

However, the effort of development agencies or equivalent institutions to subsidize solar projects may involuntarily bring distortions to the market [7]. In fact, subsidized projects may directly compete with existing ones driven by private investors. Therefore, donor support must encourage initiatives in segments where the private sector fails to find economic equilibrium or happens to be absent for any other reason. Offering subsidized electricity production infrastructure to developing countries should be avoided for the reasons mentioned above, but also as there are less incentives to keep subsidized infrastructure in optimal condition. There are, indeed, several examples in Africa, of subsidized power stations abandoned after the completion of the work or being in states of serious deterioration.

Private-public-partnerships (PPP) are nonetheless still a necessity to foster the energy transition in Africa. However, given the limited funding budgets, they should be used according to the conditions discussed above and not compete with private investment. For instance, donor funding can be implemented as a risk coverage, to attract better loans or to finance projects that are not able to attract private investors.

6 When solar met water

Many regions in Africa suffer from water scarcity and at the same time dispose of high levels of irradiation for the potential generation of solar energy. The idea to combine these and use solar power for the supply of freshwater, represents one of many technological applications that resulted when solar met water and which have been on the rise in the African continent.

It is estimated that 2.1 billion people worldwide do not have access to safe drinking water, half of which live in Africa and roughly a quarter in sub-Saharan Africa [173]. Over 200 million people in sub-Saharan Africa suffered from chronic undernutrition in 2019 [174]. As a result of climate change and population growth, these numbers are expected to rise until 2050. Among other solutions, this calls for environmentally friendly technologies to ensure the supply of fresh and drinking water, as clean water is not only needed for household use, but also in high demand for agricultural (such as watering of fields and livestock) and industrial purposes.

Currently, solutions for obtaining water in many regions on the African continent are based on either fossil fuels, such as diesel generators pumping irrigation water, or manpower, meaning people walking great distances and spending a lot of time to haul water for either their households or small crops. Usually, the latter task is reserved for women and girls which, according to the UN Commission for Human Rights, walk an average of six kilometers a day to get water [175]. To use solar PV to pump or disinfect water will thus not only have a favorable effect on the environment. Solar irrigation or solar desalination installations could also result in positive societal effects, such as girls going to school instead of fetching water. Solar disinfection could prevent, again, mainly women and girls, from having to collect firewood to boil water. And even better: A study in South Africa shows that given similar access to water, women achieve higher welfare than men [176]. Generally speaking, easier access to water can result in bigger crops, which can supply more people with food and jobs and income [177] [178].

The various markets for technologies combining solar and water are in different stages: Solar irrigation and pumping is experiencing a significant upswing, especially for agriculture in African countries. The global growth rate is expected to be as high as 12 % until 2027 [179]. The global market for solar water desalination plants is expected to grow around nine per cent in the next seven years [180]. Solar disinfection however will need a bigger boost in African countries. Outlooks suggest that due to a massive lack in awareness for the need of disinfection as a prevention of waterborne diseases, the demand for solar disinfection is not as high as it should be. Another reason for the slower growth in that area is the small amount of only microbiologically polluted water bodies, hence resources in African countries call more for desalination and pumping [181].

Generally speaking, when solar met water several technologies came in to play: solar desalination, solar irrigation/pumping, solar disinfection, as well as floating solar. Next to the specific tasks they are designed for, their applicability depends for example on monetary and geographical aspects.

Solar Desalination

Especially in coastal regions, the desalination of sea water is an important application to provide clean water. But also when it comes to saline groundwater in arid regions, desalination can help. There are different options to desalinate, for example distillation or thermal desalination and reverse osmosis (RO). In thermal desalination, the water is heated enough to evaporate. This heat can either be generated through solar thermal systems or waste heat. Afterwards, the steam is led through a membrane, while solid matter, salt and toxins are left behind. On the other side of the membrane the steam is cooled down by a cooling fluid and eventually returned to its fluid form, but now cleansed water ready for use [182]. If combined with solar energy, RO is the more energy efficient method of desalinating water. Here, the water, containing dissolved salt molecules, is filtered through a semipermeable membrane with high pressure, where the larger salt molecules do not get through the membrane pores, but the smaller water molecules do [183]. Because RO requires mechanical work and not heat, this can as well be done by power generated through PV systems. While RO is more cost effective, due to less energy needed, it produces slightly less clean water than thermal desalination and cannot efficiently be used with water with higher salt concentration.

