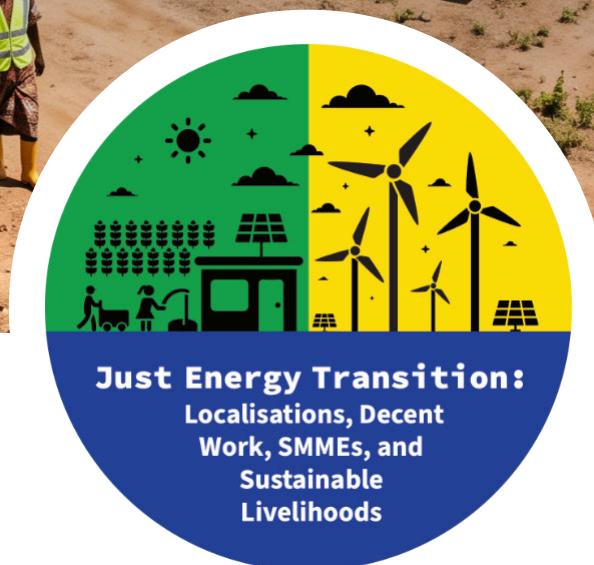


GLOBAL PRODUCTION NETWORK FOR SOLAR PV PANELS IN GHANA

By
Mohammed Saani Osman, Charles Gyamfi Ofori,
and Prosper Ahmed Amuquandoh

June 2026

SUN ENERGY GHANA
PV POWER PLANT - VOLTA REGION - 8.5 MW
CLEAN ENERGY FOR THE NATION



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EXECUTIVE SUMMARY

The global transition to renewable energy has intensified interest in the localisation of renewable energy value chains as countries seek to maximise economic benefits, create decent jobs, and strengthen industrial capabilities. In Ghana, solar PV technology has emerged as a promising renewable energy option due to growing market penetration and increasing household adoption. However, despite growing deployment of solar technologies, local participation in the production network remains concentrated in downstream activities, raising important questions about opportunities for industrial development and value capture

This study applies the Global Production Network (GPN) framework to examine Ghana's position within the solar PV panel production network and assess the prospects for localisation. The study focuses on solar PV panels as the selected component due to their strategic importance: high import dependence and potential to generate employment and industrial linkages. Using the GPN concepts of value, power, and embeddedness, the study maps the structure of the solar PV production network, identifies key actors, and evaluates the factors shaping Ghana's participation.

The analysis reveals that lead firms in the global solar PV industry are highly concentrated in China, exerting dominance in manufacturing, innovation, and technology development. These firms control critical intellectual property and supply chains, creating significant barriers to entry for late-industrialising countries. For example, Ghana's solar PV sector remains heavily dependent on imported technologies and components, without a developed manufacturing sector. Participation in the production network is concentrated at the deployment, utilisation, and end-of-life stages of the value chain. Local firms are primarily engaged in engineering, procurement and construction (EPC) services, installation, operations and maintenance, sales, and distribution.

The study finds that value creation within the production network is shaped by the capabilities of workers and firms. At the workers' level, evidence from Ghana and comparable developing countries points to the prevalence of precarious employment, particularly within private sector-led industries. Gender disparities remain significant, with women underrepresented in technical and managerial positions despite high participation in entrepreneurial activities. At the firm level, value creation is largely driven by relational rents derived from collaborations with foreign manufacturers, suppliers, and strategic partners. These relationships facilitate technology transfer, knowledge acquisition, and capability development. However, firms face significant constraints including high financing costs, expensive energy, inadequate industrial coordination, and limited access to long-term capital.

The assessment of value capture highlights the uneven distribution of benefits across workers and firms. Value capture by workers is constrained by the prevalence of temporary, insecure and project-based employment, limited opportunities for career progression, and persistent gender disparities in access to technical and managerial roles. At the firm level, high capital requirements, limited access

to long-term finance, skills and technology, create structural barriers for local RE firms to retain more profits and capture more value.

The study further demonstrates that power within the solar PV production network is exercised through corporate, institutional, and collective mechanisms. Corporate power is concentrated among global lead firms that control technology, innovation, and supply chains. Institutional power is exercised by national governments, international regulatory bodies, and development finance institutions. In Ghana, the state has established an extensive policy framework, including the Renewable Energy Act, Renewable Energy Master Plan, National Energy Policy, and National Energy Transition Framework, to promote renewable energy development and localisation. However, implementation challenges, financing constraints, policy fragmentation, and weak institutional coordination have limited the effectiveness of these interventions. International financing institutions such as the African Development Bank (AfDB) and International Finance Corporation (IFC) have supported large-scale solar projects, but these financing arrangements primarily prioritise deployment rather than local manufacturing and assembly.

The analysis of embeddedness reveals that Ghana's solar PV sector is deeply influenced by network, territorial, and societal factors. Local firms are embedded in networks of suppliers, contractors, and foreign technology providers, with relationships often based on trust, social ties, and project-based collaboration. Territorial embeddedness is reflected in the concentration of firms within the Greater Accra Region, driven by market access, infrastructure, and economic opportunities. Ghana's solar PV sector is socially embedded within strong kinship systems, gendered household divisions of labour, rural-urban social ties, and culturally influenced energy practices that shape labour participation and value capture within the sector.

Overall, the study concludes that Ghana possesses important foundations for greater participation in the solar PV production network but is constrained by structural barriers inhibiting growth and greater value capture. While policy ambitions for localisation are substantial, progress toward higher value-added activities has been limited. Achieving deeper localisation will require coordinated industrial policies, affordable financing, stronger support for research and development, targeted skills development, strategic public procurement, and deliberate efforts to strengthen linkages between local firms and global technology leaders.



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1. INTRODUCTION

Ghana's renewable energy (RE) ecosystem is primarily composed of solar photovoltaic (PV), hydroelectric, and waste-to-energy technologies.¹ Large-scale hydro accounts for the largest share of RE technologies, with an installed capacity of about 1,584 MW, about 28% of the country's total installed generation capacity. While solar PV contributes only about 2% of Ghana's total installed generation capacity, it is the most commonly deployed technology in decentralised and off-grid energy solutions (Energy Commission of Ghana, 2025). Wind energy is recognised in national policy frameworks, but it is yet to make a meaningful contribution to Ghana's generation mix.

While official data on the deployment of solar PV technologies, especially outside the national grid, remains limited, market assessments suggest a promising outlook for their adoption. Growing interest from individuals and businesses in solar PV installation reflects this positive trend. For instance, the International Finance Corporation (IFC) projected a compound annual growth rate (CAGR) between 34% (based on 1% market penetration) and 47% (for 2–4% penetration) for solar PV installations between 2018 and 2025 for commercial and industrial (C&I) consumers (IFC, 2021). This projected an increase from 9 megawatt peak (MWp) in 2018 to 63MWp (based on 1% market penetration) and 123MWp (based on 2-4% market penetration) for C&I consumers. However, recent estimates by Mordor Intelligence places C&I market share at 22.7%, representing 49.94MW of national solar PV installed capacity in 2025. CAGR between 2025 and 2031 is projected to be 39.24%. Despite the shortfall relative to the IFC's projections, Mordor Intelligence cites imminent uptake by mines, telecom towers, and food processors to counter grid tariff inflation and brownouts.²

Complementing these projections, national census data show a steady increase in the number of households relying on solar PVs as their primary source of lighting. In 2000, approximately 3700 households (0.1%) used solar-based systems as their major source of lighting. This figure grew to about 11,000 households (0.2%) by 2010, and further to about 23,000 households (0.3%) by the 2021 census. Although the percentage growth in the proportion of households appears modest, the consistent rise in absolute numbers suggests a gradual but sustained adoption of solar PV technology.

The growing interest and uptake of solar PV technologies in Ghana, though still modest in national penetration, signals a gradual shift in energy preferences that holds strategic implications for the local solar industry. While demand is increasing, the industry remains predominantly import-driven, with most components sourced from international markets. To support national targets, government interventions and private sector investments have largely relied on imported solar PV components.

UN Comtrade data shows that over time, there has been a steady increase in the value of imports of items classified under HS Code 854140³ under which solar cells and solar modules fall. Currently,

¹ Initially, Ghana's Renewable Energy Act, 2011 (Act 832) defined only hydro installations below 100 MW as renewable however, recent amendments now include all hydro capacities (Republic of Ghana, 2020).

² A brownout is a partial reduction in electricity supply, usually when voltage drops below its normal level.

³ Electrical apparatus; photosensitive, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes.

only a handful of companies in Ghana, such as Strategic Power Solutions, are involved in limited-scale assembly of solar modules (Kenning, 2016).

Ghana's growing solar market presents an opportunity to localise parts of the value chain, reducing reliance on imports and boosting local industry. While full-scale manufacturing may be limited for now, there is potential to expand local assembly, produce basic components, and strengthen installation and maintenance services. With the right investments in technical training, recycling systems, and support services like financing, research, and regulation, Ghana can grow its solar sector to be more resilient and self-sustaining.

Against this backdrop, this report provides background desk research into the prospects of localisation in the solar PV value chain in Ghana and how it can contribute to the creation of decent work. The report places Small, Medium, and Micro Enterprises (SMMEs) engaged in the solar PV value chain at the centre of the localisation objective. It also forms the basis for further research related to pathways for localisation of solar PV components in Ghana. The focus on solar PVs is driven by their increasing integration into global production networks (GPNs), their modular deployment potential, and their promise for localisation, innovation, and employment opportunities within Ghana's energy transition agenda.

This report is organised into six main sections, each reflecting a key stage of the research and analysis process, grounded in the GPN framework. Section 2 is an outline of the research methodology employed. It entails the process of selecting the solar PV panel as the focal RE component and provides an overview of the analytical framework applied in the study. Section 3 maps the physical and activity flows of the solar PV panel value chain and identifies both global and local actors involved. It concludes with a representation of the overall solar PV production network relevant to Ghana. Section 4 explores how value is created, enhanced, and captured within the solar PV panel production network. It assesses opportunities and barriers to domestic value retention and upgrading.

Section 5 analyses the distribution and exercise of power within the production network. It distinguishes between corporate, institutional, and collective forms of power and discusses how these influence the governance and direction of the solar PV industry in Ghana. Section 6 investigates the extent to which firms and actors are embedded within production networks, focusing on network, territorial, and societal forms of embeddedness. The last section concludes by summarising the main findings and insights from the analysis. It also reflects on the implications for industrial policy, localisation, and broader RE development strategies in Ghana.

2. COMPONENT SELECTION AND THE GLOBAL PRODUCTION NETWORK (GPN) ANALYTICAL APPROACH

A GPN approach enables a comprehensive assessment of Ghana's potential to localise solar PV value chains while enhancing decent employment opportunities. Specifically, the GPN analytical framework helps to identify where value is created and captured, and where there may be opportunities for upgrading. It highlights potential entry points for domestic firms, opportunities for skills development and technological learning, and policy levers that could support industrial upgrading and more inclusive participation.

