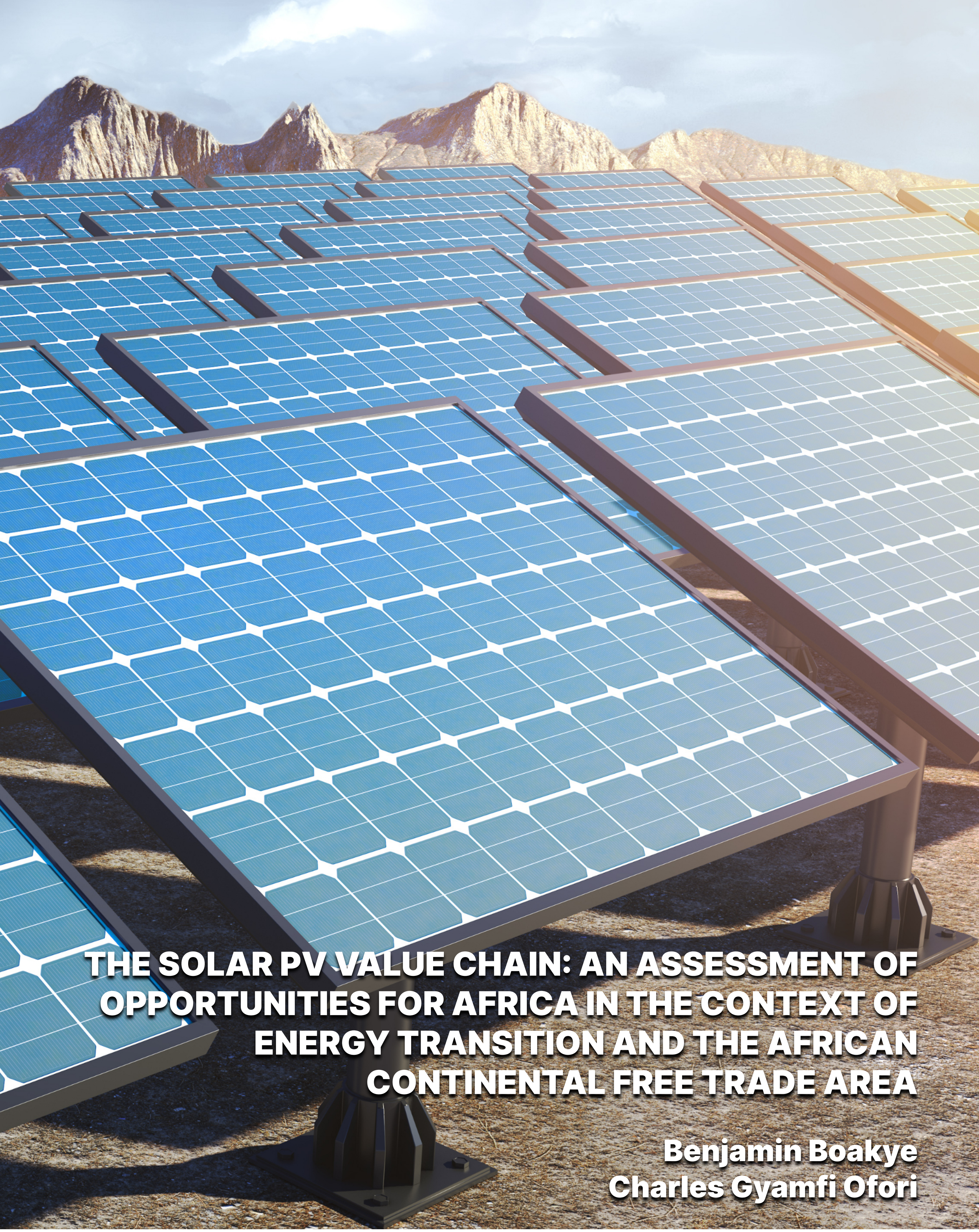


THE SOLAR PV VALUE CHAIN: AN ASSESSMENT OF OPPORTUNITIES FOR AFRICA IN THE CONTEXT OF ENERGY TRANSITION AND THE AFRICAN CONTINENTAL FREE TRADE AREA

Benjamin Boakye
Charles Gyamfi Ofori

ACEP Africa Centre for Energy Policy

FORD FOUNDATION

THE SOLAR PV VALUE CHAIN: AN ASSESSMENT OF OPPORTUNITIES FOR AFRICA IN THE CONTEXT OF ENERGY TRANSITION AND THE AFRICAN CONTINENTAL FREE TRADE AREA

BENJAMIN BOAKYE
CHARLES GYAMFI OFORI

OCTOBER 2022

Acknowledgement

ACEP wishes to express its profound gratitude to Ford Foundation for funding this study. We are also grateful to the team, Muhibatu Seidu, Nana Ama Twum and Nathaniel Essilfie Conduah, who assisted in various ways in preparing this document. We hope this report contributes to ensuring that Africa maximises its economic benefits from the energy transition.

Table of Contents

List of tables

List of Figures

Abbreviations

ACEP	Africa Centre for Energy Policy
AfCFTA	African Continental Free Trade Area
AU	Africa Union
CO_2	Carbon Dioxide
DS	Directionally Solidified
ECOWAS	Economic Community of West African States
EIA	Energy Information Administration
EVA	Ethyl Vinyl Acetate
GW	Gigawatt
GWh	Gigawatt hour
HS Codes	Harmonised System Codes
IRENA	International Renewable Energy Agency
MFN	Most Favoured Nation
MG-Si	Metallurgical Grade Silicon
MW	Megawatt
NDCs	Nationally Determined Contributions
PV	Photovoltaic
RE	Renewable Energy
RECs	Regional Economic Communities
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
TCS	Trichlorosilane
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
WAPP	West Africa Power Pool
WTO	World Trade Organisation

Executive Summary

The emission of greenhouse gases like carbon dioxide has been observed as a primary contributor to climate change and its devastating impacts. One of the activities contributing to CO_2 and other greenhouse gas emissions is electricity/heat production, which forms about 32% of global greenhouse gas emissions. Therefore, the electricity sector's contribution to emissions makes its reduction through renewable energy technologies an essential condition.

The environmental benefits of renewable energy integration and technological improvements have increased the adoption of renewable energy technologies. As a result, the global renewable energy capacity for electricity generation has increased by over 100% between 2010 and 2020. Also, renewable energy technologies form a significant proportion of many new power expansion projects. Although comparatively low, Africa has also made efforts to implement its energy transition targets and has exponentially increased the installed capacity of renewable energy technologies in its energy mix.

The increasing market for renewable energy technologies presents opportunities for Africa to develop innovative capacities to participate in the technologies' value chain, which offers several economic benefits. However, the continent's participation is mainly at the consumption end of the value chain. Consequently, Africa imports most of its renewable energy technologies and remains a continent that has not taken advantage of the energy transition's economic opportunities. Therefore, exploring how the continent can actively participate in the value chain is relevant for Africa.

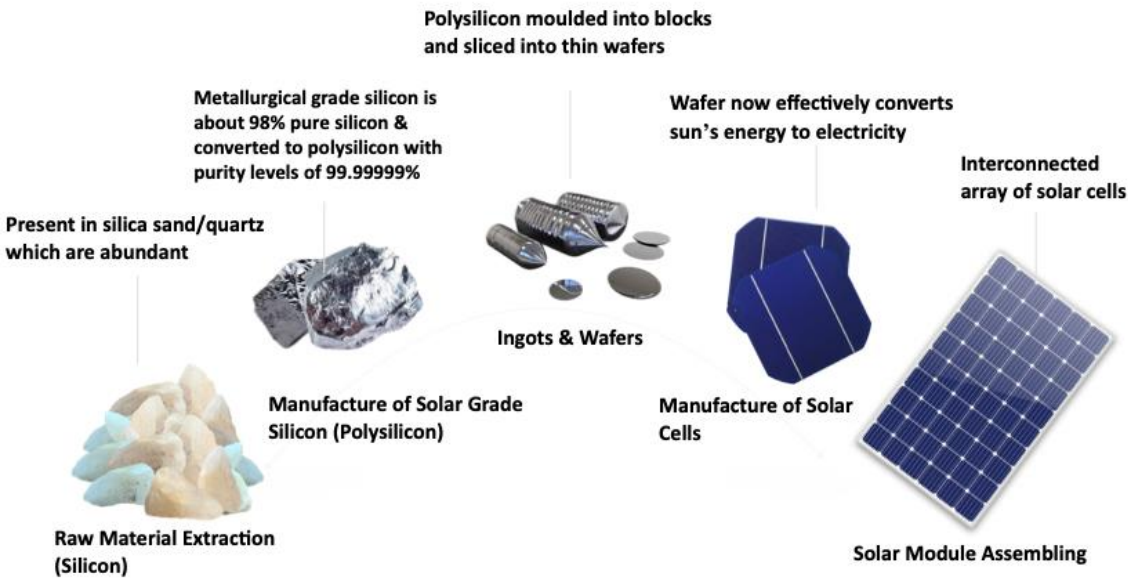
The value chain of renewable energy technologies creates opportunities for countries to build expertise and facilitate trade in inputs among states, making regional free trade agreements such as the African Continental Free Trade Area (AfCFTA) essential. Thus, AfCFTA presents opportunities for Africa to participate in the renewable energy technologies value chain through trade in inputs and outputs from each value chain segment.

This report identifies the potential for African countries to develop an integrated renewable energy industry, focusing on solar photovoltaics. It provides pathways for these countries to leverage AfCFTA towards creating a viable market for trade in renewable energy technologies with minimal trade barriers.

The results of the study are summarised below:

1. **The solar PV value chain is complex.** The value chain consists of five main segments, which range from quartz or silica extraction to the assembly of solar modules, as shown in ES 1 below;

ES 1: The solar PV value chain



2. **About 80% of the solar PV value chain segments support AfCFTA's rules of origin requirements.** Except for solar module assembly, the output under each value chain component is eligible for preferential treatment under AfCFTA to support trade in such outputs among state parties.

ES 2: Assessment of origination status along the solar PV value chain

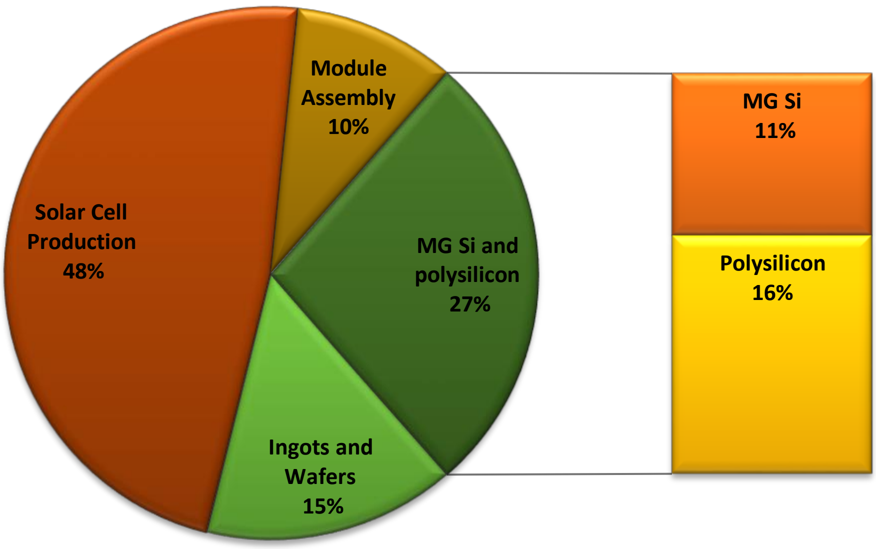
Value chain	AfCFTA Rule	Actual process	Originating status
Raw material	Wholly obtained or owned	Where quartz/silica sand can be obtained	Originating
Solar grade silicon	Change in tariff heading	Quartz (ch 25) is converted to polysilicon (ch 28)	Originating
	*Value added	Raw material cost is less than 60% of the total cost	
	Chemical processing rules	Substantial chemical processes that meet Note 8 to Appendix IV on Rules of Origin	
Silicon wafer production	Change in tariff heading	Polysilicon (C.28) changes to silicon wafers (C.38)	Originating
	*Value added	Polysilicon prices constitute about 34% of the total production cost	
	Chemical processing rules	Substantial chemical processes that meet Note 8 to Appendix IV on Rules of Origin	