The downside to desalination however is the immense creation of toxic brine as a byproduct. During the desalination process, the hypersaline water is pumped back into the ground or water body. This kind of hypersaline water can be loaded with heavy metals and chemicals, which are toxic for the environment [184].

Solar desalination has been successfully implemented in a few different African countries. In Kenya and Somalia, Berlin based company Boreal Light GmbH provides affordable solar water desalination systems that work with RO and supply especially rural areas with high quality hygiene drinking and irrigation water from polluted water or water with high saline levels [185]. In Somalia, the company currently sells 1,000 liters for as little as 50 EUR cents [186]. Also in Kenya, a solar-powered desalination plant constructed by the non-profit GivePower provides around 25,000 people with 75,000 liters of drinking water each day at a cost of 25 USD cents per liter [187]. Another noteworthy solar-powered seawater desalination plant is located in South Africa: Running since late 2018, the plant purifies around 150 kiloliters daily [188]. Looking ahead, for example the Egyptian government announced plans to evaluate a series of water desalination projects powered by renewable energy, including feasibility studies for solar-powered desalination projects in Egypt [189].

Reaching economic feasibility can be challenging for some solar desalination plants, which however can help off- and on-grid areas to supply themselves with fresh water. There are already plenty of organizations as well as governmental plans in place that aim at lowering the costs per liter for locals.

Solar Irrigation/Pumping

The irrigation or pumping of ground- or well water with solar PV has been a milestone in African countries, as solar power allows even off-grid rural areas to water their crops and provide their homes with fresh drinking water without having to walk enormous distances for it [177]. Here, solar energy is used to run an irrigation system, which pumps water automatically and is in almost no need of human intervention – with some systems being equipped with moisture sensors that detect the level of water needed by the soil [190].

Once installed, solar irrigation systems are quite cost effective, as there are no additional costs per unit of power. This makes solar irrigation very attractive and can motivate a switch from fuel or non-renewable energy to pumping with solar. Solar irrigation can help ensuring food security, generate incomes, provide jobs and drive rural development [177]. With costs of solar systems going down and subsidy schemes being rolled out, solar-powered irrigation systems have become viable options for large-scale but also decentralized, small-scale farming [177]. Systems are also used for supplying whole villages with drinking water: For example in Kenya, solar irrigation systems are used to pump drinking water for villages, oftentimes funded by the government or the World Bank and made accessible to the people free of charge [191]. In Angola, to ensure food supply, a small, autonomous solar-irrigation plant was built in the valley of Cavaco [192]. Another solar deep well system for central water supply was built in cooperation with local farmers and the German company SUNSET Energietechnik, also in Angola [193]. In Ghana, solar irrigation systems are among other places to be found in four communities in Northern Ghana, to provide 78 farmers with up to one million liters of water daily, supplying around 15 hectares of crops [194]. For 2021, Morocco announced a budget for solar installations in agriculture, mainly for powering water pumping installations [87].

Compared to e.g. diesel-powered systems, installation costs for solar pumping/irrigation are higher, however diesel is more expensive to users in the long run [195]. There is also the option of running irrigation systems as a hybrid, with diesel and solar power combined. On household-level, solely solar-powered systems have proven to suffice.

Solar Water Disinfection

In contrast to desalination and pumping/irrigation, solar water disinfection (SoDis) usually operates on a significantly smaller scale. It is often used to treat and purify microbiologically contaminated water in an environmentally sustainable, low-cost way at household level [196], which makes it beneficial for off-grid areas without access to clean water. Solar water disinfection may however as well be combined with and supported by solar-power on a bigger scale.

With SoDis, sunlight or solar energy is used to destroy pathogenic microorganisms which cause diseases and are sensitive to radiation and heat. For that purpose, water was initially filled into transparent, plastic (PET or PVC) or less often glass bottles and exposed to full sunlight for six hours. To make this technology work on a larger scale and not only be limited to a small batches process, systems were developed to clean larger quantities of water on a more constant level. Through stored solar-power, for example UV-lamps can be powered even through the night. Another method, which is called solar pasteurization, heats the water to 70–100 degrees Celsius, to boil and therefore destroy all pathogenic microorganisms [197].