This section presents the rationale for the selection of solar PV panels as the focal component for GPN mapping, reviews the GPN approach, explains data sources, and outlines the key activities and stages of production along the value chain.

2.1 Component selection

The choice of solar PV panels as the focal component for localisation in Ghana's solar value chain is driven by a multi-criteria assessment aligned with national economic and energy transition goals. Four main criteria were used in evaluating key components of a typical solar PV system:

Import value: contribution to Ghana's solar PV import statistics

Labour intensity: potential to generate local employment

Life cycle: durability, maintenance needs, and replacement frequency

Existing local manufacturing capacity: feasibility of domestic production

2.1.1 Import value trends and demand prospects

Within this component-selection framework, import values are used to assess the scale and trajectory of market demand for different elements of Ghana's solar PV system. While trade data does not capture all dimensions of domestic deployment, sustained import trends provide a reasonable proxy for identifying components with sufficiently large and growing markets to support localisation. The analysis relies on Harmonised System (HS) codes from UN Comtrade data, where:

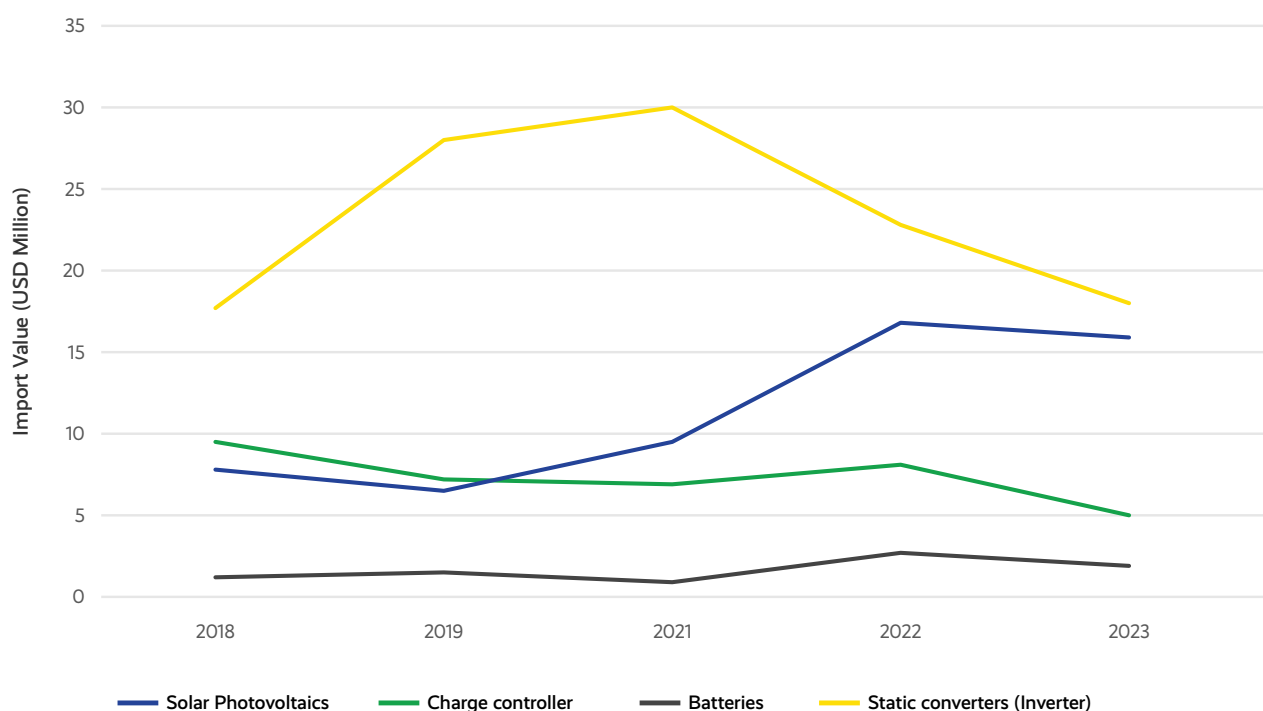
1. Solar PV panels fall under HS Code 854140: Electrical apparatus; photosensitive, including photovoltaic cells, whether or not assembled in modules or made up into panels, light-emitting diodes (LED).
2. Charge controllers are classified under HS code 903289: Regulating or controlling instruments and apparatus; automatic other than hydraulic or pneumatic.

3. Batteries are classified under HS code 850650: Cells and batteries; primary, lithium.
4. Inverters are classified under HS Code 850440: Electrical static converters.

None of the codes applies exclusively to solar PV systems. However, HS 854140 is more closely aligned with solar deployment outcomes than HS 850440, which aggregates a wide range of power-electronics equipment used across industrial, commercial, and consumer applications, many of which are unrelated to solar energy systems. As a result, import values under HS 850440 may significantly overstate inverter-specific activity.

On the other hand, the PV category, although slightly broader, more accurately reflects the demand for solar technology, especially given the prominence of PV modules within that classification. Between 2018 and 2023, solar PV panel imports under HS 854140 increased from approximately \$7.8 million to nearly \$15.9 million, with a significant rise from 2021 onwards (see Figure 1). Despite some classification overlap, this trend is directly indicative of expanding solar market uptake in Ghana.

Figure 1: Import trends of solar PV components in Ghana (2018-2023)



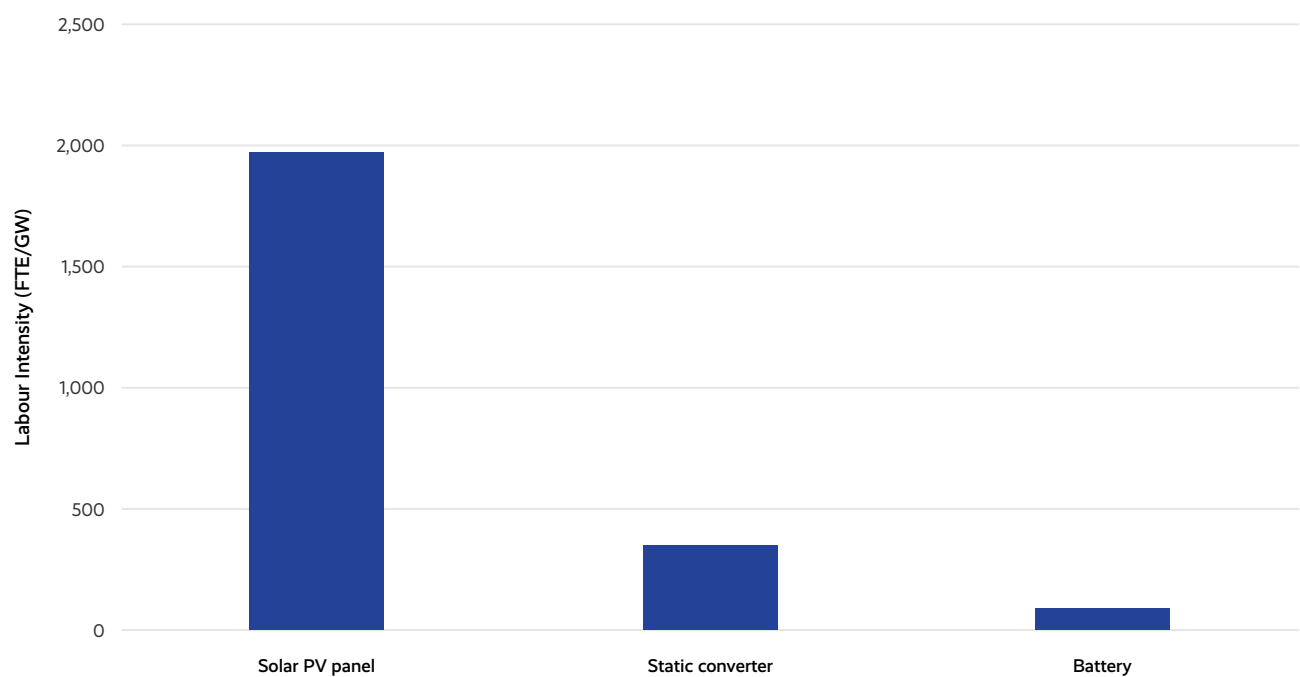
Source: UN Trade Statistics (2025)

The sustained upward trajectory of PV-related imports strengthens the commercial case for localisation by signalling a market of sufficient size and growth to support domestic manufacturing or assembly. In contrast, imports under HS 850440, while historically larger in absolute terms, have declined since 2021 and remain a weak indicator of potential localisation due to the category's heterogeneous end-use profile. On balance, PV modules present a clearer demand indicator and a more defensible starting point for localisation within Ghana's solar value chain.

2.1.2 Labour intensity: unlocking the highest potential for green jobs

Labour intensity is a critical metric for potential localisation as it directly influences employment creation and skills development. Solar PV panels demonstrate the highest labour intensity, requiring 1,970 full-time equivalent (FTE) jobs per gigawatt (GW), over five times higher than the 360 FTE/GW for inverters, and nearly twenty times greater than the 100 FTE/GWh for batteries (SolarPower Europe, 2023; Menon Economics, 2022; see Figure 2).

Figure 2: Labour intensity of solar components



Source: SolarPower Europe (2023) and Menon Economics (2022)

Solar panels also provide opportunities across multiple stages of the value chain, including manufacture, installation, quality control, maintenance, and end-of-life recycling. In a country where youth unemployment remains a pressing policy challenge, investing in labour-intensive segments of the RE sector offers a way to support both industrial development and job creation.

2.1.3 Life cycle

Solar PV panels also stand out for their long operational life. With an average operational lifespan of 30 years, PV panels significantly outlast other key components in the solar energy system value chain, such as batteries (10–15 years) and inverters or charge controllers (approximately 15 years) (IEA-PVPS, 2024; da Silva Lima et al., 2021). This extended durability translates into lower replacement frequencies and reduced lifecycle costs for consumers, making solar solutions more affordable over time. It also minimises waste generation, aligning with circular economy and environmental sustainability goals, which are prioritised in Ghana’s Renewable Energy Master Plan (REMP) (Ministry of Energy, 2019).

The long-term stability of demand for PV panels strengthens the case for local manufacturing by encouraging sustained industrial investment, reducing supply chain volatility, and supporting workforce retention. From a policy and economic perspective, localising PV panel production offers a relatively resilient and future-proof entry point into green industrial development.

2.1.4 Existing local manufacturing capacity

Currently, Ghana is almost entirely dependent on imports for solar PV panels, lacking the capability of local manufacturing (Edze, 2025). This gap presents a strategic opportunity to reduce import dependency, foster technology transfer, and catalyse the development of local manufacturing capabilities. However, due to the heavy reliance on imported finished solar PV systems, the industry skill set is predominantly focused on construction, installation and servicing (Owusu-Agyeman and Aryeh-Adjei, 2024).