Value chain	AfCFTA Rule	Actual process	Originating status
Solar cell production	*Value added	Solar wafers account for about 62% of solar cell production	Non-originating
	Change in tariff heading	Wafers (Ch 38) changes to solar cells (Ch 85.06)	Originating
Solar module assembly	*Value added	Solar cells account for about 63% of modules	Non-originating
	Change in tariff heading	Modules and solar cells have the same tariff heading	Non-originating

*Non-originating material content must not exceed 60% of the ex-ref price

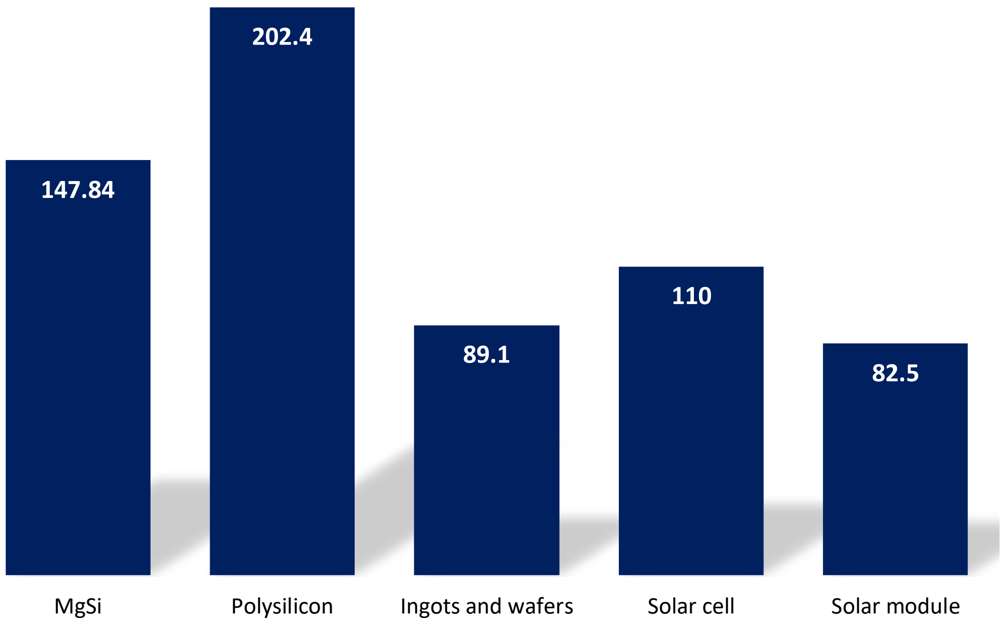
3. **The solar PV industry is capital-intensive.** Capital requirements for a fully integrated solar industry with a capacity of 1GW amount to about $900 million, with solar cell manufacturing occupying a higher proportion of the costs. Therefore, governments must create an environment that attracts both domestic and foreign investments towards solar PV development.

ES3: Cost components of the integrated solar industry (excluding quartz extraction)



4. **The solar PV industry is power intensive.** The value chain for a 1GW capacity requires estimated power consumption of about 1000GWh, of which the majority is consumed through metallurgical grade silicon and polysilicon production. Therefore, countries with cheaper and more reliable power can benefit from production efficiencies and reduced costs associated with power generation.

ES 4: Power requirements for the solar PV value chain (GWh)



5. **Bauxite, lithium, cobalt, and other minerals are critical for the industry**. These critical minerals open a bigger space for many countries with rich mineral deposits to participate in the value chain. However, this calls for improved regulatory practices within the mining sector to ensure sustainable mining.

6. **Aluminium is an essential metal for the industry.** However, primary aluminium production is both capital and power intensive. Countries can leverage cheap power, gas potential and regional power contracts to obtain affordable and reliable power to ensure aluminium production efficiency. On the other hand, aluminium has recyclable properties that make secondary production possible, thus requiring less investment. This provides opportunities to scale up aluminium production through recycling.

The study proposes the following recommendations:

1. African governments must assess the renewable energy technologies' value chain and enact policies that enable businesses and investors to partake in the various production stages of such technologies.
2. African governments and businesses must assess their core competencies within each aspect of the value chain to build a competitive advantage.

3. African governments must strengthen the regional collaboration among member states and leverage the opportunities provided by AfCFTA to boost intra-continental trade in inputs required for producing renewable energy technologies.
4. Governments must work toward providing reliable and affordable power to promote industrialisation and production efficiency. These can be achieved by leveraging gas reserves and regional power contracts like the West Africa Power Pool.
5. Governments from resource-rich countries must support and create an enabling environment for the sustainable exploration and extraction of the critical minerals necessary for the energy transition.
6. African governments must scale up research and development to drive innovation and technological improvement that support the energy transition.

Introduction

The emission of greenhouse gases such as Carbon dioxide (CO_2), Methane and Nitrous oxide have been observed as the main contributors to global warming and climate change, resulting in devastating environmental impacts. Carbon dioxide is a significant contributor, accounting for about 74% of greenhouse gas emissions. One of the main activities contributing to CO_2 and other greenhouse gas emissions is electricity/heat production, which forms about 32% of global greenhouse gas emissions.[1] Therefore, emissions reduction through energy efficiency and cleaner options for electricity production are critical to ensuring environmental sustainability.

The primary fuel sources used in power plants for electricity generation include coal, liquid fuels, and natural gas. These sources have varying levels of CO_2 emissions per every kWh of electricity generated. Coal and liquid fuels emit an average of 1.01kg/kWh and 0.97kg/kWh, respectively.[2] Comparatively, natural gas emits less CO_2 and is a transition fuel in many countries. Natural gas emits about 59% fewer emissions than coal and liquid fuels). Other cleaner power generation options have comparatively lower greenhouse gas emissions. These options, mainly renewable energy technologies (e.g., solar panels and wind turbines), are essential to reduce emissions from electricity production. For example, the emissions footprint of solar panels ranges from 25g/kWh to 32g/kWh of electricity generation, while wind technologies are about 11g/kWh[3] (see Table 1). Therefore, it is not surprising to note that many countries have committed to renewable energy generation as part of their strategies for meeting emissions reduction targets.[4]

Table 1: CO_2 emissions from the primary fuels for electricity generation

Power production source	CO2 emissions (kg) per kWh
Coal	1.01
Petroleum	0.966
Natural gas	0.412
Solar	0.025 – 0.032

Sources: US Energy Information Administration; United Nations Chronicle

Over the past decade, renewable energy integration has witnessed a significant increase. The global renewable energy capacity for electricity generation has doubled over the past decade (from **1,226 GW in 2010 to 2,799 GW in 2020**), with an approximate annual growth rate of

---

[1] 2018 Emissions data from ClimateWatch. Available at https://www.climatewatchdata.org/data-explorer/historical-emissions?historical-emissions-data-sources=cait&historical-emissions-end_year=2018&historical-emissions-gases=All%20Selected&historical-emissions-regions=All%20Selected&historical-emissions-sectors=total-including-lucf%2Ctotal-including-lucf&historical-emissions-start_year=2015&page=1

[2] US Energy Information Administration. (EIA). Available at https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

[3] United Nations Chronicle. The Promise of Solar Energy: A Low-Carbon Energy Strategy For The 21st Century. Available at https://www.un.org/en/chronicle/article/promise-solar-energy-low-carbon-energy-strategy-21st-century

[4] United Nations Framework Convention on Climate Change (UNFCCC). (2021). *Nationally Determined Contributions under the Pris Agreement. Synthesis report by the Secretariat*

about 8%. Again, renewable energy technologies have become a dominant source among new power expansion projects. In 2019, renewable energy technologies formed about **72% of all power expansion projects**.[5]

Technological improvements and reduced installed costs further aid the transition to renewable energy technologies. For example, there have been more efficient renewable energy technologies with reduced operation and maintenance costs. Again, innovations in wind turbine blades have yielded wind turbines with increased strength, reduced cost, and improved energy generation capacities.[6] The weighted average wind turbine capacity factors increased from 27% in 2010 to about 36% in 2020. The efficiency of Solar Photovoltaics (Solar PVs) has increased from 14% to 24% between 2010 and 2020.[7] Between 2010 and 2020, the average installed costs of solar PVs had reduced by about 81%, whereas onshore wind decreased by about 32%,[8] increasing the competitiveness of renewable energy technologies.

The role of Africa in the energy transition

Amid the global intervention to mitigate climate change, Africa has made great efforts to drive the global climate agenda, demonstrated by the high ratification rate of the Paris Agreement. As of September 2019, 53 out of 54 African countries had submitted their Nationally Determined Contributions (NDCs), prioritising climate adaptation measures and transitioning to cleaner energy options.[9]

African countries have shown progress in implementing energy transition targets and climate change interventions. These interventions include increasing renewable energy generation capacities, enhancing energy efficiency, and using clean cooking technologies. Statistics from the International Renewable Energy Agency (IRENA) show that installed capacities of renewable energy technologies have increased exponentially over the past decade, albeit minimal, compared to Europe and Asia. Between 2010 and 2020, the installed capacity of renewable energy technologies like solar, wind and geothermal energy increased from 2094MW to 18,880MW (See Figure 1).

[5] Renewables Account for Almost Three Quarters of New Capacity in 2019. Available at: https://www.irena.org/newsroom/pressreleases/2020/Apr/Renewables-Account-for-Almost-Three-Quarters-of-New-Capacity-in-2019

[6] Lucena, J. D. A. Y. (2021). Recent advances and technology trends of wind turbines. In *Recent Advances in Renewable Energy Technologies* (pp. 177-210). Academic Press.

[7] International Renewable Energy Agency (IRENA). (2021). Renewable Technology Innovation Indicators: Mapping progress in costs, patents and standards

[8] International Renewable Energy Agency (2021). *Renewable Power Generation Costs in 2019.* Available at: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019

[9] AMCEN. (2019). African Ministerial Conference on the Environment. Retrieved from https://bit.ly/2T2gE7r

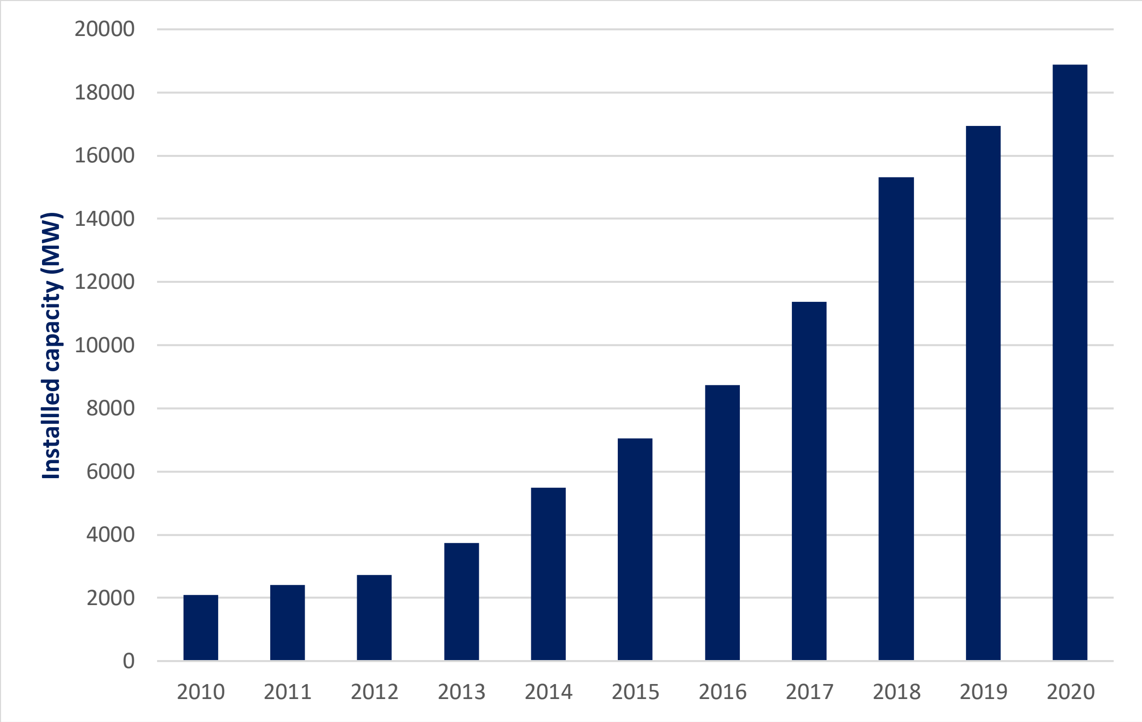


Figure 1: Cumulative installed capacity of solar, wind and geothermal energy in Africa from 2010 to 2020
Source: International Renewable Energy Agency (IRENA)