The advantages of SoDis are of course the lowering of health hazards and its simple handling as well as its extreme affordability on the small scale. However, it requires already relatively clean water without chemical pollution or salt water [178]. Small-scale SoDis has been applied in many sub-Saharan African countries such as Angola, Ethiopia, Ghana, Kenya, Tanzania, Uganda, and many more for quite a while now. Larger installations have also made their way into African countries and are being used frequently: One example is a project in rural sub-Saharan Africa funded by the EU, which specializes on SoDis technologies using special reactors that have the potential to treat 200 liters of rainwater in five hours [198]. More installations can be found in Ghana and Mali, where so-called "UV WaterBoxes" purify 5,000 to 10,000 liters of water a day and even at night or during a rainy day, due to included batteries, a UV-lamp and energy from solar panels [199]. In Rwanda, the government initiated the Integrated Development Program supplying villages with larger solar-powered SoDis systems to improve sustainable development, especially in rural areas [200].

Floating Solar

Floating solar is another interesting player in the combination of solar and water. Here, solar panels float on – so far mainly – inland and artificial water bodies and generate around ten per cent more power than land-based PV installations do. Another advantage is the simultaneous cooling of the panels trough the water [201]. As opposed to ground-mounted solar systems, floating solar does not compete with agricultural use of land and might even help preserving water for alternative uses [202]. The possibility of growth by adding modules also makes floating solar scalable and easily adaptive to demand [203][204]. Another application of floating solar is to use existing hydropower infrastructure. It is estimated that covering as little as three to four per cent of the reservoir of a large hydropower plant with floating solar panels could double the electricity generation capacity of a dam [205]. However, recently, the plans for the first solar hydro hybrid plant in Uganda were abandoned over concerns for water animal life and economic feasibility [206].

In 2019, the first commercial floating solar park in Africa was opened in South Africa near a fruit farm. With an installed capacity of 60 kWp, future steps for the park are among others also to use the system for water pumping [207]. Other utility-scale floating solar-systems are planned in Seychelles and Tunisia [208][209]. In Burundi, a solar hydro hybrid plant will be built with help of the African Development Bank [210].

Especially large-scale floating solar systems on artificial water bodies have proven itself to be commercially viable. While system prices are estimated to be around 18 % higher compared to ground-mounted systems, over time the higher initial capital expenditures of floating solar are more than balanced by the higher energy yield [203]. It is estimated that Africa has over 100,000 km^2 man-made freshwater reservoirs that could be used for floating solar [203].

7 Outlook on electric vehicles and storage deployment

This section covers the respective contributions that electric vehicles and storage can provide to support the grid and energy management, and gives an overview of the market developments in several countries.

Electric Vehicles

Generally speaking, electricity storage is a vital alternative to peaking thermal units and to ensure adequacy of energy supply at all times. Indeed, electricity stored during times when solar energy exceeds demand can be returned to the grid when production falls below consumption. As demonstrated in section 4.4, storage is also crucial in off-grid and mini-grid systems, especially to integrate larger shares of renewable energy sources. In theory, electric vehicle (EV) batteries can also be used to accommodate the fluctuating availability of renewable energy by loading the battery when energy is the most available. Therefore, electric cars, electric scooters or electric bikes represent a solution for the further integration of solar PV in Africa. Electric mobility will also benefit the air quality in Africa's congested cities.

The African market is lagging behind when it comes to the adoption of electric vehicles. However, some market dynamics are starting to develop, especially in urban areas, and rising fuel costs could increasingly become a driver to adopt electric mobility. As it is the case for PV, innovative financial models are needed to compensate for the higher upfront costs. Furthermore, a charging infrastructure will have to be developed.

For example, Egypt has been working on a plan to increase the share of EV towards 2040, with new legislations coming and several cooperation agreements between Egypt and China to boost the use of electric vehicles in Egypt. Egyptian officials prepare the ground for the widespread use of EV: 1,000 fast electric charging stations should be set up across Egypt over the next three years.

Morocco also wants to increase EV deployment, and therefore electric and hybrid vehicles have been exempted from customs duties since 2017. The government developed charging infrastructure on the highway between Agadir and Tanger and further development is planned. Since last year, the government`s plan is to gradually renew its car fleet with EV aiming at achieving 30 % EV towards 2021.

Tesla delayed its plans to launch electric cars in South Africa by the end of 2019 due to high import duties. EV models are not yet popular in the South African market because of load shedding and the price difference which outweighs the savings on fuel. Therefore, the growing competitiveness of SHS could solve both issues by providing cheap and reliable power.