A rise in Engineering Procurement and Construction (EPC) firms locally, with links to international partners as suppliers or strategic partners, presents an opportunity for the knowledge and skills transfer required to enhance local capabilities related to the manufacture of solar PV modules (Edze, 2025).

2.2 Analytical approach

This study employs the GPN framework as an analytical lens to examine the nature and context of the solar PV panel industry in Ghana. According to Coe et al. (2008), the GPN involves “interconnected nodes and links extending spatially across national boundaries and, in so doing, integrating parts of disparate national and subnational territories”. The GPN approach enables a holistic understanding of how firms, state institutions, transnational actors, and social movements, such as civil society and labour organisations, interact across space to shape processes of value creation, enhancement, and capture within global production contexts.

Building on this foundation, the rest of the study applies the GPN framework across three core dimensions:

1. **Value creation, enhancement, and capture:** the study examines how value is created and captured within the solar PV production network, focusing on the roles played by labour, firms, and the state. It examines factors that enhance competitiveness and investigates the extent to which these enable firms to engage in higher value-added activities. It also assesses whether current market and policy conditions facilitate or hinder the localisation of manufacturing and technological advancement.
2. **Corporate, institutional and collective power:** the GPN lens is used to explore how institutional arrangements and power asymmetries shape the development of the RE sector. The study examines how power is exercised and distributed within the production network, focusing on corporate, institutional, and collective power.
3. **Network, territorial and societal embeddedness:** the study assesses the extent to which foreign and domestic actors are embedded in the local economy and how this affects capability

development. This dimension investigates the extent to which firms and institutions are embedded within network relationships. The study also considers how firm-level strategies and investment decisions are shaped by local capabilities, infrastructure, and institutional support. It further explores the depth of integration of global actors within the local production system and the potential for knowledge and skills transfer.

2.3 Data Sources

Data for the study was gathered from secondary sources. These include published documents, such as academic literature, and industry and policy texts. Trade data was acquired from the UN Comtrade database.

3. VALUE CHAIN AND GPN MAPPING APPROACHES

Mapping the value chain of solar PV panels is the initial step towards a more detailed GPN analysis. The value chain outlines the key processes involved in production, while the GPN provides a more comprehensive analysis of the ecosystem of actors involved in value-adding processes.

3.1 The solar PV panel value chain

Multiple approaches can be used for value chain mapping. These include the material flow approach, the activities approach, the (pre-) deployment approach, and hybrid approaches. Each of these is described below.

The **Material Flow Approach** primarily focuses on the movement of tangible inputs, such as raw materials and components, through the value chain, from extraction to the final product. An example of this approach can be seen in Box 1.

Box 1: Physical flow of materials in the solar PV value chain

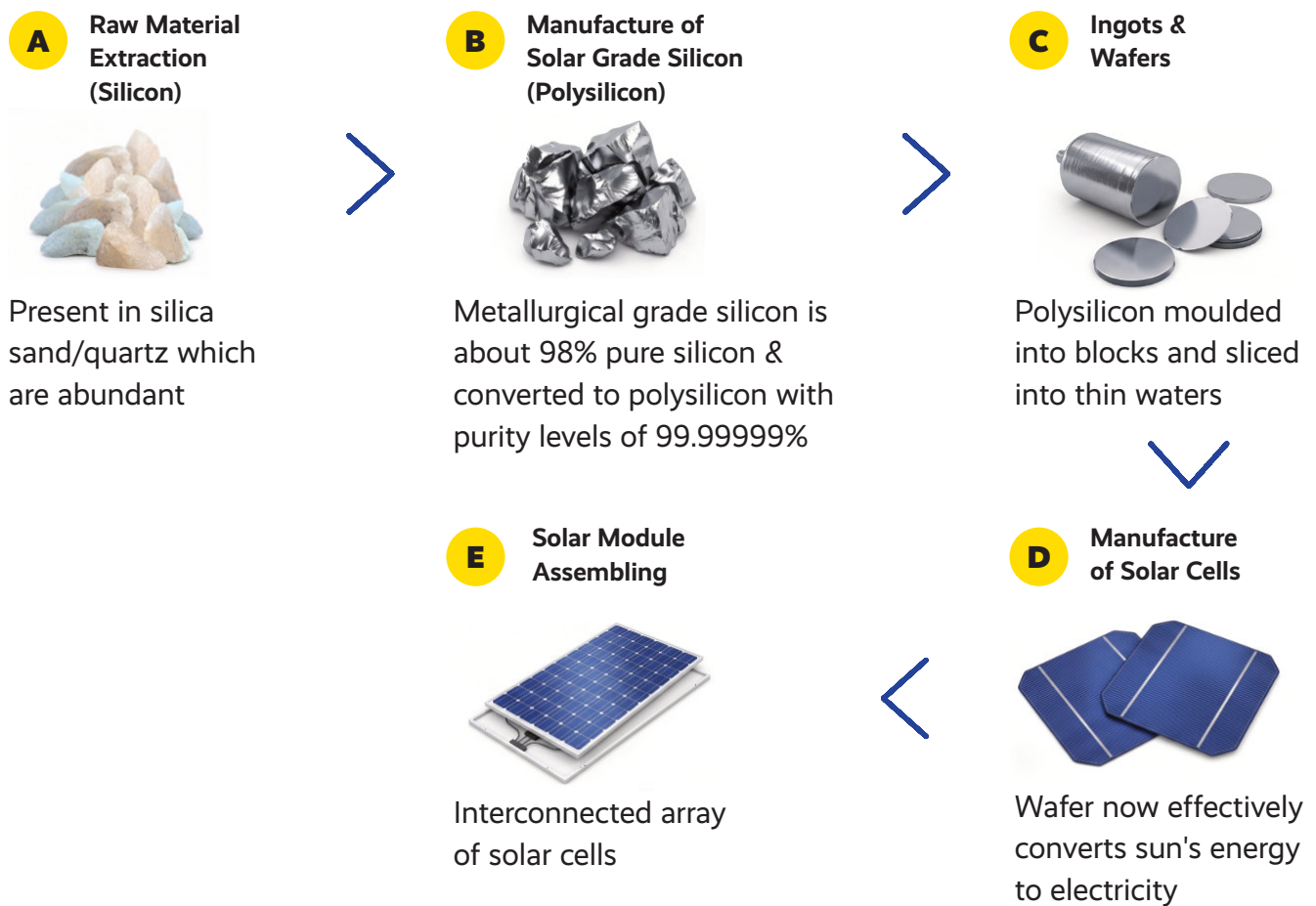
The physical flow of materials in the processing of solar PV panels encompasses a series of interconnected stages from raw material extraction to the assembly of solar modules (Boakye & Ofori, 2022). These inputs include the mining, processing and conversion of raw materials into solar cells. Figure 3 illustrates the solar PV value chain, beginning with the extraction of raw materials.

This initial stage involves obtaining silicon, which is abundantly present in silica sand or quartz. This raw material then undergoes processing to become metallurgical-grade silicon, typically with about 98% purity. This metallurgical-grade silicon is converted into polysilicon which has exceptionally high purity levels of 99.99999%, essential for solar applications. The polysilicon is subsequently moulded into ingots and then precisely sliced into thin wafers, forming the foundational material for solar cells.

The subsequent stages focus on converting these wafers into functional solar PV components. The wafers are manufactured into solar cells, which are the fundamental units that convert the sun's energy directly into electricity. Finally, these individual solar cells are interconnected and assembled into larger units known as solar modules or panels (see Figure 3).

These modules represent the finished product in the solar PV value chain, ready for deployment in various solar energy systems to harness solar power for electricity generation.

Figure 3: The solar PV panel value chain



Source: Boakye and Ofori (2022)

However, while useful, this approach captures only part of the picture.

The activities approach maps the sequence of economic and technical activities that add value to a selected component or technology. It spans upstream to downstream activities including research and development (R&D), design, engineering, component manufacturing, assembly, distribution and logistics, marketing and sales, and after-sales services.

The (pre-) deployment approach focuses on the value-adding activities that take place before and during the actual deployment of the component. This includes site selection and feasibility assessments, engineering design, permitting, financing, procurement, and planning. It also covers deployment-stage activities such as civil works, plant construction, transportation, grid interconnection, and testing.

The hybrid approach combines elements of two or more of the above approaches to offer a more holistic view. For example, combining the activities and material flow approaches can illuminate both the service and material aspects of a value chain. Similarly, integrating deployment and end-of-life elements offers insights into the lifecycle performance, socio-economic impacts, and circular economy opportunities of the selected component. This flexibility makes the dual approach particularly effective

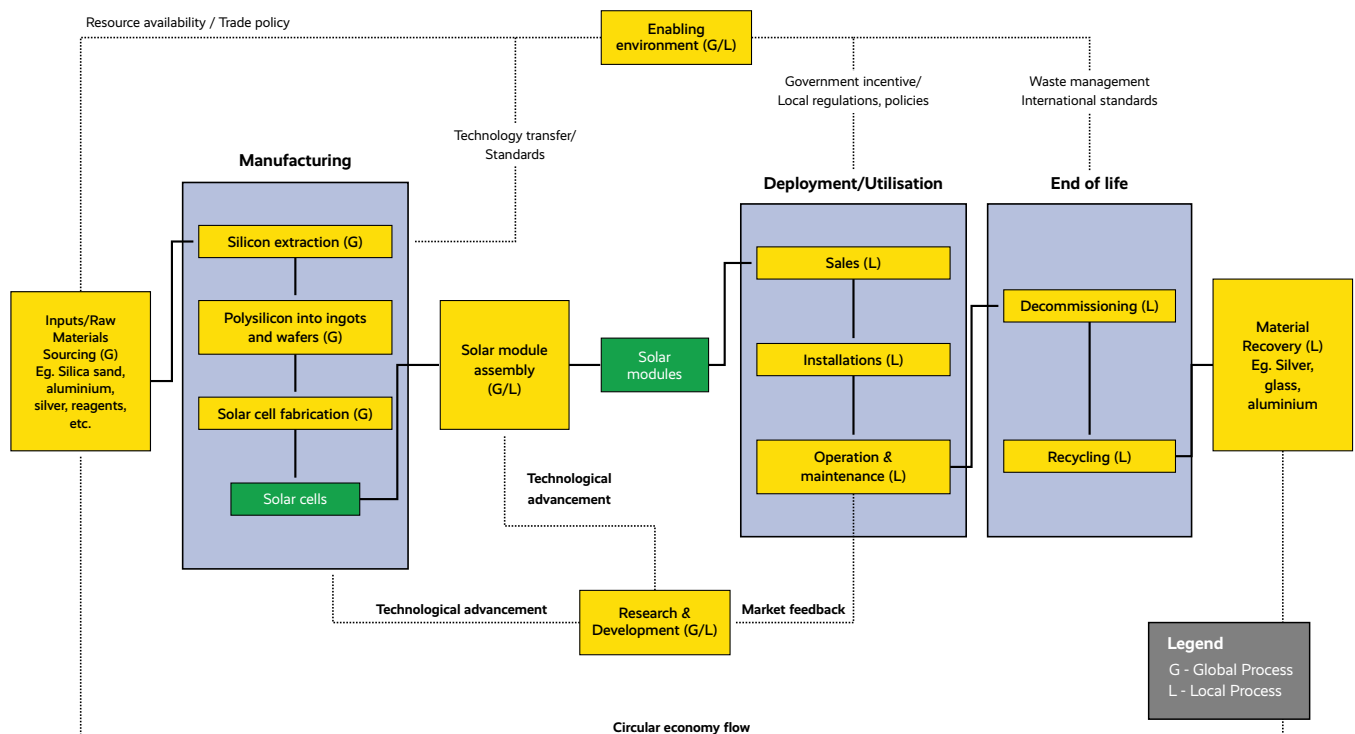
for multi-dimensional analyses, such as those involving industrial development, localisation, sustainability, or geopolitical risk.