Many African countries have shown substantial progress in renewable energy integration. For example, Kenya currently relies on geothermal energy for 38% of its power.[10] Wind and solar energy contributed 16% to Morocco's energy mix in 2019. Ethiopia has also focused on energy efficiency and low-carbon transport options.[11] In addition, Ethiopia is constructing the Grand Renaissance Dam, Africa's largest hydropower plant, which has a generating capacity of about 6400MW. Egypt increased solar energy to about 3%, and South Africa generates about 6% of its electricity from wind and solar. Biomass and renewable energy projects are ongoing in Tanzania, Ghana, Mali, Benin, and Niger. [12]

There is, therefore, no doubt about a growing market for cleaner energy options in Africa. The energy transition is leading the frontiers towards a future that depends significantly on renewable energy and presents opportunities for economic benefits through innovative participation in its value chain. However, current efforts toward energy transition are more of adoption than innovation. Africa imports most of its renewable energy technologies, such as solar PVs and wind turbines. Renewable energy businesses are primarily involved in imports, sales, and services of renewable energy technologies. In addition, a few companies are engaged in the assembly of these technologies. The slow pace of innovations and development in RE technologies stems from low investment in the sector occasioned by financial constraints and the dearth of knowledge of the energy transition's economic

[10] BBC. (2021). How Kenya is harnessing the immense heat from the earth. Retrieved from https://bbc.in/3vEJAAV
[11] AMCEN. (2019). African Ministerial Conference on the Environment. Retrieved from https://bit.ly/2T2gE7r
[12] UNDP. (2018). Transforming lives through renewable energy access in Africa: UNDP's Contributions. Retrieved from https://bit.ly/3vId6Wa

opportunities to Africa. Consequently, Africa has not maximised its opportunities through active participation in the value chain of renewable energy technologies.

Africa can benefit from innovation, production, and manufacturing processes along the value chain of renewable energy technologies. This approach would enable the continent to create the supply potential to meet its energy needs. Therefore, an integrated renewable energy industry can provide an available market and foster intra-continental trade in such technologies. Creating a fully integrated renewable energy industry would be cost-intensive for a single country. However, individual countries can build competence and trade inputs and outputs relevant to manufacturing within each segment of the renewable energy value chain. For example, a country with large reserves of industrial minerals relevant to solar PVs could effectively trade with another country that can cheaply process these minerals into finished products. Therefore, a regional trade agreement like the African Continental Free Trade Area (AfCFTA) presents an opportunity for the continent to drive industrialisation through an integrated renewable energy industry.

The African Continental Free Trade Area (AfCFTA) seeks to provide a more liberalised market for trade among African Union (AU) member states. It can potentially reduce the costs of raw materials, increase production efficiency, and enhance competition. Therefore, it is essential for governments and businesses within the energy transition space to explore how the AfCFTA mechanism can facilitate trade in renewable energy technologies while ultimately developing an integrated renewable energy industry. If Africa does not expedite its involvement and participation in the renewable energy value chain, it will forgo substantial economic benefits of the energy transition.

This report identifies the potential for African countries to develop an integrated renewable energy industry, focusing on solar photovoltaics. It provides pathways for these countries to leverage AfCFTA towards creating a viable market for trade in renewable energy technologies with minimal trade barriers. The ensuing chapter discusses AfCFTA and its product origination rules. Subsequent chapters examine the solar PV value chain, how it responds to AfCFTA's rules of origin criteria, and the key cost drivers for the integrated renewable energy industry. This report does not provide a complete overview of the solar PV value chain. However, it still presents information that sets the tone for broader research and discussion into how Africa can leverage regional trade pacts and competencies of member states to build a resilient solar PV industry.

Overview of AfCFTA

At the 18th Ordinary Session of the Assembly of Heads of State and Government of the African Union (AU) in 2012, member states decided to set up a framework that establishes an action plan to boost intra-continental trade. This action plan was formulated to curtail the intra-continental trade challenges, such as tariff and non-tariff barriers to entry in many African jurisdictions. Accordingly, AfCFTA was birthed as the mechanism for the continent to realise its aspirations of creating a market that facilitates the free movement of persons, goods, and services to deepen economic integration among member states.

A thriving free trade area would enhance economic integration through trading within a liberalised market. The general objectives of AfCFTA include creating a single and liberalised market for goods and services, contributing to the free movements of people, and facilitating investments (See Box 1 for a complete list of the general objectives of AfCFTA). Specific objectives of AfCFTA include the elimination of tariff and non-tariff barriers to trade, liberalisation of trade, and cooperation among member nations on investment, property rights and other trade-related matters (See Box 2 for the list of specific objectives). In addition, the free trade area is anchored on several principles of the World Trade Organisation (WTO), including but not limited to the principle of Most Favoured Nation (MFN) and the principle of National Treatment. The MFN principle ensures that whatever preferential treatment is given to a third party, similar treatment must be offered to a state party that is an AfCFTA signatory. The National Treatment principle, on the other hand, provides similar treatment to foreign nationals or goods as that of the nation.

One of the main approaches to trade liberalisation through the AfCFTA mechanism is the removal of import duties. Accordingly, the treaty urges all parties to progressively eliminate import duties or charges that affect goods from any state party's territory. However, it excludes charges equivalent to internal taxes, antidumping and countervailing duties, and duties levied on safeguards.

Box 1: General objectives of the African Continental Free Trade Area

1. Create a single market for goods, services, facilitated by the movement of persons in order to deepen the economic integration of the African continent and in accordance with the Pan African vision of “An integrated, prosperous and peaceful Africa” enshrined in Agenda 2063;
2. Create a liberalized market for goods and services through successive rounds of negotiations;
3. Contribute to the movement of capital and natural persons and facilitate investments building on the initiatives and developments in the State Parties and RECs;
4. Lay the foundation for the establishment of a Continental Customs Union at a later stage
5. Promote and attain sustainable and inclusive socioeconomic development, gender equality and structural transformation of the State Parties;
6. Enhance the competitiveness of the economies of State Parties within the continent and the global market;
7. Promote industrial development through diversification and regional value chain development, agricultural development and food security;
8. Resolve the challenges of multiple and overlapping memberships and expedite the regional and continental integration progress

Source: Agreement establishing the African Continental Free Trade Area (AfCFTA treaty)

Box 2: Specific objectives of the African Continental Free Trade Area

1. Progressively eliminate tariffs and non-tariff barriers to trade in goods
2. Progressively liberalise trade in services
3. Cooperate on investment, intellectual property rights and competition policy
4. Cooperate on all trade-related areas
5. Cooperate on customs matters and the implementation of trade facilitation measures
6. Establish a mechanism for the settlement of disputes concerning their rights and obligations
7. Establish and maintain an institutional framework for the implementation and administration of the AfCFTA.

Source: Agreement establishing the African Continental Free Trade Area (AfCFTA treaty)

Rules of origin underlying AfCFTA

It is important to note that goods originating from a State Party (a signatory to AfCFTA) can benefit from the preferential treatment (i.e., the elimination of tariff and non-tariff barriers) AfCFTA offers. On the other hand, goods not considered to originate from a state party are not eligible for tariff elimination under AfCFTA. WTO defines rules of origin as "*the criteria needed to determine the national source of a product.*"[13] The rules of origin provide the basis for establishing whether goods are eligible for preferential treatment.

Free trade agreements identify goods as originating from a state party if they have been wholly obtained in that state party or have undergone substantial transformation in the state party. Wholly owned products must be extracted, produced, or raised within the State Party. For example, goods manufactured within a State Party can be considered originating, hence

[13] World Trade Organisation (n.d.). Technical Information on Rules of Origin. Available at https://www.wto.org/english/tratop_e/roi_e/roi_info_e.htm

eligible for preferential treatment. Agricultural produce is wholly obtained if the plants or animals are grown or raised within the state party. Also, mineral products or other natural resources extracted from the ground or seabed within the territory of the State Party are considered wholly originating.

On the other hand, products that are not wholly obtained from a State Party must undergo a substantial transformation in that State Party before they are considered as originating. This condition allows products whose raw materials are not obtained from the State Party but have undergone significant value-addition processes to obtain originating status. Box 3 illustrates the confirmation of the originating status of a product not wholly obtained from a state party.

Box 3: Confirmation of originating status to non-wholly obtained products: The aluminium value chain

Country A is a large-scale producer and exporter of aluminium. The country leverages its cheap electricity and efficient smelters to produce aluminium at a relatively cheaper cost. Country A, however, does not have reserves of bauxite, hence it imports bauxite from Country B, which it refines to alumina before smelting to aluminium. It is also a signatory to a regional trade agreement that provides an opportunity to trade in goods with other State Parties. Country A would like to benefit from preferential treatment from exporting aluminium to other State Parties who are signatories to the free trade agreement.

Country A does not qualify for preferential treatment given the definition of wholly obtained products. This is because aluminium was not wholly obtained from materials originating from country A. However, the bauxite mineral, having gone through substantial value addition and transformation in Country A, can make it eligible for preferential treatment when it exports to other State Parties. Thus, value addition helps Country A optimize its benefits from the free trade area.

Typically, rules of origin on products not wholly originating from a state party are based on three identified rules: the value-added, change in tariff heading, and specific processes. A brief description of the rules for non-wholly originating products is given below:

1. **Value-added:** The AfCFTA treaty defines value-added as the *"difference between the ex-works price and the Customs Value of the material that is imported from outside the state parties and used in the production."* The value-added rule accounts for a minimum degree of manufacturing or processing that adds value to a raw material not originating from a State Party. Usually, the rule would specify that the value a manufacturing process adds to a raw material must exceed X% of the ex-works price of the final product. It can also restrict the components of non-originating raw material to a maximum of X% of the ex-works price of the final product. The rule

implies that the process of value addition must account for a substantial portion of the total cost of production.

Illustrative example: *Glass and other glassware are made from raw materials such as sand and limestone. AfCFTA confers originating status on manufactured glass products when the value of all non-originating materials used in the glass production* ***does not exceed 60%*** *of the ex-works price of glass.*

2. **Change in tariff heading**: All products and materials are classified under different tariff headings within the Harmonised System coding framework (HS Codes). The Harmonised System is a globally standardised system of classifying traded products. The coding system identifies goods to assess product characteristics, taxes, and duties. A manufacturing or value-addition process can change the status of a raw material into a different product (e.g., the conversion of pure silicon into solar cells), resulting in a new product classification. The change in tariff heading concept specified by AfCFTA requires that all non-originating material contents that make up a product are not classified under the same tariff heading as the final product.

   Illustrative example: *Quartz is the primary raw material for the manufacture of solar PVs, which is classified under chapter 25 of the Harmonised System codes (HS codes) under "****Salts, sulphur, earths and stones."*** *On the other hand, Solar PVs are classified under chapter 85, "****Electrical machinery and equipment****." Thus, solar PV can be considered originating from a state party if it imports quartz from another country and takes the quartz material through other processes to manufacture solar PV, given the rule on change in tariff heading.*

3. **Specific processes:** Originating status can be conferred on a product if the non-originating input undergoes specific production processes, mainly chemical. Production processes like parts assembling, bottling, washing, packaging, simple ironing, and painting operations are not sufficient to confirm the origination status for a non-wholly obtained product.[14] Eligibility for origination is mainly conferred on goods whose non-originating contents have undergone specific chemical processes that result in a molecule with a new chemical structure. Other eligible chemical processes include fractionation processes, cracking, and purification processes that eliminate at least 80% of the content of existing impurities.