In Kenya, following a successful pilot, more vehicles have been ordered with a Finnish taxi company known as Nopea Ride. All Nopea vehicles are 100 % electric. For the drivers, the company claims that it offers 30 to 50 % higher revenues than traditional gasoline cars. The company is co-guaranteeing the vehicles together with the drivers which has given financial institutions confidence to extend financing.

Mitsui, a Japanese electric auto manufacturing company, launched an assembly plant in Ethiopia for its electric three-wheeler (E-Trike). It invested about USD ten million to operate the project, including the costs of installing facilities and labor in Ethiopia.

A team of young engineers in Uganda developed an EV prototype that runs on rechargeable lithium batteries. The prototype can attain a speed of 100 km/h and is engineered to achieve an inter-charge distance of 80 km according to the designers. In parallel, the team developed an electric bus and a hybrid five-seater front-wheel drive specially adapted for Africa's rural roads and cheaper than the average EVs.

Storage

The falling costs of storage technologies will make it possible for African countries to rely on decentralized systems based mainly on solar in combination with storage, bringing access to electricity to people in remote areas but not only. As of 2019, the largest form of grid energy storage in Africa is dammed hydroelectricity, both conventional hydroelectric generation as well as pumped storage [27]. However, there are some important disparities between countries depending on the local hydrological potential [211].

Pumped water systems are versatile as they combine a high dispatch ability, meaning they can come on line very quickly, with the capacity to store energy on a larger time scale. Therefore, pumped hydro can be operated to compensate for the rapid changes in electrical demand from consumers and also allow to store excess energy from renewable sources for longer periods. Hydroelectric dams with large reservoirs can also provide peak generation and, depending on the reservoir capacity, can provide daily, weekly, or seasonal load. As the demand decreases, water will be accumulating in the reservoir to be released through the plant turbine only when the demand is higher. The net effect is the same as pumped storage, but without the pumping loss.

Commercial thermal energy storage solutions are increasingly reaching the market and competitive solutions already contribute to the system balance. A common approach to thermal storage is based on a phase change material: Input heat melts the material which changes phase, from solid to liquid for instance. Indeed, molten salt can be employed as a thermal energy storage to temperatures over 400°C [212]. This technology has been chosen for the phases I and III of the Noor project in Morocco for its compatibility with the solar CSP installation. Molten salt tanks can store thermal energy up to ten hours [212].

The falling costs of lithium batteries already create new economic opportunities in Africa, especially in SHS and mini-grids. As costs decrease and the performance of batteries further improves, these could reach new market segments in the coming years. For instance, South Africa is about to launch one of the largest electricity storage projects in the world. This involves the installation of batteries that will be able to store the equivalent of 1.4 GWh of electricity [213]. The call for tenders will be implemented in two phases and should soon be launched by the state-owned company Eskom [213]. At the University of Benin in Nigeria, a 15 MW solar plant combined with a 5 MWh storage system is under development [214][215]. Other examples of solar-plus-storage can be found in Kenya, Madagascar, Mali, Namibia and la Réunion. Uganda is hosting the world's first solar-hydrogen powered mini-grid as the Belgian renewable energy company Tiger Power signed an agreement with the Ugandan government to power 3,000 rural households and businesses [216]. The project is supported by the Belgian exporting agency and the rural Energy Agency.

The competitiveness of storage units is directly related to their cost but also the incomes they can generate. The business case for delivering ancillary services such as frequency response or capacity reserve depends on the price that the end consumers are willing to pay for grid stability and power reliability. Most of the African countries must improve grid management and could provide more reliable market conditions for storage.

8 Conclusion

As this report has shown, merely an excellent irradiation is not sufficient to reap the benefits of solar energy as a cheap and abundant resource. While renewable energy and electrification rates are high on the agenda in many of the markets analysed (see chapter 3.2), the actual installation rates of solar energy in many African countries remained low in the last year (see chapter 3.1) and Africa still represents a mere one per cent of the world's installed solar PV capacity [8].

The reason for this low share is a myriad of challenges, most of which relate to one or more of the three fundamentals needed for any solar market: First, favourable framework conditions (among them grid connection rules, low or no import duties on renewable technology, little bureaucracy). Second, access to financing, preferably without a currency risk in case material is sourced in USD or EUR. In fact, the abundance of cheap financing available in some European markets has led to a LCOE comparable to that of some African countries in the sunbelt [217]. The third fundamental is the availability of skilled labour to lay out, engineer, plan and install systems as well as the components that work with them, such as batteries. Given the growing electricity demand in many of the markets surveyed, the need in employment for implementing these systems cannot be overstated. Due to the high level of automation in today's solar manufacturing plants, it is estimated that around 73 % of the gross added value created and 75 % of jobs supported by the PV industry occur after a module has left the factory [218].