For this study, a hybrid approach is adopted, combining the activities and material flow approaches, for a more comprehensive overview of the diverse value-adding functions that shape the solar PV panel across its lifecycle. This includes not just physical transformation of materials but also services, regulation, innovation, and logistics. These functions are undertaken by actors in the value chain, such as the firms engaged in producing the solar PV panel, international regulatory institutions that ensure standards, and firms that engage in marketing and after-sale services. In Ghana, some value-adding functions, particularly downstream processes, are undertaken within the country, while upstream processes occur outside the country.

3.2 The solar PV panel GPN map

The production network, which represents the connections between all actors involved in the production of solar PV panels, is illustrated in a GPN map (see Figure 4). The map or production network delineates processes that occur both within and outside Ghana, annotated as local (L) and global (G) respectively. This model generally consists of three major interconnected stages: manufacturing, deployment and utilisation, and end-of-life.

Figure 4: The solar PV production network



Source: Authors' own construction

3.2.1 Manufacturing

The manufacturing phase is primarily dominated by global processes, as Ghana currently has limited capacity in high-tech solar manufacturing. It begins with the sourcing of raw materials such as silica sand, aluminium, silver, and various chemical reagents, which are essential inputs into the upstream production activities. These materials feed into a series of global processes, including silicon extraction, conversion of polysilicon into ingots and wafers, and the fabrication of solar cells. These processes are largely carried out in countries with established industrial capabilities and access to affordable energy and technology.

However, there is a transitional phase — solar module assembly — that connects upstream manufacturing to downstream deployment. This is a process that predominantly takes place globally, with limited local participation. Only one firm is cited as being engaged in assembling PV modules (Kenning, 2016). Beyond a consensus on the lack of local manufacturing capability, the literature is unclear on the current state of local panel production.

The global solar PV market shows positive growth potential, with installed capacity expected to triple by 2030, according to IEA projections (IEA, 2024). While China plays a major role in manufacturing, this market growth is accompanied by shifting geographic patterns of production, as countries like India and the United States implement policies to boost domestic manufacturing. The US Inflation Reduction Act and, recently, the broad imposition of import tariffs seek to incentivise local US production, while India's Production Linked Incentives (PLI) scheme aims to create a self-sufficient solar industry.

Technological advancements continue to drive the sector forward, with traditional Passivated Emitter and Rear Cell (PERC) technology giving way to more efficient solutions like Tunnel Oxide Passivated Contact (TOPCon) and heterojunction cells. Additionally, emerging technologies such as perovskite-silicon tandem cells, which could increase efficiencies of solar modules by over 30%, are nearing commercialisation (IEA, 2022).

3.2.2 Deployment and utilisation

In this phase the production network moves from global manufacturing processes to local level deployment, with the majority of activities taking place within Ghana. This stage includes sales, installation, and operation and maintenance (O&M). These activities are labour-intensive and provide significant opportunities for local employment, skill development, and enterprise growth. Sales and installation activities support the expansion of energy access, while the O&M phase ensures the long-term performance and reliability of systems. This stage also generates critical market feedback that can inform technological innovation and the design of future products.

In Ghana, these functions are led by local and international energy service companies, including Meinergy Technology Limited, BXC Company Ghana Limited, Translight Solar Limited, Deep Solar, Suka Solar, etc. (Energy Commission of Ghana, n.d.). The Energy Commission plays a key regulatory role, issuing licenses for importation, installation, maintenance, and electricity generation, in accordance

with the Renewable Energy Act. These regulatory processes are central to maintaining safety, quality, and performance standards in the sector. This phase also aligns closely with objectives of the National Energy Transition Framework (NETF) to increase RE access and promote decent, green jobs through localised services and entrepreneurship in the energy sector.

3.2.3 End of life

As solar PV systems are deployed and used over time, the panels eventually reach the end of their useful life and become waste. End of life could also be reached as a result of damage to functioning solar PV panels at the point of use. Effective management of this waste is crucial for a circular economy approach to the solar PV production network. Ghana's REMP recognises the need to effectively manage solar PV waste through government facilitation of recycling infrastructure (Ministry of Energy, 2019). However, official reports on the management of solar PV waste are yet to be published (Agyeman et al., 2025).

Effective waste management policies and adherence to international standards are essential to ensure safe and efficient recycling processes. The lag before the operationalisation of infrastructure recycling could result in solar PV waste being handled by informal waste collectors. Ghana's Hazardous and Electronic Waste Control and Management Act of 2016, which includes provisions for the management and disposal of hazardous electrical and electronic waste, does not clearly include the country's informal e-waste sector in the process (Ndzibah et al., 2022). This phase of the local production network has the potential not only to contribute to environmental sustainability but also to open new local economic activities in formal, structured solar PV panel recycling and material recovery

3.2.4 Production network cross-cutting dynamics

Across the production network, critical enablers determine the success and sustainability of each activity. For instance, effective material sourcing depends on both the availability of local raw materials (such as silica, aluminium, and copper) and enabling trade policies (such as trade facilitation measures and access to regional markets). Feedback from the utilisation stage, including customer experience and performance data, can drive continuous innovation and R&D, helping to produce more efficient, durable, and affordable solar PV technologies. In manufacturing, adherence to global technical standards and adoption of modern technologies can enhance the quality and competitiveness of locally made products. Likewise, supportive government policies and investment incentives (e.g., tax holidays, green finance mechanisms, public procurement mandates, and net metering policies) can accelerate the deployment of solar systems across urban and rural areas.

The solar PV panel production network involves a diverse set of actors, each playing distinct but interconnected roles. Actors are situated at either the global or local level and include multinational and local firms, state institutions, regulatory bodies, social movements, research organisations, and financial institutions. The roles of these actors in the production network are discussed in detail using the GPN framework in the subsequent chapters.

4. VALUE IN THE PV PANEL PRODUCTION NETWORK

As goods or services move through different stages of production from raw materials to finished goods, economic value is generated. As the first conceptual category of the GPN framework, value refers to the processes of creation, enhancement and capture of economic worth, as a product or service moves through the production network. This section discusses these processes and how they are shaped by interactions among key actors within the solar PV panel production network. The actors involved in this category include labour, firms, non-governmental organisations and governments. While labour has a direct role in adding value to goods and services in a production network, the conditions provided by firms, institutions, and government also play a key role in ensuring the creation, enhancement, and capture of value. Within this broader dynamic, this section focuses on the roles of workers and firms.

4.1 Value creation and enhancement

While firms and governments often operate within formal systems, formal and informal working conditions also influence how value is created. Factors such as wages, working environments, and conditions of service play a crucial role in determining how effectively labour can contribute to value creation in the production network.

Similarly, firms drive value through innovation, investment, and market linkages, while the state provides the regulatory, institutional, and infrastructural framework that enables or constrains production efficiency and competitiveness. The collective roles of these actors form the ecosystem through which value is created and enhanced. The following sections examine the individual roles and conditions of labour and firms in value creation and enhancement within the solar PV production network.

4.1.1 Workers

Within the GPN framework, workers play a central role not only in the physical production of goods, but also in shaping how value is created and enhanced across production networks. According to Henderson et al. (2002), value creation and enhancement involve the conversion of labour power into productive labour through the labour process, a conversion shaped by factors such as the nature of employment, skill levels, working conditions, and production technology. These factors directly influence workers' productivity and, over time, the scope for learning, innovation, and upgrading within production networks.

There is a substantial body of empirical literature on working conditions, precarity, and productivity in developing economies including Sub-Saharan Africa. These studies focus primarily on traditional

sectors such as agriculture, manufacturing, construction, and services. Studies on Ghana's agricultural and agro-processing sectors show that insecure employment, underemployment, and limited skill formation constrain workers' productivity and income stability (Lambon-Quayefio and Owoo, 2018). Similarly, firm-level analyses of Ghana's manufacturing sector demonstrate that employment practices, skills, and product innovation are closely linked to productivity and wage outcomes (Chatterjee, 2016; Baffour et al., 2020).

However, while these studies provide strong empirical grounding for labour–productivity relationships in Ghana's traditional sectors, this kind of analysis has rarely been extended to emerging green industrial sectors, such as solar PV manufacturing and assembly. More importantly, existing studies seldom situate labour dynamics within a GPN framework that explicitly links employment conditions to value creation, value capture, and value enhancement.

Nevertheless, some evidence from Ghana's formal labour market remains directly relevant. Baffour and Abbey (2023) show that private-sector employment in Ghana is significantly more precarious than public-sector employment, with higher risks of job insecurity and weaker conditions of service. In GPN terms, such conditions restrict the potential for innovation and upgrading. Conversely, improving job security, working conditions, and access to skills development can strengthen workers' role as a strategic asset within the solar PV production network, supporting sustained productivity gains and the long-term competitiveness of Ghana's solar PV industry (Mutuku & Mbatia, 2020). Given that employment in Ghana's RE sector is overwhelmingly private-sector-led, these dynamics raise concerns about productivity, skill accumulation, and sustained value enhancement as the sector expands.

Against this background, available evidence suggests that employment in Ghana's solar PV sector is currently concentrated in downstream segments of the value chain, particularly in installation, O&M, sales, and distribution, reflecting the industry's import-dependent structure (Lijfering and van der Veen, 2024). While comprehensive national employment statistics for the solar PV sector are not publicly available, a broad jobs survey by the African Development Bank (AfDB) reveals that women are as likely as men to be employed in Ghana. However, women constitute about 21% of energy jobs in Ghana and are less likely to occupy high-skilled technical, professional, or managerial roles in green growth sectors such as RE (AfDB, 2022). The AfDB findings suggest that the downstream concentration of employment and the underrepresentation of women in higher-skilled roles suggest that, without deliberate upgrading and targeted inclusion strategies, the expansion of the solar PV sector may reinforce existing structural and gender inequalities in the energy labour market, rather than transforming them.