   Illustrative example: *The raw materials for fertiliser production are mainly natural gas, sulphur, urea, etc. Fertiliser production requires an intensive chemical process that blends the raw materials, generating a new product with a different chemical*

[14] Article 7. *Compiled annexes to the on the establishment of the continental free trade area.*

component and structure. The rules of origin under fertiliser production require that chemical production criteria are met before origin is conferred on fertilisers produced by a State Party.

The rules of origin under AfCFTA make provisions for materials considered originating and those considered non-originating. They ensure minimum value-addition standards that the product must meet within each jurisdiction. Thus, for the renewable energy industry, governments and businesses must identify whether the primary outputs and the raw materials required under each aspect of the value chain originate from a state party. AfCFTA can create an excellent opportunity for intra-continental trade of renewable energy products if investors, manufacturers, and governments understand the rules of origin requirements underlying each output within the value chain.

The Solar PV Value Chain

The solar PV value chain consists of five main phases. The first and second stages involve raw material (silica) extraction and solar-grade silicon production. The third stage converts the solar-grade silicon into ingots and wafers. Next, solar cells are produced from solar wafers. Finally, the cells are assembled into modules for power generation (see Figure 2). The subsequent sections briefly describe the solar PV value chain while indicating the primary materials used in each process.

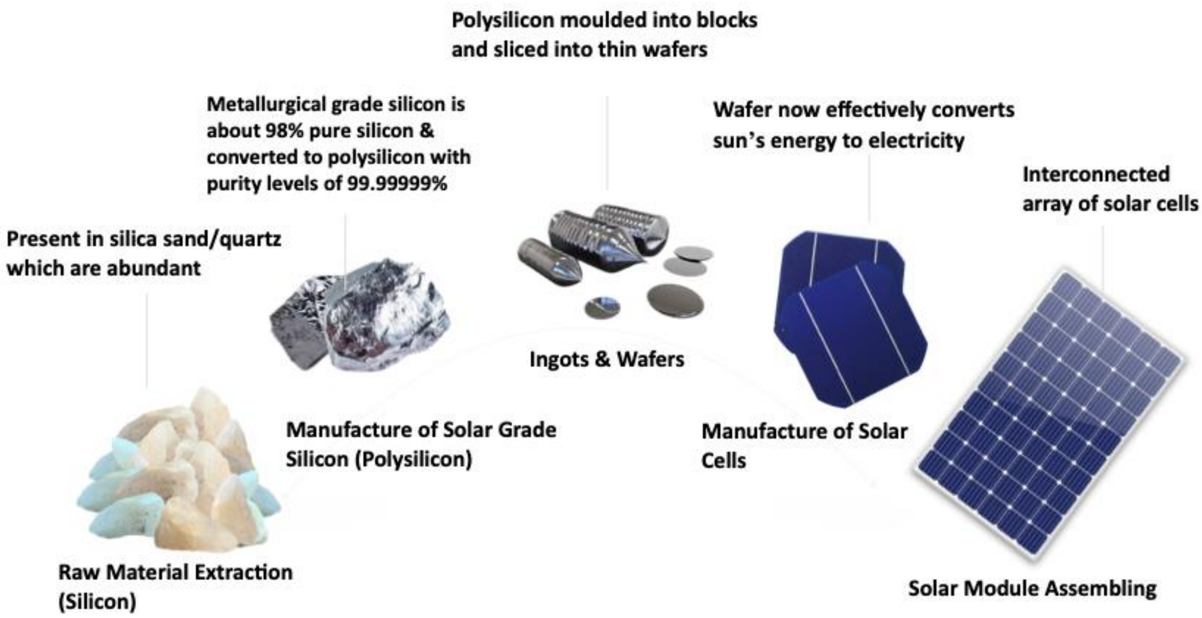


Figure 2: Outline of the solar PV value chain

Raw material extraction

Silicon is the primary raw material used for solar PV manufacturing. In addition to solar cells, silicon is used in many industrial operations, such as the manufacture of glass, abrasives, ceramics, and semiconductors. Next to oxygen, silicon is the most abundant element on the earth's crust. However, it does not occur in its pure state. Instead, silicon exists as silicon dioxide (Silica), mainly found in rock quartz, silica sand (white sand or quartz sand), or silicate material like tridymite and cristobalite.[15]

Quartz is found in many igneous, sedimentary, and metamorphic rocks, which exist in various forms with different levels of silica content. Solar cell manufacturing requires a quartz

[15] Satpathy, R. K., & Pamuru, V. (2020). *Solar PV Power: Design, Manufacturing and Applications from Sand to Systems*. Academic Press.

material with a high silica concentration. The quartz material for manufacturing solar cells must contain about 98-99% silicate.[16] Next to feldspar, quartz is the second most abundant naturally occurring mineral. However, unlike precious minerals such as gold, diamond and bauxite, there is scant information on its actual reserves.

The information from US Geological Survey (USGS) indicates that global production of quartz sands or industrial sand and gravel, having various levels of silica, averaged about 260 million metric tonnes between 2016 and 2020. In 2020, industrial sand and gravel production amounted to about 235 million tonnes. The top-producing countries include the United States, Netherlands, Spain, Italy, and India. South Africa was the only African country represented in the top 20 producing countries, with a total production of about 2.3 million tonnes as of 2020.[17] Figure 3 illustrates the leading producers of quartz sand for 2020.

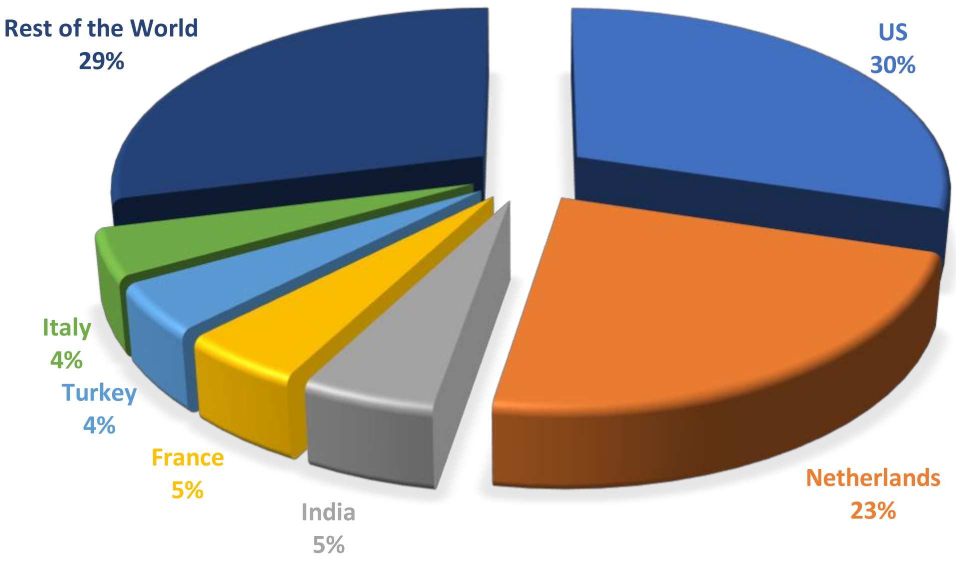


Figure 3: Top producers of industrial sand and gravel for 2020
Source: US Geological Survey

[16] Satpathy, R. K., & Pamuru, V. (2020). *Solar PV Power: Design, Manufacturing and Applications from Sand to Systems*. Academic Press.
[17] US Geological Survey. *Minerals Yearbook – Metals and Minerals (2020).* Data available at https://www.usgs.gov/centers/national-minerals-information-center/silica-statistics-and-information

Manufacture of Solar Grade Silicon

The first step in value addition towards producing solar-grade silicon material involves a reduction process where oxygen is removed from silicon oxide. This reduction process is termed a *carbothermic process.* The name suggests that the process requires carbon and heat. Silica is reacted with a carbon source (e.g., coal, woodchips) under extremely high temperatures of about 1500-2000°C in an electrode arc furnace. The carbon material reacts with silicon oxide to produce molten silicon and carbon dioxide during this chemical process. The resulting liquid silicon is *Metallurgical Silicon* (MG-Si) which has a purity level of about 98% and is used extensively in the metallurgical industry. The molten MG-Si is drained, solidified, and crushed into pieces. In its current state, MG-Si contains impurities such as boron, aluminium, and carbon, which must be removed to obtain solar-grade silicon.

Solar-grade silicon or polysilicon requires high purity levels of at least 99.9999% silicon (also known as 6N). The trichlorosilane (TCS) process is the most used process for Polysilicon production. Trichlorosilane is the primary feedstock for polysilicon and undergoes a distillation process to obtain higher purity levels of silicon. The process involves the reaction of anhydrous Hydrogen Chloride with MG-Si, which produces TCS. A technique known as chemical vapour deposition decomposes TCS into silicon atoms at high temperatures and pressure. The result is pure silicon which is solidified and broken into smaller pieces.

Between 2016 and 2020, the annual production of silicon metals with purity levels above 99.99% averaged about 2.9 million metric tonnes. Major producers of silicon metals include China, Brazil, Norway, France, and Russia. Over the same period, China has been the major producer of silicon metal, producing over 2.2 million tonnes annually. In 2020, China's production accounted for about 77% of the global output. Brazil, Norway, and France produced about 484,000 metric tonnes, accounting for 15% of the global production (see Figure 4). South Africa is the only African country with significant production volumes of silicon metals. Between 2016 and 2019, South Africa produced an annual average of about 29,000 metric tonnes. The country's highest production of silicon metals occurred in 2018 when it had about 51,000 metric tonnes. There are no records of production from South Africa in 2020.[18]

[18] US Geological Survey. *Minerals Yearbook – Metals and Minerals (2020).* Data available at https://www.usgs.gov/centers/national-minerals-information-center/silicon-statistics-and-information

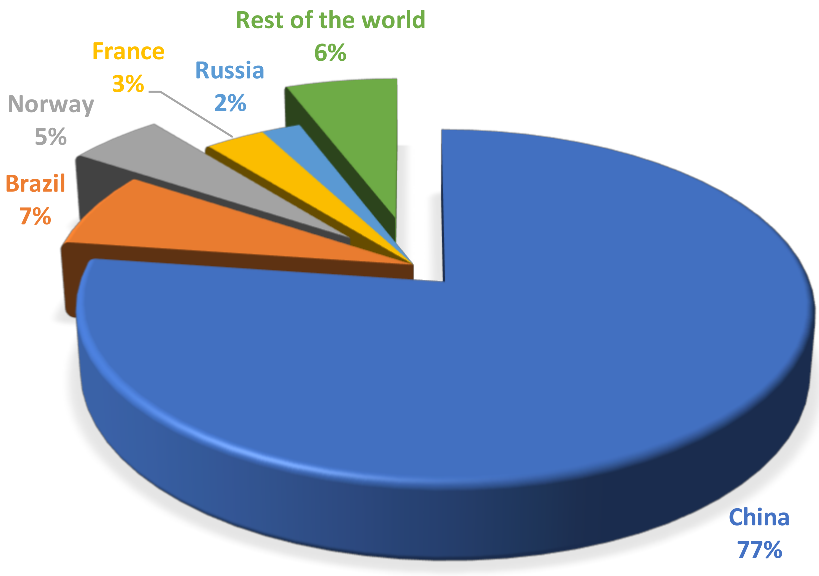


Figure 4: Top producers of silicon metal for 2020
Source: US Geological Survey

Ingots and wafer production

Solar wafers are discs of semiconductor material that form the building blocks for the assembly of solar modules. The first step in wafer production is the conversion of chunks of polysilicon material into ingots. There are two methods of converting raw polysilicon feedstock into ingots: the Czochralski (Cz) process and the Directionally Solidified (DS) method. The Cz process results in a monocrystalline solar wafer since it is produced from a single silicon crystal. On the other hand, the DS process results in a multi-crystalline silicon wafer mainly made from multiple silicon crystals. Generally, monocrystalline solar wafers have higher efficiencies than multi-crystalline wafers because single crystals typically have higher crystalline purity.