As some examples in this report have shown – where these fundamentals are met, national solar PV markets are growing. Those stakeholders who set the framework are well advised to plan ahead not only in setting the rules, but also in allowing access to finance (here also donor organizations or banks in exporting nations can help mitigate risks). They should also calibrate education and training programmes to make sure the growing energy demand is matched with a growing availability of skilled labour. In addition to these three general fundamentals, a typical challenge for the African market is the theoretically high availability and low cost of land – favourable for solar – while getting a title to the usage of land or even finding who owns it can constitute a time-consuming task in some markets (see chapter 5).

With all the focus on challenges, there are a lot of positive turns in many markets: While large tenders have been met with hiccups (for instance, one GW scale installations tendered in Nigeria in 2016 have not been built [99]), generally the handling of such processes has improved. Some of the markets in Northern Africa function very similarly to the mature solar markets of Western Europe or the United States of America, as far as their business models are concerned. Other markets are finding innovative ways of leapfrogging some infrastructure as well as innovative business models, even though this effect so far has not been as strong as the hype around it.

In individual markets, we see highlights that point to an upward market development needed to meet a growing continent's energy hunger. Just to give three examples: In Algeria the government endorsed a plan in 2020 to make solar the sole technology of a four GW installation "push" from 2020 to 2024 [16]. Egypt's Renewable Energy plan aims to install 3.5 GW solar energy by 2027 [35]. We estimate that in 2019, more than 500 MW of utility scale solar PV were in different stages of project development in Kenya [66].

Looking at these figures and tapping into the discussions in the various markets, we have found a new mood of invigoration. It sure feels like the African continent is at the beginning of a large wave coming, one that has built its groundswell for years. We are looking forward to riding it to success with our partners and all who strive to change the energy system to the sustainable, digital, renewably sourced system it will become.

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Acronyms and abbreviations

ACEC – Africa Clean Energy Corridor

ADER – Agency for Rural Electrification (Madagascar)

BOOT – Build Own Operate Transfer

C&I – Commercial and Industrial

CSP – Concentrated Solar Power

DC – Direct Current

DFIs – Development Finance Institutions

DTI – Department of Trade and Industry (South Africa)

ECOWAS – Economic Community of West African States

ERA – Electricity Regulator (Uganda)

EREP – ECOWAS Renewable Energy Policy

EUR – Euro

EV – Electric Vehicle

FiT – Feed in Tarif

FiP – Feed in Premium

GCF – Green Climate Fund

GDP – Gross Domestic Product

GEF – Global Environment Facility

GSM – Global System for Mobile Communications

GTP – Growth and Transformation Plan (Ethiopia)

GW – Gigawatt

IEA – International Energy Agency

IMAS – Interconnected Mini-Grid Acceleration Scheme (Nigeria)

IPP – Independent Power Producer

IPCC – Intergovernmental Panel on Climate Change

IRENA – International Renewable Energy Agency

IRP – Integrated Resource Plan (South Africa)

KNES – Kenyan National Electrification Strategy

kW – Kilowatt

LCR – Local Content Requirements

MAS – Mini-Grid Acceleration Scheme (Nigeria)

MASEN - Moroccan Agency for Sustainable Energy

MENA – Middle East & North Africa

MINEA – Ministry of Energy and Water (Angola)

MW – Megawatt

NEP – National Electrification Program (Ethiopia)

NEP – New Energy Policy (Madagascar)

NIRP – National Integrated Resource Plan (Namibia)

NREL – National Renewable Energy Laboratory

LCOE - Levelized Cost of Electricity

LCR – Local Content Requirements

LUT – Lappeenranta University of Technology

OECD – Organisation for Economic Co-operation and Development

PAYG – Pay-as-you-go

PPA – Power Purchase Agreement

PPP – Private-public-partnership

PV – Photovoltaic

REA – Rural Electrification/Energy Agency

REF – Rural Electrification Fund

RES – Renewable Energy Source

RO – Reverse Osmosis

SoDis – solar water disinfection

SREP – Scaling Up Renewable Program (Ghana)

SSA – sub-Saharan Africa

SHS – Solar Home system

VAT – Value Added Tax

WEF – World Economic Forum

USD – US Dollar

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