4.1.2 Firms

The GPN framework also shows that firms derive competitive advantage from their ability to create and enhance their value through different forms of rent, including technological, organisational, relational, and brand rents, as well as rents related to the policy environment in which they operate (Henderson et al., 2002). In addition, value in GPNs is created outside of these rents. Such value can include value created in communities through economic development, and more directly through the creation of jobs.

The following presents evidence of local firms' capacity to create and enhance value in the solar PV industry through the various forms of rents outlined by Henderson et al. (2002), as well as the creation of jobs.

- 1. Technological rents:** these refer to a firm's ability to generate value from access to technology, innovation, and technical know-how. In Ghana, this remains a major limitation to firm competitiveness. As Edze (2025) and Sackey et al. (2020) note, Ghana remains a net importer of solar technologies and currently has limited domestic manufacturing capacity for critical components such as PV modules, inverters, and batteries. Nonetheless, existing local content and local participation policies in the electricity supply industry establish minimum requirements for Ghanaian employment, training, and equity participation in RE businesses. In principle, these provisions are designed to create entry points for domestic firms and workers to participate in solar PV projects, particularly through EPC arrangements, in which local firms collaborate with foreign partners and are able to access technology.

While the implementation of local content requirements may face practical challenges related to skills availability, enforcement capacity, and market structure (Ettmayr and Lloyd, 2017), effective and consistent application has the potential to support technological learning, skills transfer, and incremental upgrading by domestic firms. Some firms involved in solar PV system construction, installation and maintenance have benefited from training programmes and joint project executions with international firms, leading to a gradual process of upgrading (Kuada and Mensah, 2020). However, through these developments, foreign partners remain the main sources of technology for local firms, thereby deepening the dependence on imported equipment and expertise. Domestic R&D remains underfunded. The lack of long-term capital financing, weak R&D support systems, and insufficient infrastructure constrain firms' ability to develop proprietary technologies or adapt existing ones (Sackey et al., 2020).

- 2. Organisational rents:** these arise from firm-level managerial and operational efficiencies. Firms that transitioned to the solar industry from other sectors, such as ICT, marketing, and printing, have leveraged their prior organisational knowledge to enhance their absorptive capacities (Kuada and Mensah, 2020). Although the evidence does not specify which capacities have been enhanced by this prior organisational experience, these firms may have been able to build upon existing customer relations to enhance their market acceptance. However, the evidence does not show whether they also leveraged organisational efficiencies to generate rents.
- 3. Relational rents:** these emerge from strategic partnerships and inter-firm collaborations that facilitate knowledge sharing, access to markets, and improved supply chain capability. Ghana's solar PV firms exhibit both vertical and horizontal collaborations. Kuada and Mensah (2020) found that vertical linkages exist between manufacturers, distributors, and installers. Horizontal collaborations occur in specific projects when firms pool resources for joint execution. These relationships have been instrumental in enhancing access to solar technologies, skilled labour, and trade credit.

As mentioned above, Ghanaian firms have benefited through relationships with global firms. Some firms have co-designed systems with foreign partners to better adapt products to local climatic and consumer conditions (Kuada and Mensah, 2020). Such partnerships not only reduce

operational costs but also foster incremental innovation and local capacity building. However, as Sackey et al. (2020) point out, the absence of sustained public incentives for research and technology partnerships limits the scalability of these collaborations across the industry.

Social networks and professional ties also serve as valuable sources of rent. Kuada and Mensah (2020) show that engineers and managers often use informal relationships across firms to access market information, coordinate projects, and secure product supplies. Social networks and professional ties also serve as valuable sources of rent.

4. **Brand rents:** these refer to firms' ability to leverage market reputation and brand recognition for competitiveness. In Ghana, the solar PV market is still emerging, and brand differentiation remains underdeveloped. While a few firms have built reputations for quality installation and after-sales service, the market is dominated by foreign brands whose products are associated with superior quality and reliability (Kuada and Mensah, 2020). Among some consumers, local firms are generally perceived as inferior to foreign brands (Kuada and Mensah, 2020). However, the current state of firms' brand reputation in Ghana needs more up-to-date study as the industry evolves. Local firms will need to enhance marketing strategies, while adhering to regulatory compliance, to improve their brand reputation.
5. **Additional Rents:** beyond these four forms of rent firms can also generate other forms of value that arise from specific national or regional policies. Firms that effectively align their operations with supportive policy frameworks or local content requirements can derive some rent. Such rents emerge when firms benefit from preferential procurement, tax incentives, or public-private partnership opportunities linked to RE policies. Edze (2025) highlights that local content policies not only encouraged technology transfer but also incentivised firms to strengthen local linkages, thereby indirectly enhancing their rents related to the policy environment. Similarly, Sackey et al. (2020) note that government policy support, though uneven, can shape firms' capacity to invest in long-term technological development.

4.2 Value capture

Value capture within the production network concerns how actors can benefit from the value created. For this study, value capture is considered at the level of workers and firms.

4.2.1 Workers

Wage distribution is generally marked by disparities shaped by education, level of skill, or role. In Ghana, the education premium is higher for women than men at the same level of secondary or tertiary qualifications (Gradín and Schotte, 2020). Baffour and Abbey (2023) also found that men in Ghana are more likely to be in precarious employment than women. However, the available evidence does not establish whether these labour-market differences translate into gender-based wage

⁴ Specifically the Energy Commission (Local Content and Local Participation) (Electricity Supply Industry) Regulations, 2017 (L.I. 2354).

inequalities.

The inequalities that exist are compounded by the nature of the work. Routine tasks in the industrial sector, often manual, tend to attract lower wages and fewer benefits, while non-routine, technical, or managerial roles receive higher compensation (Gradín and Schotte, 2020). As automation and digitisation grow across the value chain, these disparities may widen further. The shift from manufacturing-oriented roles to service-based employment, as reflected in Ghana's contracting manufacturing sector and expanding service sector, also introduces new forms of vulnerability, particularly for informal and low-skilled workers (Gradín and Schotte, 2020).

Job precarity in the solar PV sector has been linked to the well-being of workers. Nizam et al. (2025) associate employee well-being in the sector with employment type, wages and benefits, vulnerability, and work schedules. Where employment is insecure, wages and benefits are poor, workers are vulnerable, and schedules are unpredictable or excessive, precarious work may limit workers' ability to capture the value created by their participation in the sector.

Ghanaian labour literature and international evidence from emerging solar PV markets, confirms that precarious and insecure employment arrangements can undermine workers' ability to capture value from the sector. Studies consistently show that short-term contracts, weak labour protections, and limited access to training are associated with lower technological learning (Hewison, 2016; Moscone et al., 2016; Wiengarten et al., 2021; Nizam et al., 2025). While sector-specific evidence for Ghana's solar PV industry remains limited, the predominance of private-sector employment, and the broader incidence of labour precarity documented in Ghana, suggest similar risks, as localisation efforts expand.

4.2.2 Firms

A critical dimension of value capture within GPNs is the role of firms, and in particular how value created benefits different types of firms and geographies, and how lead firms exercise and sustain their dominance. To assess how firms capture value from the production network, issues such as profit distribution between foreign and local firms, mechanisms by which lead firms dominate, repatriation of profits by multinational corporations (MNCs), and the influence of financiers on firm-level gains need to be interrogated.

In Ghana, solar PV firms operate as wholesale electricity suppliers (i.e. grid-scale generators) or as installation and maintenance firms (Energy Commission, n.d.). These firms are either wholly foreign-owned, wholly Ghanaian-owned, or joint ventures between foreign and local owners. Evidence suggests that local firms remain largely positioned at the downstream segment of the value chain, focusing on distribution, installation, and maintenance services (Kuada and Mensah, 2020; Edze, 2025). Local firms are able to capture more value through collaborations with foreign-owned firms that have more secure access to components. Foreign firms are allowed to repatriate their profits from their operations, subject to an 8% tax on the gross amount to be repatriated (Republic of Ghana, 2016). Beyond this, foreign firms are subject to the same corporate tax rates as local firms (Republic of Ghana, 2015).

Midstream activities, such as solar PV panel assembly, present significant entry points for countries like Ghana to capture more value within the GPN, as they are less technologically intensive than

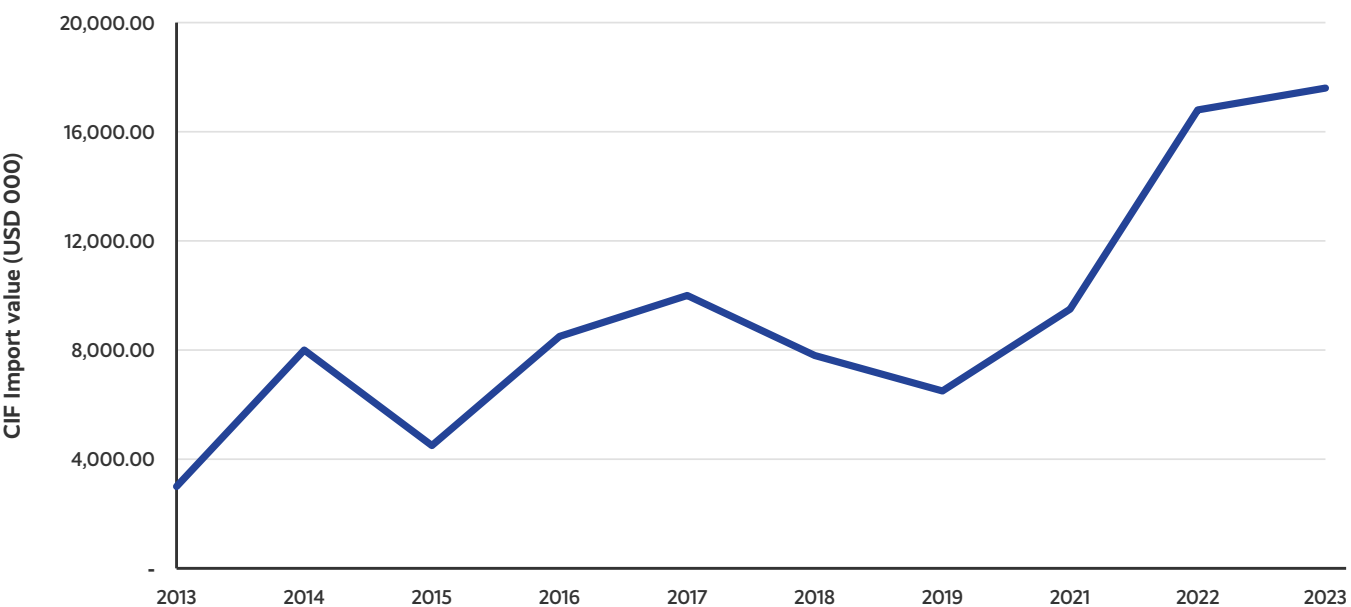
upstream production and offer opportunities for decent job creation. For instance, Vietnam and Malaysia have emerged as regional manufacturing hubs in Asia, especially for module assembly, benefiting from lower labour costs and trade treaties (IEA, 2022).