Under the Cz process, chunks of polysilicon material are loaded into a Cz crucible and melted at high temperatures, after which boron is introduced to create the required electric charge. Next, a seed crystal, a piece of saturated single crystal material, is dropped into the molten silicon in the crucible. Finally, the seed crystal is pulled out of the molten material, which results in a cylindrical shaped ingot with a mass between 150-200kg. The production of ingots under the Cz process is illustrated in Figure 5.

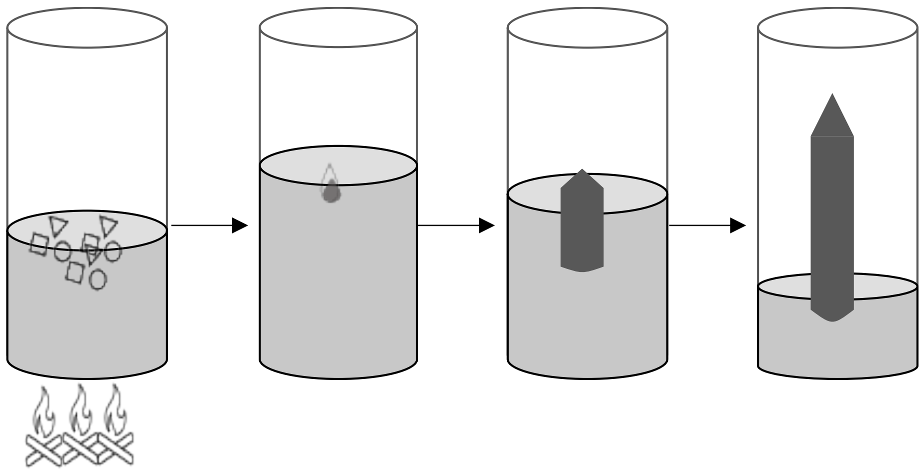


Figure 5: Silicon ingot production using the Cz process

The extreme ends of the ingot are cropped off to remove impurities. Further, ingots undergo a "squaring process", which trims the cylindrical-shaped ingots into pseudo-squared ingots to enhance cell packing density. Next, the ingots are sliced into thin pseudo-squared wafers with a maximum thickness of 180μm. Finally, the wafer is cleaned to clear any debris generated from previous chemical processes.[19]

Multicrystalline wafer production under the DS process results in a cube-shaped ingot sawed into wafers with a thickness of about 150μm. First, the polysilicon material is placed in a cubed-shaped quartz crucible, after which a vial of boron is added. Next, the material is heated in a furnace at its melting point. The molten polysilicon material is solidified and cooled. After cooling, the ingot is removed from the crucible and cropped to remove all scrap material. The finished ingot material is sawed into tiny bricks and polished, after which the wafers are produced through additional sawing.

Solar ingots and wafer-producing companies are mainly available in China. Other major companies are found in the USA, Taiwan, Japan, and South Korea. ENF Solar[20] has a directory of about 91 solar wafer-producing companies, out of which 50 are in China. However, the database does not provide information about African solar wafer-producing companies, suggesting that Africa has a low profile for manufacturing solar wafers.

[19] Woodhouse, M. A., Smith, B., Ramdas, A., & Margolis, R. M. (2019). *Crystalline silicon photovoltaic module manufacturing costs and sustainable pricing: 1H 2018 Benchmark and Cost Reduction Road Map* (No. NREL/TP-6A20-72134). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[20] ENF Solar is a directory that profiles major companies within the solar PV value chain.

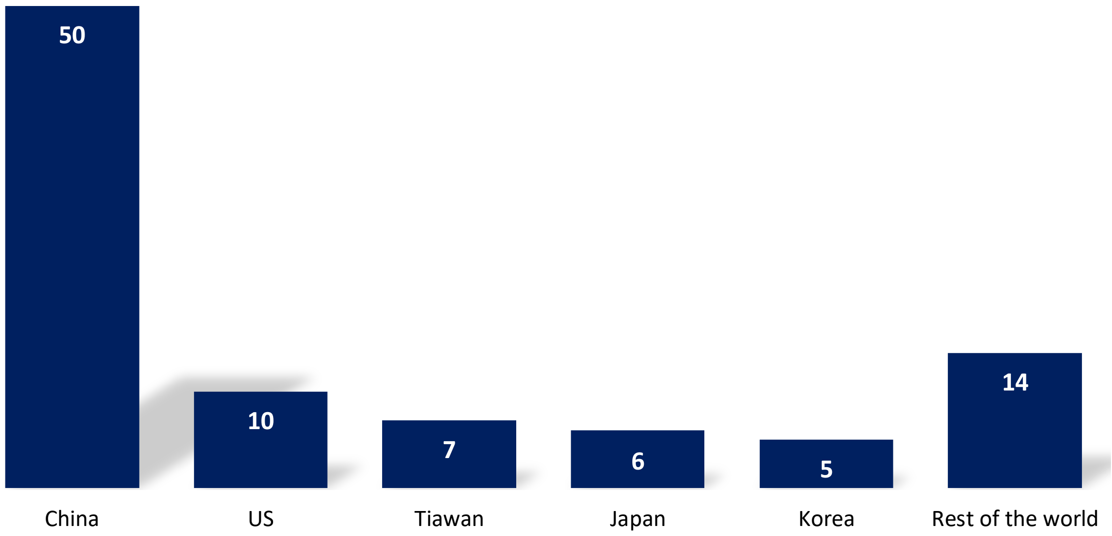


Figure 6: Countries with solar wafer manufacturing companies
Source: ENF Solar database

Manufacture of solar cells

Another critical aspect of the solar PV value chain is the conversion of the semiconductor wafers into solar cells, which convert the sun's energy into electricity. The first step in solar cell production involves an assessment of the quality of the wafer based on its thickness, size, concentration, and distribution of dopants. Next, the wafer is loaded into a wafer handling machine and inspected thoroughly for cracks and edge chips which can hamper electric conductivity. The sawing process that slices silicon ingots into wafers leaves a damaged crystal lattice that must be removed; else, it could affect the solar cell's performance. The wafer is then texturised to reduce its reflectance, promoting an effective penetration of photons into the solar cell.

In the manufacture of solar wafers, the texturised wafer is doped with boron to create a positively charged (p-type) semiconductor. During the solar cell manufacturing process, the wafer is doped with phosphorus which gives a corresponding negatively charged (n-type) semiconductor, creating a positive-negative (p-n) junction to support an even flow of electrical energy. After diffusing the dopant, a layer is formed on the cell's surface, a chemical combination of phosphorus and silicate. This phosphosilicate is etched from the cell's surface as it affects the efficiency of the solar cell.

Screen printing is another important crystalline silicon solar cell production stage. Screen printing creates fine circuit lines on the front and back sides of the wafer to increase electric conductivity and efficiency.[21] After the screen-printing process, the solar cell can effectively convert solar energy to electrical energy. The ENF Solar database has a directory of about 240 solar cell manufacturers, of which about 60% are in China. About 23% of the manufacturers are in India, Taiwan and USA. According to the directory, Egypt is the only African Country reported to host a solar cell manufacturing company.

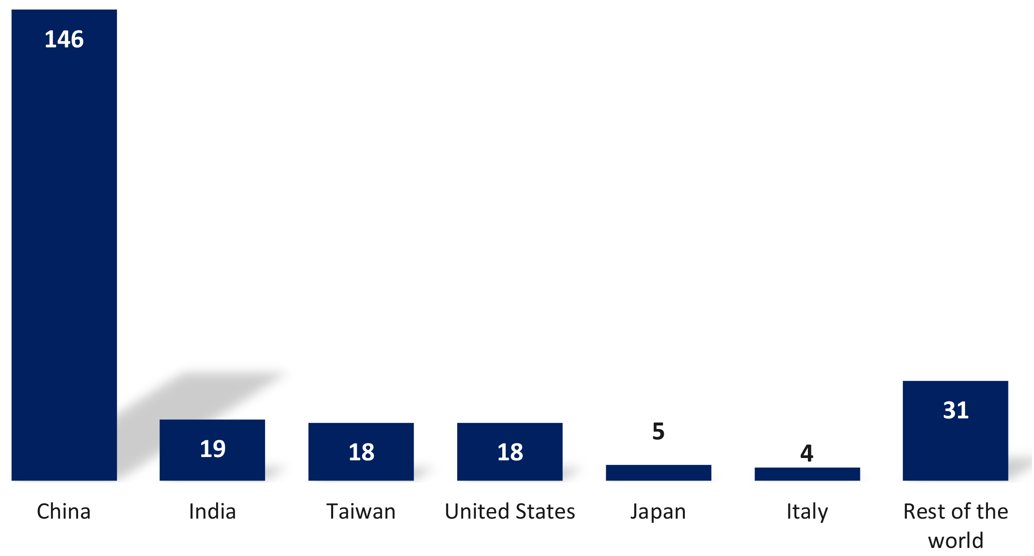


Figure 7: Countries with solar cell manufacturing companies
Source: ENF Solar database

Solar module manufacturing

Solar modules are an interconnected array of solar cells that generate the required power output for solar PVs. Solar cells are stringed with a metallic ribbon, and the front and back sides of the cells are laminated with an encapsulant. While the metallic ribbon ensures the flow of electricity through the solar cells, the encapsulant provides adhesion between the solar cells and the front and back sides of the solar panel. Qualities of encapsulants include high transparency, low shrinkage, good adhesion, and moisture resistance. Ethyl Vinyl Acetate (EVA) is widely used for encapsulating solar cells.[22]

The surface of the solar module requires a high transmission rate and a low rate of reflection. Anti-reflectance coating provides a good alternative for reducing reflection rates but is not strong enough to withstand harsh physical conditions. Tempered glass coatings with low iron

[21] Applied Materials (2011). Screen printing for crystalline silicon solar cells. Available at https://www.appliedmaterials.com/files/Screen_Printing_Backgrounder_0.pdf

[22] Satpathy, R. K., & Pamuru, V. (2020). *Solar PV Power: Design, Manufacturing and Applications from Sand to Systems*. Academic Press.

content are robust, water-resistant, and highly transparent. They also have good self-cleaning properties to reduce the dust and dirt on the module, reducing transmission rates.

The rear surface of the solar module is protected with an insulation material known as a *backsheet*. The backsheet protects the base of the PV module and prevents the entry of water or vapour. In addition, it must be UV resistant to protect the solar cells from UV rays. A junction box is placed on the backsheet to accommodate connectors from the metallic ribbons. Lastly, a frame is placed around the perimeter of the solar module to hold it firmly. Aluminium oxide alloys are primarily used in framing the modules. The material has good mechanical and thermal properties, can withstand extreme physical conditions, and has low corrosive properties. The modules are packaged and shipped for consumption.

The ENF Solar directory has about 1344 monocrystalline solar module manufacturers, of which about 45% are found in China, followed by India, which hosts about 14% of the manufacturing companies. Other notable countries for solar module manufacturing include the USA (5.5%), Germany (5.2%) and Italy (2.7%). Again, China dominates in the manufacture of multi-crystalline solar modules. About 574 (44.3%) companies out of 1293 multi-crystalline manufacturing companies are located in China. India follows with about 241 companies, while Germany and USA respectively have 55 and 53 companies, according to the ENF registry.

The ENF solar directory also indicates that about 20 solar module-producing companies in Africa produce either monocrystalline or multi-crystalline solar modules. For example, Egypt has five solar module manufacturing companies, of which four produce multi-crystalline and monocrystalline solar modules. Nigeria and South Africa each have four manufacturing companies, of which three produce mono and multi-crystalline modules. Other African countries that host module manufacturing companies include Ghana, Algeria and Tunisia.