The source of finance for firms also plays a role in determining how much value can be captured. High cost of credit limits the ability of firms to retain profits, while concessional credit increases fiscal space. The structural barriers facing Ghanaian RE businesses include high capital requirements, limited access to long-term finance, skills and information gaps, and regulatory and licensing frictions (Sackey et al., 2020). Additionally, the Africa Centre for Energy Policy (2020) identifies Ghana’s limited domestic market as a constraint on sustained demand for RE technologies, citing lack of awareness of their economic potential, continued policy focus on conventional energy and a lack of market data to guide start-ups. These constraints limit local firms’ capacity to invest in inventory, equipment, workforce development, and project development functions, confining them largely to low-margin activities such as installation, retail, and basic operations. As a result, higher-value segments of the chain, including system design, project structuring, technology integration, and procurement, remain dominated by foreign firms.

This stands in sharp contrast to the experience of solar PV companies in other countries, particularly in China, which have benefited from sustained government support in the form of grants, subsidised credit, and state-backed finance. This has allowed them to scale up, move into higher-value activities, and retain a larger share of profits within their domestic economy (IEA, 2022). In GPN terms, this illustrates how access to affordable finance is not merely a commercial issue but a decisive factor shaping firms’ ability to capture and enhance value within GPNs.

The cumulative effect of foreign dominance in technology supply is illustrated in Figure 5, which shows increasing importation of solar systems, translating into increasing value captured by foreign firms.

Figure 5: Import value of items classified under HS Code 854140 into Ghana



Source: UN Trade Statistics (2025)

5. POWER IN THE SOLAR PV PANEL PRODUCTION NETWORK

Power dynamics are central to understanding how GPNs are structured and governed. Different forms of power – corporate, institutional, and collective – shape who has greater influence, who benefits, and whose interests are prioritised within the RE value chain. This section examines the key actors exercising power in Ghana’s RE sector, the strategies they use, and how their interactions influence investment flows, policy direction, and labour outcomes.

5.1 Corporate power

The global solar PV industry is dominated by a few large multinational firms that control the majority of global module production and are critical players in setting both the pace of technological innovation and the structure of supply chains. According to Wood Mackenzie’s rankings, the top-tier manufacturers accounted for about 62% of global production capacity and about 82% of shipments in 2024; Chinese firms rank as the three dominant manufacturers (Wood Mackenzie, 2025).

Table 1: Top global solar PV manufacturers

Rank	Manufacturer	Country	Score (out of 100) ⁵
1	Jinko Solar	China	90.6
2	JA Solar	China	89.8
3	LONGi	China	86.5
4	Canadian Solar	Canada/China	84.0
5	Trina Solar	China	83.7
6	DMEGC Solar	China	83.0
7	Astronergy	China	78.2
8	Boviet Solar	Vietnam	76.3
9	Risen Energy	China	74.2

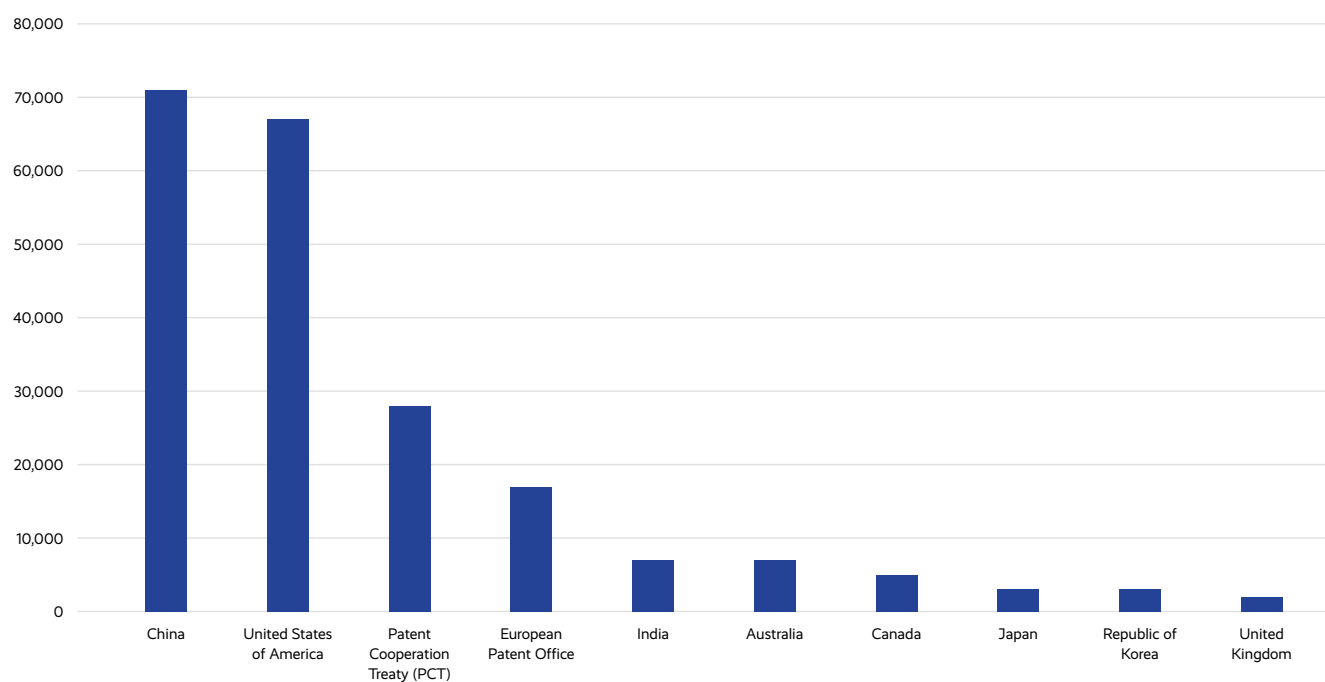
⁵ **Scoring is based on 10 criteria:** capacity utilisation (15%), technology maturity (15%), adherence to ESG and CSR principles (10%), third-party certification availability (10%), financial conditions (10%), production experience (10%), supply chain resilience (10%), vertical integration (10%), years of manufacturing experience (5%), and R&D investment (5%). These collectively assess a firm’s operational efficiency, technological advancement, sustainability, and long-term viability in solar PV manufacturing.

Rank	Manufacturer	Country	Score (out of 100)
10	Qcells	South Korea	73.9
11	Adani Solar	India	72.8
12	TCL Solar	China	70.8
13	Tongwei	China	70.7

Source: Wood Mackenzie (2025)

Chinese firms' dominance in the production network is reflected in the number of inventions they have produced in recent years. From 2016 to 2025, China led global solar PV innovation, accounting for approximately 34% of all solar PV-related patents registered worldwide (see Figure 6).

Figure 6: Number of solar PV-related patents filed by country (2016-2025)



Source: Authors' compilation based on data from World Intellectual Property Organization (n.d.).⁶

Other firms in the United States, Europe, and other countries control most of the rest of the global innovation system through patent ownership. This concentration of intellectual property ownership outside Ghana limits domestic firms' technological autonomy, increases dependence on licensed technologies and imported know-how, and raises barriers to upgrading into higher-value-added segments such as cell manufacturing and advanced module design.

⁶ Search syntax: "solar AND photovoltaic"; period: 2016–2025.

Chinese firms in Ghana are among the country's leading grid-scale solar energy suppliers. In particular, BXC Solar and Meinergy are the only private solar PV firms in Ghana with power purchase agreements with the government (Energy Commission, n.d.). This demonstrates their ability to independently execute large-scale projects without collaborating with local firms. These Chinese firms are also licensed as construction and installation companies (Energy Commission, n.d.). In the absence of local manufacturing, as highlighted by Edze (2025), these Chinese firms also rely on imports from their foreign partners and can leverage economies of scale, supported by Chinese state policies, to achieve lower prices than smaller local firms. The links between Chinese firms and China's innovation system, which dominates global solar PV innovation, provides an entry point for these firms to influence technical specifications and quality standards in Ghana, as they are easily able to comply.

Local firms in Ghana largely depend on technologies developed by these lead firms for materials and components used in downstream activities such as installation and maintenance (Kuada and Mensah, 2020). Although the nature of direct relationships between global lead firms and Ghanaian firms remains unclear, it is evident that global lead firms operate within innovation systems that consistently elevate them above Ghanaian competition in terms of quality, efficiency, technological advancement, and financing capacity (IEA, 2022). Sackey et al. (2020) highlight the lack of access to long-term concessional finance as a key challenge faced by local firms. Chinese lead firms can take advantage of this challenge by relying on concessional state-backed Chinese financing (IEA, 2022).

Nonetheless, Ghanaian firms are increasingly recognising the opportunity to deepen their participation in the solar PV production network. Industry associations such as the Association of Ghana Industries (AGI) and the Association of Ghana Solar Industries (AGSI) are increasingly shaping the solar PV ecosystem. AGI, which represents firms across the manufacturing and industrial sectors, provides capacity-building programmes, offers energy management certification, and facilitates market access for its members and practitioners in the solar industry through its Energy Service Centre (ESC) (AGI ESC, n.d.). For instance, the ESC organised the AGI Renewable Energy & Efficiency B2B Expo in 2025 to facilitate business-to-business collaborations in the RE and energy efficiency sectors (AGI ESC, 2025). AGSI, a sector-specific body representing solar firms in Ghana, also provides training and capacity building for its members, market awareness, and solar PV advocacy, among other things (AGSI, n.d.).

Through these initiatives, the industry associations are gradually laying the groundwork for enhanced skills development, stronger technology transfer mechanisms, and improved sector coordination. These efforts represent important early steps toward enhancing local firm competitiveness.

5.2 Institutional power

Institutional power involves the capacity of states, both domestic and foreign, as well as supranational bodies such as the World Bank and the EU, to shape corporate investment decisions, firm capabilities, and operational strategies within the GPNs. An assessment of Ghana's policy landscape suggests that the state demonstrates a strong formal commitment to localisation in the RE sector, but its practical capacity to influence firms to localise remains uneven and structurally constrained.

5.2.1 The role of Ghana's state policy

Across key policy frameworks, including the National Energy Policy (2021), the Renewable Energy Master Plan (2019), the National Energy Transition Framework (2022), and the National Energy Transition and Investment Plan (2023), the state articulates ambitious localisation objectives. These include explicit local participation targets in solar manufacturing, the promotion of domestic assembly and manufacturing of RE technologies, and the enforcement of Local Content and Local Participation Regulations (LI 2354), which mandate minimum local sourcing thresholds in RE projects. The proposed phasing out of import duty exemptions in the REMP where domestic capabilities exist further signals an intention to protect and nurture local industry. Collectively, these measures provide the state with formal regulatory tools to shape firm behaviour through procurement rules, market access conditions, and industrial incentives.