Table 2: Solar module manufacturing companies in Africa

Country	Type of solar module (Mono or multi-crystalline)			Total
	Mono	Multi	Both	
Algeria	-	1	-	1
Egypt	1	-	4	5
Ghana	-	2	-	2
Morocco	-	-	2	2
Nigeria	1	-	3	4
South Africa	-	1	3	4
Tunisia	-	-	2	2

Source: ENF Solar database

The solar PV value chain and the rules of origin requirements under AfCFTA

In an ideal situation, a country maximises its gains through AfCFTA when fully integrated along the solar PV value chain. However, considering the high capital requirements and other cost components, governments can strategise and invest in aspects of the value chain that resonate with their core competencies to increase their gains from AfCFTA. Therefore, this assessment will determine how each country with competence in the PV value chain component can benefit from preferential treatment under AfCFTA. For illustration, we consider five hypothetical countries: These countries are State Parties (or signatories to AfCFTA) interconnected through a solar PV supply chain network (See Box 4 for a description of the countries).

Apart from quartz and other silicates, the other aspects of the PV value chain are chemical processes whose materials are not necessarily wholly obtained within the country the outputs are manufactured. Therefore, the origination status for these products will be determined by the value-added, change in tariff heading or the specific processes criteria. Appendix IV of the AfCFTA annexes provides rules under which originating status is given to products whose materials are not wholly obtained from the state party.

Box 4: Profile of hypothetical countries in the solar PV value chain

1. **Country A** has deposits of quartz and other raw materials that are rich in silicates and ideal for the manufacture of solar PVs.
2. **Country B** receives quartz material from Country A and processes them into metallurgical silicon and polysilicon.
3. **Country C** imports polysilicon from Country B to produce silicon ingots and wafers.
4. **Country D** imports solar ingots from Country C and converts them into solar cells.
5. **Country E** has a plant that assembles solar cells into solar modules and sells the end-product to consumers within Africa.

Minerals extraction

Under Article 5 of the rules of origin for AfCFTA, "*mineral products and other wholly natural resources extracted from the ground, sea bed, below sea bed and in the Territory of a State Party…*" are considered as wholly obtained in a State Party when exported to another State Party. Quartz material and other silicates are mineral products wholly obtained from the ground. Thus, any State Party capable of producing and exporting quartz and other silicates is eligible for preferential treatment under AfCFTA. Hence Country A enjoys the benefits of removing trade, tariff, and non-tariff barriers when it exports quartz and other silicates to Country B or any other State Party.

Polysilicon production

Polysilicon material falls under Sub Heading 04 in Chapter 28 of the HS coding system (*Inorganic chemicals; organic and inorganic compounds of precious metals; rare earth metals, radio-active elements and isotopes*). According to AfCFTA's rule of origin criteria, products under Chapter 28 shall be considered originating if they meet the value-added, specific processes or change in tariff heading standards. For example, under value-added, the rule states that the value of non-originating materials used in polysilicon production **must not exceed 60% of the ex-works price of polysilicon**. Typically, power, labour, and depreciation costs account for a more significant proportion of polysilicon production costs. Hence the likelihood of having raw material costs exceeding 60% of the total costs for polysilicon production is low.

Again, quartz material is subjected to an intense chemical reaction to generate polysilicon. Polysilicon production is a purification process that eliminates impurities such as oxygen, aluminium, boron etc., from silicates and MG-Si. Thus, even when polysilicon production does not meet the value-added criterion, the purification process provides a substantial basis for originating status under AfCFTA.

Lastly, there is a tariff heading change after quartz conversion to polysilicon. Whereas quartz is under Chapter 25 (*Salt; sulphur; earths, stone; plastering materials, lime and cement*), polysilicon falls under Chapter 28 of the HS codes. Thus, quartz is completely transformed during this conversion process. Country B, therefore, meets the requirement for consideration of preferential treatment under AfCFTA when it exports polysilicon to Country C or any other State Party. Therefore, countries with the potential to produce solar-grade silicon do not necessarily need silica or quartz reserves to benefit from preferential treatment under AfCFTA.

Production of silicon wafers

Silicon wafers are produced from silicon ingots whose raw material is polysilicon. They are classified under chapter 38 of the HS coding system (miscellaneous chemical products). Like polysilicon, wafers are also considered originating if they satisfy the value-added, change in tariff or the specific processes rules.

AfCFTA's rule on value-added indicates that originating status is granted to products specified under Chapter 38 of the HS coding system if **non-originating material content does not exceed 60% of the ex-works price of polysilicon.** Generally, polysilicon and other materials necessary to produce silicon wafers constitute about 34% of the total cost of wafers.[23] Thus, silicon wafers meet the value-added criteria for preferential treatment.

Additionally, there is a change in tariff heading. Polysilicon, classified under Chapter 28, is converted to wafers, classified under Chapter 38 of the HS coding system. Lastly, the manufacture of wafers involves a substantial chemical process enough to grant an originating status. Thus, Country C can export solar wafers to Country D or any other state party and benefit from preferential treatment under AfCFTA.

Production of solar cells

Solar cells are manufactured from solar wafers and are classified under Chapter 85 of the HS coding system (*Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles*). For the products specified under Chapter 85, AfCFTA rules apply either the value-added or change in tariff heading criterion.

Under the value-added criterion, the rule specifies that the manufacture of solar cells should have **non-originating raw materials whose value does not exceed 60% of the ex-works price** of the final solar cell product. Generally, solar wafers account for about 62% of the total cost of producing solar cells, which does not justify origination status.[24] However, the conversion from silicon wafers to solar cells shifts the tariff heading from Chapter 38 to Chapter 85. This change in tariff heading provides a basis for solar cell production from non-originating silicon wafers to be considered as originating. Thus, Country D can benefit from preferential treatment when exporting solar wafers to Country E or other state parties.

Assembly of solar modules

Solar modules fall under the same tariff heading as solar cells and thus would require value-added or the change in tariff heading criterion to be considered originating. Generally, solar cells account for about 63% of the cost of solar module production, which means that the assembly of solar PV modules from non-originating solar cells would not qualify for preferential treatment under AfCFTA. Again, solar module manufacturing from non-originating solar cells would not benefit from preferential treatment under AfCFTA since they fall under the same tariff heading. Further, solar module assembly has a minimal chemical process that does not qualify for preferential treatment even if specific processes were required under chapter 85 of the HS coding system. Thus, although Country E would be the

[23]Woodhouse, M. A., Smith, B., Ramdas, A., & Margolis, R. M. (2019). *Crystalline silicon photovoltaic module manufacturing costs and sustainable pricing: 1H 2018 Benchmark and Cost Reduction Road Map* (No. NREL/TP-6A20-

[24] Woodhouse, M. A., Smith, B., Ramdas, A., & Margolis, R. M. (2019). *Crystalline silicon photovoltaic module manufacturing costs and sustainable pricing: 1H 2018 Benchmark and Cost Reduction Road Map* (No. NREL/TP-6A20-72134). National Renewable Energy Lab. (NREL), Golden, CO (United States).

last link to the end-user, solar PV exports from Country E to any state party would not be considered for preferential treatment under AfCFTA.

An examination of the solar PV value chain shows that many African manufacturers participate at the module manufacturing end of the solar PV value chain. Unfortunately, these manufacturers cannot benefit from preferential treatment under AfCFTA if they assemble modules from non-originating solar cells. Therefore, countries with solar module assembly plants could begin to consider adding the process of manufacturing solar cells, which provides enough justification for preferential treatment under AfCFTA. Table 3 summarises the rules of origin requirements for each solar PV value chain segment under AfCFTA.

Table 3: Assessment of origination status along the solar PV value chain

Value chain	AfCFTA Rule	Actual process	Originating status
Raw material	Wholly obtained or owned	Where quartz/silica sand can be obtained	Originating
Solar grade silicon	Change in tariff heading	Quartz (ch 25) changes to Polysilicon (ch 28)	Originating
	*Value added	Raw material cost is less than 60% of the ex-ref price of polysilicon	
	Chemical processing rules	Substantial chemical processes that meet Note 8 to Appendix IV on Rules of Origin	
Silicon wafer production	Change in tariff heading	Polysilicon (ch 28) changes to silicon wafers (ch 38)	Originating
	Value added	Polysilicon prices constitute about 34% of the ex-ref price of wafers	
	Chemical processing rules	Substantial chemical processes that meet Note 8 to Appendix IV on Rules of Origin	
Solar cell production	Value added	Solar wafers account for about 62% of solar cell production	Non-originating
	Change in tariff heading	Wafers (ch 38) changes to solar cells (ch 85.06)	Originating
Solar module assembly	Value added	Solar cells account for about 63% of modules	Non-originating
	Change in tariff heading	Modules and solar cells have the same tariff heading	Non-originating

*Non-originating material content must not exceed 60% of the ex-ref price

Key cost drivers for the solar PV value chain

Typically, a 60-cell solar module has a capacity between 250 and 300 Watts, which implies that a 1GW solar PV capacity requires a module factory with a capacity of about 3.3 million to 4 million modules. Therefore, about 200 million to 240 million solar wafers would be required to produce the needed modules. A tonne of polysilicon material would produce an average of about 63,000 wafers. Also, 1 tonne of polysilicon needs about 3 tonnes of Mg-Si, and a tonne of MG-Si requires about 3.5 tonnes of quartz. Thus, for a 1GW solar PV capacity, about 36,000 to 45,000 tonnes of quartz material are needed. In addition, the quartz material must undergo various production processes, as outlined in the previous sections.

The preceding sections have underscored the relevance of leveraging AfCFTA to promote intra-continental trade in solar PVs. However, evaluating the main cost drivers for an integrated solar PV industry is also essential. Knowledge of such cost drivers helps investors to identify strategies to reduce costs and improve efficiency and productivity in the manufacturing process. This section outlines the main cost drivers for the PV value chain. The focus will be on the cost drivers that enable the creation of a 1GW solar PV module capacity.

Capital expenditure

The solar PV industry is capital-intensive. While average capital costs would differ based on location, there is a consensus on its colossal capital requirement. The capital costs under each value chain also vary based on the extent of operations and the kind of infrastructure required. This analysis does not provide granular detail on the capital build-up for the industry; however, it indicates what investors must consider when considering an integrated solar PV industry in Africa.

The capital required for an integrated solar PV industry with a capacity of 1GW is approximately $900 million. The actual investment depends mainly on location and the cost of raising capital. The manufacture of solar cells has the highest capital cost, forming about 48% of the total cost of the integrated solar industry, followed by the cost for MG-Si and polysilicon production, which comprise about 27% of the total cost. MG-Si forms about 11% of the cost components of polysilicon, while polysilicon forms 16%. Ingots and wafers production comprises about 15% of the total costs. Solar module assembly requires the least capital expenditure, constituting about 10% of the total cost for an integrated solar PV industry (See Figure 8).

The least cost-intensive component for solar module assembly likely explains why solar PV manufacturing companies in Africa operate within this area. However, the assessment of opportunities under AfCFTA shows that solar module assembly may not qualify for preferential treatment. While it is right to acknowledge the enormity of capital required for the industry, it is also essential for Africa to realise the need to create the necessary environment that encourages investments and allows for renewable energy businesses to thrive.