A central constraint is finance. Local manufacturing of solar PV components is capital-intensive and requires long-term, affordable credit, and sustained investment in technological upgrading. Yet policy documents highlight the absence of robust financing strategies, continued reliance on donor support, and high domestic borrowing costs (Ofori et al, 2025). Without targeted industrial financing mechanisms or concessional support structures, domestic firms may struggle to compete with imported products, particularly from established manufacturing hubs such as China. This weakens the credibility and enforceability of localisation targets, as firms may find compliance commercially unviable.

In addition, while localisation targets are clearly articulated, policies often lack detailed operational roadmaps and incentives. There is limited clarity on sequencing, enforcement mechanisms, technology transfer arrangements, or measurable milestones for SMME integration (Ofori et al, 2025). The absence of detailed implementation frameworks risks reducing localisation commitments to aspirational statements rather than actionable strategies.

Institutional fragmentation further constrains state capacity. Localisation requires coordinated action across energy, trade, industry, finance, labour, and gender institutions. However, Ghana lacks a unified industrial policy that integrates localisation, SMME development, and gender inclusion within a coherent framework (Ofori et al, 2025). The advisory nature of the National Development Planning Commission limits its ability to enforce long-term industrial planning, while periodic policy and institutional changes disrupt continuity. This weakens investor certainty and undermines the sustained coordination necessary for structural transformation.

Gender integration highlights these coordination gaps. Although the National Gender Policy (2015) and the National Green Jobs Strategy (2021) promote women's economic empowerment and skills development, gender-specific pathways are not clearly embedded within RE localisation strategies (Ofori et al., 2025). The limited institutional integration of gender-focused bodies into RE policymaking suggests that localisation efforts may proceed without systematically addressing structural inequalities in access to technical, managerial, and entrepreneurial roles.

Overall, the state's capacity to influence firms to localise can be characterised as conditionally strong in regulatory design but constrained in implementation. The government has established policy frameworks that signal clear developmental intent and provide legal instruments to shape firm

behaviour. However, financial limitations, insufficiently detailed implementation mechanisms, weak data systems, and institutional fragmentation reduce the effectiveness of these policies in practice.

In terms of direct involvement, the state-owned Bui Power Authority (BPA) plays a significant role in pursuing the state's solar energy generation objectives. Backed by an Act of Parliament, BPA has successfully developed solar power generation facilities as part of its strategy to diversify the national energy mix. However, BPA's role is limited to EPC contracting for solar projects, with no direct involvement in the manufacturing of RE components such as solar PV panels or inverters. Similarly, the Volta River Authority (VRA), another state-owned power company, is actively engaged in expanding its share of RE in the generation mix, through granting EPC contracts. However, despite the role of state-owned firms in driving national solar PV deployment, it is unclear whether their EPC contracting is reserved for local firms. Reserving a share of these contracts could create opportunities for capability upgrading along the value chain. Without deliberate procurement preferences, public solar projects risk reinforcing foreign firms' dominance.

The state also plays a role in setting and enforcing industry standards. To ensure that solar PV components meet global standards, the state certifies both locally produced and imported solar PV components through the Energy Commission and the Ghana Standards Authority (GSA) (Adomdza et al., 2016). Local standards are guided by legal instruments, including the Renewable Energy (Standards & Labelling) (Inverters) Regulations, 2022 (LI 2461), the Renewable Energy (Standards & Labelling) (Renewable Energy Batteries) Regulations, 2022 (LI 2452), and the Renewable Energy (Standards & Labelling) (Solar Panels) Regulations, 2022 (LI 2449).

5.2.2 The role of foreign regulatory institutions

On the global front, international regulatory institutions govern the rules and standards that shape global trade and quality assurance in the solar PV market. For example, the International Electrotechnical Commission (IEC) sets global technical and safety standards, such as IEC 61215, which ensures long-term reliability and performance of PV modules. Additionally, IEC 61730 focuses on module safety and protection during operation. These standards are essential for market access, as most importing countries require IEC certification to allow the installation and grid integration of PV systems. The International Organisation for Standardisation (ISO) complements the IEC through quality and environmental standards such as ISO 9000 and 14001, which focus on quality management systems and environmental management practices respectively. Adherence to these standards have become important tools for market access.

International or supranational governance institutions also exercise power within the GPN, with implications for Ghana's PV panel production network. For instance, the EU's trade frameworks, such as the Carbon Border Adjustment Mechanism (CBAM) currently in development, will impose carbon tariffs on imported goods with high embedded emissions. This is particularly relevant for Chinese polysilicon, often produced using coal-fired electricity, which could face higher costs when exported to Europe. For Ghana, the CBAM creates a strategic incentive to position itself in lower-carbon segments of the value chain, particularly if powered by relatively cleaner energy sources. If Ghana seeks to develop local assembly or manufacturing capacity with export ambitions, compliance with

emerging carbon accounting and reporting requirements will become essential. Failure to anticipate these regulatory shifts could constrain market access, while proactive alignment could open niche opportunities in a decarbonising global solar industry.

5.2.3 The role of foreign governments

Foreign governments' industrial, trade, and innovation policies significantly shape the competitive landscape in which Ghanaian local solar PV firms operate. Advanced economies such as Germany and the United States retain dominance in high-technology segments of the value chain, including advanced materials, system integration, and innovation-intensive activities. For example, Germany's Energiewende has historically combined domestic deployment targets with strong R&D support, reinforcing its firms' capabilities in specialised and high-value segments of the industry. Although German and U.S. firms may no longer dominate large-scale module manufacturing, their continued leadership in innovation and system design shapes global standards, intellectual property regimes, and technology trajectories, further widening the technology access gaps for local firms.

Aggressive industrial policy instruments in mature and emerging manufacturing hubs in Asia further intensify competitive pressures. China provides subsidised energy, concessional financing, automation, and vertically integrated production systems (IEA, 2022). These advantages enable Chinese firms to dominate module production and supply global markets at highly competitive prices. India's Production-Linked Incentive (PLI) scheme, which ties government subsidies directly to production volumes, is rapidly expanding domestic PV manufacturing capacity (Ministry of New and Renewable Energy, n.d.). Such output-linked subsidies enable firms to scale up quickly, reduce unit costs, and compete aggressively in export markets.

For Ghanaian firms operating without comparable fiscal support or scale economies, this creates a structural disadvantage. If global supply becomes cheaper due to foreign subsidies, local manufacturing initiatives in Ghana may struggle to achieve cost competitiveness without complementary industrial financing and targeted incentives, particularly for cost-competitive and reliable power, and concessional financing.

5.2.4 The role of financiers

Foreign financing agencies play an increasingly visible role in enabling solar PV deployment in Ghana, but their contribution to localisation remains indirect and limited. The involvement of institutions such as the African Development Bank (AfDB) and the International Finance Corporation (IFC) underscores the importance of concessional and blended finance for the large-scale deployment of solar PV. However, these financing arrangements primarily support the expansion of generation capacity rather than the development of domestic manufacturing or assembly capabilities.

For instance, the BPA's commissioning of the first 30 MW of the 50 MW Yendi solar generation project was supported by AfDB concessional debt (Mordor Intelligence, 2026). Similarly, the IFC's \$130 million loan package to LMI Holdings for the proposed 200 MW Dawa Solar Park signals strong support for private-sector-led utility-scale solar development (Mordor Intelligence, 2026).

Despite these benefits, the structure and conditionalities of such financing arrangements do not appear to prioritise localising manufacturing or assembly, but rather large-scale clean energy generation. As a result, while local firms such as LMI Holdings may gain experience in large-scale solar project development, the role of financiers reinforces historical import dependence for solar PV components.

5.2.5 Conclusion

Ghana's localisation ambitions in the solar PV sector are shaped not only by domestic policy choices but also by external regulatory regimes, international standards, and the strategic priorities of foreign financiers that condition participation in GPNs. To export, assemble, or import quality components, Ghana must align with internationally recognised technical and trade standards, while ensuring that domestic regulations do not undermine access to affordable technologies or violate trade commitments. At the same time, multilateral and development finance institutions, such as the AfDB and IFC, play a pivotal role in determining which segments of the value chain receive capital, often prioritising large-scale generation over local manufacturing. This means that financing structures can inadvertently reinforce Ghana's downstream positioning, unless deliberately aligned with industrial policy goals.

Navigating these layered forms of institutional power requires a strong internal capacity to certify products, enforce quality assurance, coordinate trade, industrial, and energy policies, and strategically negotiate financing arrangements that embed localisation incentives. Ultimately, the state's ability to localise effectively depends on how well it manages global governance frameworks and external financing dynamics, while safeguarding national development and industrial upgrading objectives.

5.3 Collective power

Collective power has played a critical role in shaping Ghana's broader energy sector. Various agents, including civil society organisations (CSOs), trade unions, community-based organisations (CBOs), and the media, leverage their platforms to influence policy, enhance transparency, and promote equitable access. Though less visible in the RE sector specifically, these forms of collective power have nonetheless contributed to creating a broader enabling environment for reform and innovation in energy governance.

5.3.1 Strategies and successes

Civil society actors and the media have employed diverse advocacy strategies, including public engagements, research publications, investigative journalism, and direct government dialogue. These efforts have led to significant policy shifts, particularly around power purchase agreements, energy-sector debt, and inefficiencies in electricity distribution. For example, sustained advocacy from civil society contributed to ongoing government efforts to restructure the electricity distribution sector by promoting increased private sector participation, an initiative aimed at improving efficiency and reducing losses (Ghana News Agency, 2025).

Trade unions, while not specifically in the renewables sector, also influence the energy landscape. Their strategies often involve industrial action and collective advocacy, particularly when labour rights, employment conditions, or state reforms intersect with energy-sector issues. These tactics have historically proven effective in protecting workers' interests and shaping public discourse on energy-sector reforms. For instance, the dismissal of workers by an Independent Power Producer (IPP) in the thermal energy sector in 2023 prompted the Ghana Mine Workers Union to intervene, raising labour rights issues and leading to a court process (Twumasi, 2025). However, the reviewed literature lacks evidence of unionisation specific to the national solar PV sector.

5.3.2 Community organising and civil society coalitions

In resource/project-host communities, CBOs often work closely with residents to demand accountability from stakeholders such as the government and firms (Bosau and Asenso, 2020; Akanchalabey, 2015). Bosau and Asenso (2020) find that CBOs in the Ashanti Region of Ghana play a key role in enhancing community livelihoods in agriculture through facilitating access to information, education and training, and resource mobilisation. Baddianaah and Baaweh (2021) also found that the Zupkiri Community Resource Management Area in the Upper West Region mobilised forest-dependent communities to combat deforestation and protect community members' livelihoods.