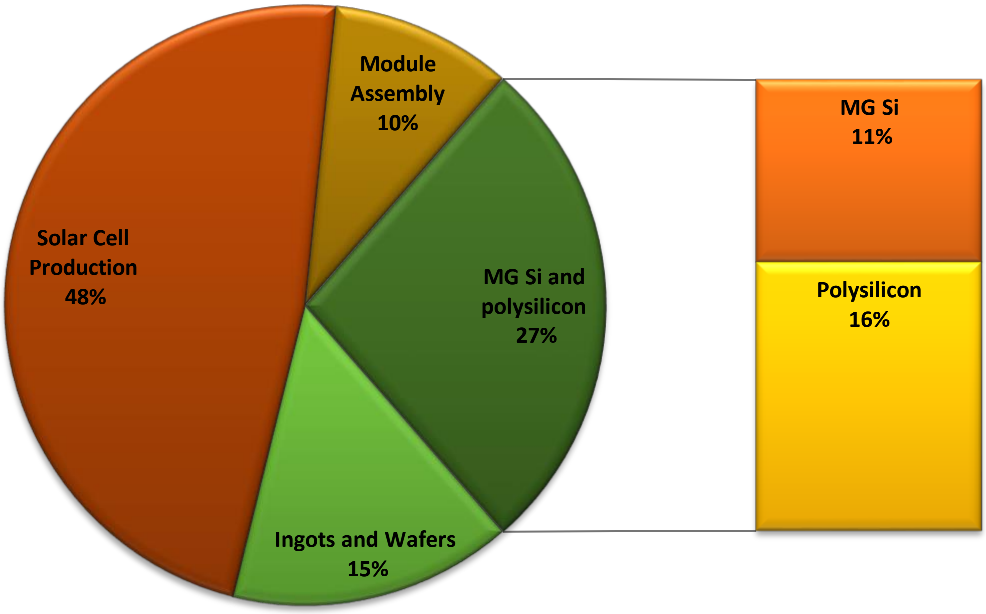


Figure 8: Cost components of the integrated solar industry (excluding quartz extraction)

Table 4: Capital costs of the integrated solar industry (excluding quartz extraction)

Value chain	Price range	Unit	Capex type	Average unit cost	Total for 1 GW plant
MG-Silicon	$8-$9	kg	Equipment and facility	$8.5	$89.7m
Polysilicon	$30-$45	kg	Equipment and facility	$37.5	$132m
Ingots and Wafers	$0.07 - $0.1	Watt Capacity	Equipment	$0.09	$85m
	$0.02 - $0.06	Watt Capacity	Facility	$0.04	$40m
Solar Cell	$0.03-$0.05	Watt Capacity	Equipment	$0.04	$40m
	$0.03-0.06	Watt Capacity	Facility	$0.05	$45m
Solar Module	$0.03-$0.05	Watt Capacity	Equipment	$0.04	$40m
	$0.04	Watt Capacity	Facility	$0.04	$40m

Power

The value chain comprises various thermal and chemical processes which are power intensive. The value chain segment comprising MG-Si and Polysilicon production is the most power-intensive process. A 1GW solar PV module requires about 352GWh of power for MG-Si and polysilicon production. Of this value, MG-Si requires approximately 150GWh and polysilicon requires about 202GWh of power. Solar cell production requires about 110GWh, while the production of ingots and wafers requires about 89GWh of power. Solar modules require the least amount of power, approximately 82GWh (See Figure 9).

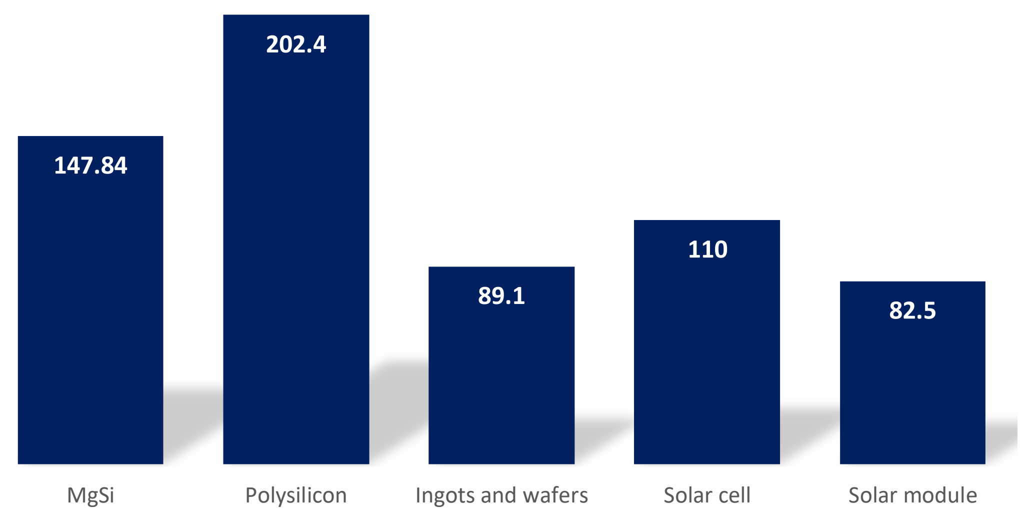


Figure 9: Power requirements for a 1GW capacity solar PV value chain (GWh)

The power-intensive nature of the industry requires an environment with significantly lower power costs. The average costs of electricity differ among countries within Africa with wide variations. World Bank's statistics indicate that as of 2019, electricity prices in Africa ranged between 2.1 US cents per kWh and 39 US cents per kWh.[25] Countries like Algeria, Ethiopia, Angola and Zambia had lower electricity tariffs, less than 5 US cents per kWh.

Tunisia, Congo Brazzaville, and Mozambique also had average tariffs ranging between 5 to 10 cents per kWh. Other countries such as the Democratic Republic of Congo, Central African Republic and Nigeria had tariffs ranging between 10 to 15 cents per kWh. These tariffs were below the 2019 global median tariff of about 15 cents per kWh. Generally, these countries with relatively cheaper electricity tariffs have the chance to reduce their costs of production along the value chain.

Countries such as Namibia, South Africa and Botswana had tariff ranges above the global median. These tariff ranges were between 15 to 20 cents per kWh and would contribute to increased production costs along the value chain. Therefore, subsidies may be required to stabilise the production costs within the industry, which must be justified by the economic potential of the production along the value chain.

Other countries with tariffs between 20 and 30 cents include The Gambia, Guinea, Kenya, Eritrea, Ghana, and Cape Verde. These countries had relatively higher tariffs, which would consequently impact production costs. For example, high power costs have been one of the main reasons businesses opt for self-generation options in Ghana, a situation that the

[25] The subsequent analysis on power is subject to the tariff information obtained from the World Bank's Doing Business Database (DB16-20 Methodology). These tariffs are subject to change in 2022 and beyond, considering local currency exchange rate movements and other power generation costs.

country's electricity regulatory body, the Energy Commission, has periodically lamented. Table 3 provides the list of electricity tariffs of African countries.

Table 5: Average price of electricity for African countries in 2019

Electricity price range (Cents/kWh)	Number of African countries	Names of African countries
less than 5 cents	5	**Algeria**, Sudan, Ethiopia, Angola, Zambia
5-10 cents	4	**Tunisia**, Congo Brazzaville, Mozambique, **Egypt**
10 cents - 15 cents	12	D.R. Congo, Central African Republic, **Nigeria**, Madagascar, **Morocco**, Zimbabwe, Ivory Coast, Libya, Tanzania, Rwanda, Lesotho, Mali
15 cents to 20 cents	15	Namibia, **South Africa**, Botswana, Swaziland, Uganda, Cameroon, Malawi, Burundi, Eq. Guinea, Mauritania, Togo, Sierra Leone, Senegal, Sao Tome & Principe, Gabon
20 cents - 30 cents	15	Gambia, Guinea, Mauritius, Benin, Chad, Niger, Kenya, Eritrea, South Sudan, **Ghana**, Burkina Faso, Djibouti, Cape Verde, Guinea-Bissau, Comoros
More than 30 cents	2	Seychelles, Liberia

Source: World Bank Doing Business Archive[26]

A review of the electricity costs per kWh for some countries integrated along the value chain shows that some African countries can favourably compete on cheaper power. For example, China is fully integrated along the value chain and had an average power cost of about 12.8 cents per kWh in 2019. On the other hand, other countries that participate along the value chain, such as the USA, Italy, Japan, and Germany, had relatively higher power costs ranging between 16 cents and 25 cents per kwh. African countries with solar module manufacturing companies (Tunisia, Egypt, Nigeria, Morocco, South Africa and Ghana) had power costs ranging between 2 and 23 cents. Algeria, Tunisia and Egypt, which had power cost less than 10 cents per kWh, could compete favourably on power with producing countries in Europe, Asia and America (see Figure 10)

[26] Tariff data is available at https://govdata360.worldbank.org/indicators/h6779690b?country=DZA&indicator=42573&countries=GHA,NGA&viz=line_chart&years=2014,2019

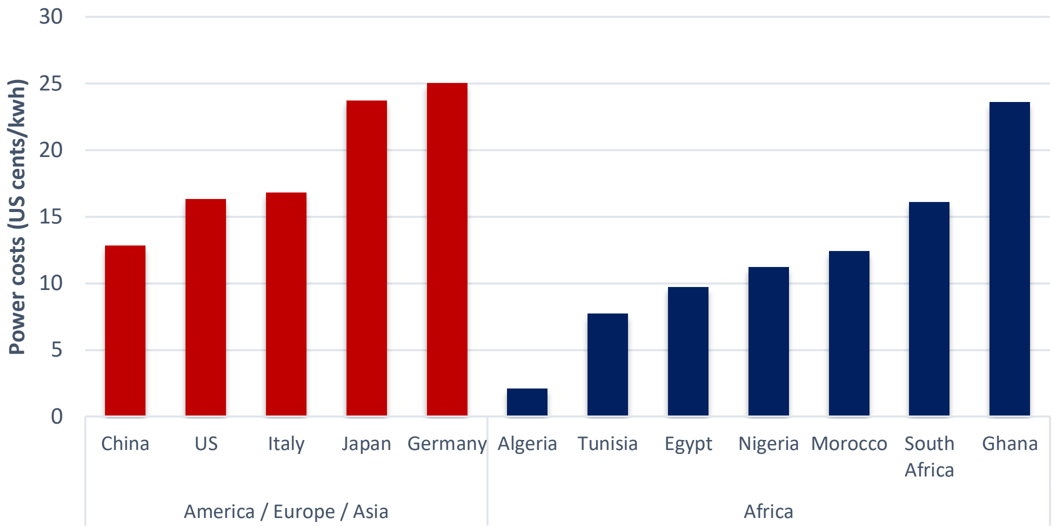


Figure 10: Comparative power costs among participating countries in the PV value chain
Source: World Bank Doing Business Archive

The solar PV industry comprises many industrial processes and requires a reliable power supply. Industries that operate with unreliable power supply, irrespective of the cost, would incur additional costs to improve reliability. Power reliability can be measured using the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI). SAIDI and SAIFI, respectively, measure the average duration and frequency of power interruptions for customers at a particular time. Highly reliable power systems are characterised by lower SAIDI and SAIFI values.

Figures 11 and 12 present reliability indices for selected countries operating within the solar PV value chain for 2019.[27] Generally, Africa had higher SAIDI and SAIFI values than other countries. For example, Nigeria, Ghana, and South Africa recorded the highest SAIDI and SAIFI scores, showing more frequent power interruptions that relatively last for a more extended period. However, Morocco, Tunisia and Egypt have comparatively lower SAIDI and SAIFI values which are competitive with some countries from Europe, America and Asia. The cheaper and more reliable power sectors in these countries provide avenues to create industrial capacity to manufacture solar PV components at an appreciable level of energy efficiency.

The unreliability of power offsets the competitive advantage that could be obtained from cheaper power. Therefore, African governments and companies operating within the supply chain must ensure reliable power sources to boost competitiveness. In addition, the power value chain's generation, transmission and distribution ends must be enhanced to meet the growing power demand.

[27] Source: World Bank Doing Business Archive. Available at https://archive.doingbusiness.org/en/data/exploretopics/getting-electricity

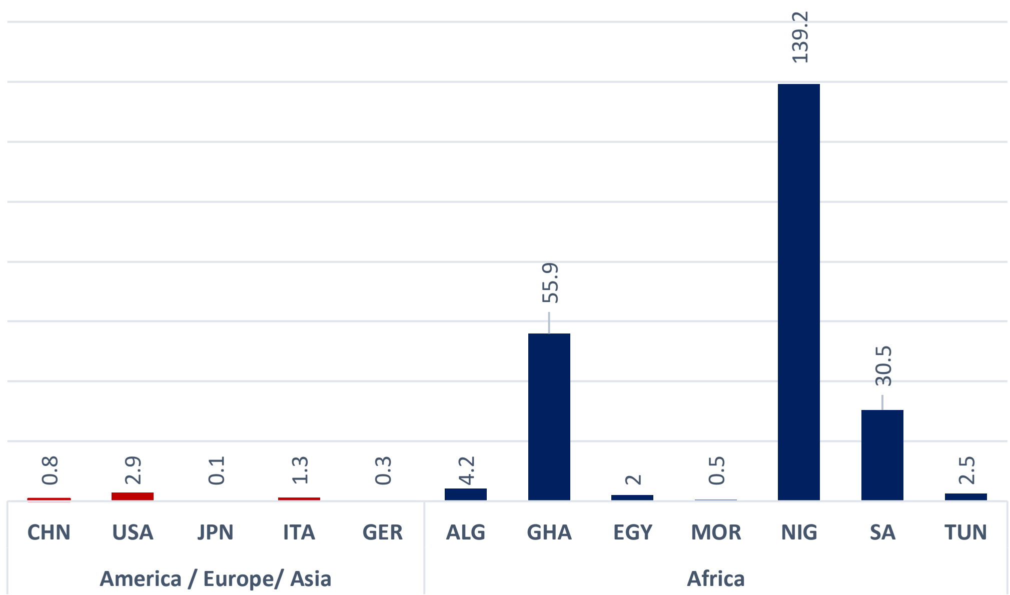


Figure 11: Comparative 2019 SAIDI values among participating countries in the PV value chain

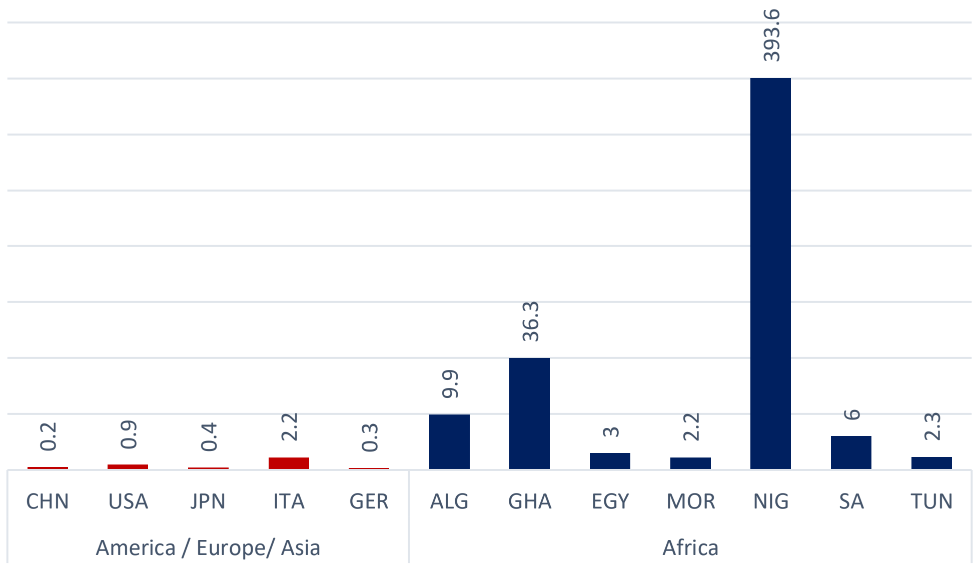


Figure 12: Comparative 2019 SAIFI values among participating countries in the PV value chain
Source: World Bank Doing Business Archive

Other input materials

The previous sections have identified the main output and raw materials required at each solar PV value chain stage. In addition to these main inputs, other materials are needed to produce the required output along each value chain segment. For instance, reducing oxygen from silicon oxide for Mg-Si production requires carbon. Also, calcium chloride and silicon chloride are needed for purifying metallurgical silicon into polysilicon. Polysilicon is doped with boron to create a positive charge during wafer production. Subsequently, the wafer is doped with phosphorus to form a p-n junction during the manufacture of solar cells. While these chemicals are easily produced in large quantities at various laboratories, other materials, such as aluminium, must undergo more laborious chemical processes before they are produced.

The properties of aluminium make it stand out as a preferred option for various operations in solar PV production. Aluminium is lightweight, has anti-corrosive properties, has higher surface reflectivity, and is a good conductor of electricity and heat. As a result, aluminium alloys are preferred to steel for framing solar PV modules. In addition, many solar farms use aluminium metals to manufacture solar panel stands.

Aluminium is obtained from the smelting of alumina, which is also mainly obtained from bauxite. Thus, the demand for bauxite and alumina would increase with the increasing demand for solar PVs. In addition, Africa has one of the largest bauxite reserves, estimated between 17 billion and 24 billion tonnes (about 32% of global bauxite reserves)[28], primarily located in Guinea, Mozambique, Ghana and Sierra Leone. Therefore, the requirement of bauxite and alumina for aluminium smelting allows these bauxite-rich African countries to increase production volumes and obtain more value from bauxite production.

Primary aluminium produced from alumina is highly power-intensive, which requires low electricity tariffs for the industry's sustainability. ACEP's analysis of Ghana's aluminium industry indicates two approaches necessary to lower the cost of power for the country's aluminium smelter: cheaper power and efficient smelters. Highly efficient smelters have reduced power consumption rates and can save up to about 4MWh of electricity per tonne of aluminium produced. ACEP's analysis shows that efficient smelters reduce power costs by about $353 per tonne of aluminium.[29]

Natural gas is an alternative source of heat for aluminium smelters which is more convenient and efficient. Thus, aluminium-producing countries with gas reserves can leverage their resource to channel part of their gas production volumes to power their aluminium smelters.

[28]United States Geological Society. (USGS). (2022). Bauxite and Alumina. Available at https://pubs.usgs.gov/periodicals/mcs2022/mcs2022-bauxite-alumina.pdf

[29] Boakye, B. & Ofori, C. G. (2019). *Evaluation of the proposed Integrated Aluminium Industry and the $2 billion Chinese barter deal.* Africa Centre for Energy Policy. Available at https://acep.africa/works/evaluation-of-the-proposed-integrated-aluminium-industry-and-the-2-billion-chinese-barter-deal/

However, this requires a robust plan that focuses on how these countries can leverage new and existing gas discoveries to drive industrialisation and reduce gas flaring, which has environmental impacts. In addition, regional policies that create the potential for a regional gas market are essential to meet the gas needs of other countries without gas reserves. For instance, the West African Power Pool (WAPP), with the vision to integrate national power systems into a unified electricity market, can lead the charge for ECOWAS member states.

Secondary aluminium production involves recycling aluminium-containing scrap materials and forms about a third of world aluminium consumption.[30] It reduces waste generation and has high recycling rates ranging between 50% to 85%.[31] Recycling aluminium involves cleaning, melting, and refining aluminium recovered from scrap material. Comparatively, refining aluminium uses less power than primary aluminium production. Recycled aluminium uses about 5% of the energy required to produce primary aluminium. The properties of secondary aluminium provide opportunities to create aluminium recycling companies that can operate at a minimum cost.

Beyond bauxite and silica, other critical minerals are required to sustain the solar PV industry. For example, battery technologies require cobalt, graphite, lithium and manganese. Other rare earth minerals such as indium, germanium and tellurium are also critical for solar panel production. Thus, countries with these mineral deposits could leverage them to supply the required minerals necessary for the transition. However, it becomes essential for governments and regulatory bodies to ensure that the resources are extracted without damaging the environment.

---

[30] Wallace, G. (2011). Production of secondary aluminium. In *Fundamentals of Aluminium Metallurgy* (pp. 70-82). Woodhead Publishing.

[31] Maung, K. N., Yoshida, T., Liu, G., Lwin, C. M., Muller, D. B., & Hashimoto, S. (2017). Assessment of secondary aluminum reserves of nations. *Resources, conservation and Recycling*, *126*, 34-41; Wallace, G. (2011). Production of secondary aluminium. In *Fundamentals of Aluminium Metallurgy* (pp. 70-82). Woodhead Publishing.

Conclusions

The desire to mitigate the impacts of climate change has led to a global call for transitioning towards cleaner energy sources. This call has resulted in a renewed effort for governments globally to adopt renewable energy technologies, and Africa has taken steady steps towards renewable energy integration. The statistics for the continent show exponential growth in installed capacities of renewable energy technologies. The growing market for cleaner energy options presents the opportunity for Africa to develop the necessary capabilities for innovation and investment attraction in energy transition technologies. Additionally, existing mechanisms such as AfCFTA provide an avenue to promote intra-continental trade in raw materials required to produce these technologies. Therefore, the continent must not delay its efforts to create and implement policies that ensure economic benefits by participating in the clean energy technologies' value chain.

This study assessed the solar PV value chain to determine the segments of the chain that qualify for the removal of trade barriers under AfCFTA. In addition, the study identified the critical drivers for the solar PV value chain and how countries could benefit based on their key competencies, such as cheap and reliable power, abundant mineral resources, and existing refinery capacities. Although this report does not provide a complete overview of the solar PV value chain, it presents information that sets the tone for a deep dive into approaches for Africa's sustained benefits from the energy transition. Further studies must focus on Africa's competitiveness through economies of scale and strengthening regulatory capacities among countries.

The results of the study are summarised below:

1. **The solar PV value chain is complex.** The value chain consists of five main segments, which range from quartz or silica extraction to the assembly of solar modules.
2. **About 80% of the solar PV value chain segments support AfCFTA's rules of origin requirements.** Except for solar module assembly, the output under each value chain component is eligible for preferential treatment under AfCFTA to support trade in such outputs among state parties.
3. **The solar PV industry is capital-intensive.** Capital requirements for a fully integrated solar industry with a capacity of 1GW amount to about $900 million, with solar cell manufacturing occupying a higher proportion of the costs. Therefore, governments must create an environment that attracts both domestic and foreign investments towards solar PV development.
4. **The solar PV industry is power intensive.** The value chain for a 1GW capacity requires estimated power consumption of about 1000GWh, of which the majority is consumed through metallurgical grade silicon and polysilicon production. Therefore, countries

with cheaper and more reliable power can benefit from production efficiencies and reduced costs associated with power generation.

5. **Bauxite, lithium, cobalt, and other minerals are critical for the industry**. These critical minerals open a bigger space for many countries with rich mineral deposits to participate in the value chain. However, this calls for improved regulatory practices within the mining sector to ensure sustainable mining.
6. **Aluminium is an essential metal for the industry.** However, primary aluminium production is both capital and power intensive. Countries can leverage cheap power, gas potential and regional power contracts to obtain affordable and reliable power to ensure aluminium production efficiency. On the other hand, aluminium has recyclable properties that make secondary production possible, thus requiring less investment. This provides opportunities to scale up aluminium production through recycling.

The study proposes the following recommendations:

1. African governments must assess the renewable energy technologies' value chain and enact policies that enable businesses and investors to partake in the various production stages of such technologies.
2. African governments and businesses must assess their core competencies within each aspect of the value chain to build a competitive advantage.
3. African governments must strengthen the regional collaboration among member states and leverage the opportunities provided by AfCFTA to boost intra-continental trade in inputs required for producing renewable energy technologies.
4. Governments must work toward providing reliable and affordable power to promote industrialisation and production efficiency. These can be achieved by leveraging gas reserves and regional power contracts like the West Africa Power Pool.
5. Governments from resource-rich countries must support and create an enabling environment for the sustainable exploration and extraction of the critical minerals necessary for the energy transition.
6. African governments must scale up research and development to drive innovation and technological improvement that support the energy transition.

ACEP

Africa Centre for Energy Policy

No. 26 Lemming St. | North Legon | GM-058-1968
P. O. Box CT 2121|Cantonments|Accra
Tel: +233(0) 302 900 730
Email: info@acep.africa
Website: www.acep.africa

ACEP is a thought leader in Africa's energy and extractive governance space, working towards improving economic transformation and inclusive sustainable development. We contribute to developing alternative and innovative policy interventions through high-quality research, analysis, and advocacy in Africa's energy and extractives sectors.