Additionally, well-organised CSOs and coalitions have emerged around issues of resource governance. For instance, the Ghana Anti-Corruption Coalition (GACC), comprising CSOs in resource governance, public policy, and anti-corruption, among other areas, mobilises citizens on issues relating to natural resources, governance, and accountability. They have previously raised awareness and drawn citizens' attention to the inefficiencies in the management of oil revenue, while advocating for reforms in effective resource allocation (Ghanaweb, 2023). The Alliance of Civil Society Organisations for Clean Energy Access also coordinates members towards clean energy in Ghana and across Africa (Energypedia, 2025).

These groups demonstrate the existence of social movements with the potential to mobilise citizens, engage policy makers, and advocate for reforms. While their engagement with the solar PV sector is lacking in the reviewed literature, their presence provides a platform to potentially champion such initiatives.

6. EMBEDDEDNESS

Embeddedness captures the extent to which firms are anchored in and relate to other firms and actors within the GPN (Henderson et al, 2002). This section examines embeddedness in Ghana's solar PV production network along three interrelated dimensions: network embeddedness, which focuses on inter-firm relationships and integration within the GPN; territorial embeddedness, which considers the spatial distribution of firms and activities; and societal embeddedness, which explores the social context within which firms operate. These dimensions provide insight into the depth and quality of Ghana's participation in the solar PV GPN and the structural factors shaping local value creation and capture.

6.1 Network embeddedness

Network embeddedness encompasses firms' positioning within the network, the degree of connectivity within a GPN, the stability of agents' relationships, and the network's importance to participants (Henderson et al., 2002). Local firms in Ghana's solar PV value chain are primarily positioned at the deployment and utilisation stages, and at end-of-life. Within these stages, local firms are connected, on the one hand, with other firms and, on the other hand, with a broader ecosystem of stakeholders, including CSOs, academic institutions, industry experts, and state regulators.

Due to the downstream positioning of the local production network, firms rely on vertical relationships with Original Equipment Manufacturers (OEMs) and foreign partners for the supply of technology and knowledge (Kuada and Mensah, 2020). These relationships signal an adaptive strategy by local firms to overcome capacity constraints, reduce transaction costs, and mitigate risks associated with operating in a highly import-dependent and capital-intensive industry. However, while relationships with foreign partners facilitate short-term value creation, they may also reinforce functional specialisation at the lower end of the value chain if not accompanied by deliberate efforts toward upgrading into higher-value activities, such as manufacturing, system design, or technology development.

The structure of relationships between firms in Ghana's solar PV sector reflects a relatively informal and socially influenced network configuration rather than a highly institutionalised or vertically integrated production system. Interactions among firms are largely driven by project-based collaboration, particularly through joint implementation of solar installations and EPC contracts (Edze, 2025). Relationships resulting from these interactions tend to combine transactional elements with trust-based social ties. Firms show a strong willingness to acquire skills and knowledge through collaborations, but these exchanges are often facilitated informally through social connections rather than through structured industry platforms (Kuada and Mensah, 2020). As a result, while trust plays an important role in sustaining certain business relationships, the overall network remains loosely organised and project-driven. This pattern of embeddedness enables some degree of capability development but may limit the sector's scale, coordination, and long-term upgrading potential without more formalised institutional arrangements.

The durability of these relationships varies. While some firm interactions are tied to specific contracts, there are examples of more stable and enduring linkages. Some firms maintain relationships of five years or more, particularly in cases where technology is supplied on credit (Kuada and Mensah, 2020). However, the broader network does not appear to be characterised by long-term, institutionalised partnerships across the industry as a whole, and there is little evidence of coordinated, aggregate-level efforts to systematically enhance value within the sector.

Network embeddedness can also be assessed through firms' ownership structures, which could impact how these firms relate. In Ghana, detailed studies would be needed to fully map inter-firm ownership structures in the national solar PV production network. However, insights from the broader electricity sector show the presence of co-ownership arrangements (Energy Commission, n.d.). These arrangements could largely be driven by Ghana's local content and local participation law, which mandates shared investments between foreign and local entities. Supply contracts, such as those involving fuel provision for IPPs, also reflect the existence of formal inter-firm agreements in Ghana's energy sector.

For SMMEs in the RE sector, the main barriers to deeper integration into the GPN appear to be economic. High production costs make it difficult for local firms to remain competitive (Sackey et al., 2020). While more research is needed to determine the extent to which relationships with OEMs and lead firms affect their positioning, these economic constraints remain a major obstacle to full embedding in the GPN.

In addition to the national level, the global literature shows that how firms are embedded within international innovation and production networks has important implications for economic performance, learning, and upgrading. Shubbak (2018), drawing on evidence from China's solar PV sector, finds that firms embedded in well-structured "small-world" networks, characterised by dense clustering and short path lengths, achieve better economic outcomes, but only when their innovation quality is high. Importantly, these clustered networks outperform simple high-centrality positions, suggesting that indirect connections and network architecture matter more than the number of direct ties. This insight shows that effective network embeddedness is less about being connected to many actors and more about being embedded in networks that facilitate efficient knowledge diffusion and collective learning.

Drawing from the experience of the United States fuel cell industry, Vasudeva et al. (2013) suggest that firms must align their networking strategies with the norms and governance frameworks of their partners to enhance innovation outcomes. This highlights the interaction between network structure and the institutional power of foreign countries within the GPN. In the solar PV industry, Teng et al. (2021) further demonstrate that organisational and cognitive proximity, such as shared routines, norms, and knowledge bases, are influential factors in shaping networks. Together, these studies suggest that global solar PV networks privilege firms that are deeply embedded in organisationally coherent and institutionally supportive environments.

Evidence from developing-country contexts reinforces these insights, while highlighting pathways relevant for latecomer firms. Davy et al. (2021), examining South Africa's solar PV sector, show that multinational subsidiaries achieved rapid innovation upgrading through dual embeddedness: early-stage

learning was driven by strong ties to parent companies and internal firm processes, while collaboration with local research institutions became important only after foundational capabilities were established. This sequencing underscores the importance of phased network embeddedness, where firms initially rely on global pipelines before gradually deepening local linkages. Similarly, Oh and Gress (2017) demonstrate that extra-firm actors, such as government agencies, research institutes, and industry associations, play a critical role in shaping firm performance in the solar PV sector, though their impact varies according to technological capability and scale. Finally, Yan et al. (2019) show that both relational embeddedness (trust-based ties) and structural embeddedness (network positioning) support exploitative innovation, reinforcing the idea that stable inter-firm relationships are central to incremental upgrading.

Ultimately, the global literature suggests that network embeddedness is a dynamic and multi-scalar process that combines global production linkages, local institutional support, and firm-level learning strategies. For Ghana, these insights imply that, while current horizontal and vertical relationships among local firms support short-term participation and diffusion of solar PV technologies, deeper and more strategic forms of embeddedness, particularly those linked to innovation quality, institutional alignment, and phased capability building, will be critical for moving local firms into higher-value segments of the global solar PV production network.

6.2 Territorial embeddedness

Territorial embeddedness refers to the extent to which firms are rooted in specific locations, drawing on and sometimes being shaped or constrained by economic activities, institutional arrangements, and social dynamics already present there (Henderson et al., 2002). In Ghana's solar PV sector, despite tax incentives for manufacturing firms to locate outside regional capitals (Republic of Ghana, 2015), territorial embeddedness is reflected in the strong spatial concentration of firms within the Greater Accra Region. According to the Energy Commission (n.d.), approximately 90% of registered solar PV firms are located in Greater Accra, with the remaining 10% distributed across the Northern, Central, Upper East, Western, and Ashanti regions. While this concentration suggests a spatial clustering of industry actors, Adomdza et al. (2016) note that many of these firms operate outlets and dealer networks across other regions, enabling national market coverage while their administrative and operational bases are in Accra.

Greater Accra's dominance reflects its role as the country's primary commercial and administrative hub, characterised by higher population density, superior infrastructure, proximity to regulators and financiers, and the highest mean annual household income and expenditure in the country (Ghana Statistical Service, 2019; 2021). These factors create strong demand-side and logistical advantages that tend to anchor firms to the capital region. Although the literature does not directly link firms' embeddedness within the capital to these demand-side factors, firms appear to be territorially embedded through market access, service demand, and institutional proximity. This reinforces Accra's role as the central node in the national solar PV production network.

Insights from international literature are useful for interpreting Ghana's territorial dynamics and identifying alternative pathways for fostering strong, locally embedded production networks. In China,

Huang and Liu (2017) show that RE firms became geographically clustered around pioneering companies and in locations where proactive local government interventions, such as the establishment of RE-oriented industrial parks, created concentrated ecosystems of production, innovation, and supply chain linkages. Similarly, in France, Cointe (2018) finds that agricultural-led solar PV deployment through cooperatives anchors solar industries within specific rural territories, with inter-sectoral linkages between agriculture and energy fostering durable locally embedded economies .

Applied to Ghana, these cases suggest that stronger local development in the solar PV sector may require deliberate place-based strategies beyond fiscal incentives. The absence of specialised industrial parks, sector-specific clusters, or strong cross-sectoral linkages between RE and sectors such as agriculture, mining, or manufacturing, limits the extent to which solar PV firms become embedded outside Accra. Lessons from China and France indicate that private-sector initiatives and sectoral integration could help anchor solar PV activities in other regions, transforming them from peripheral markets into active sites of production, learning, and value creation within Ghana's national production network.

6.3 Societal embeddedness

Within the GPN analytical framework, societal embeddedness refers to the ways in which firms are shaped by prevailing social norms, household structures, gender relations, and cultural expectations within the communities where they operate. This section examines the lived social conditions that structure everyday life and that any new worker, entrepreneur, or investor entering the Ghanaian solar PV sector would immediately encounter.

A defining feature of Ghanaian society is the centrality of extended family systems and strong kinship obligations. Income earned by workers in sectors such as electricity and solar PV is rarely confined to the individual; it is often redistributed through intra-household and extended family transfers to support food, housing, education, and family obligations such as parent support and childcare, among others. According to the Ghana Living Standards Survey (seventh edition), Ghanaian households spend, on average, 45.4% of their income on food, while housing, education, clothing and transport account for a further 43.3% (Ghana Statistical Service, 2019). Family support also forms part of household expenditure, accounting for 3.1%. Within total transfers, income transfers to parents account for 25.9%, while transfers to children, siblings, and spouses account for 21.4%, 14.9%, and 8.5%, respectively. Transfers to other relatives and non-relatives account for the remaining 29.3%.

These obligations influence labour market participation, savings capacity, and risk-taking behaviour. For example, workers may prioritise income stability over risky entrepreneurial ventures due to financial responsibilities toward dependents. For firms, this social structure can shape wage expectations, labour mobility, and employee retention patterns.

Gender dynamics within households and the broader labour market significantly condition participation in the solar PV sector. Although women are active economic agents in Ghana, structural inequalities persist in both paid and unpaid spheres of work. Women perform almost 3.4 times more unpaid work than men, averaging 15.5 hours per week compared to 4.6 hours for men (AfDB, 2022). This unequal

distribution of care and domestic responsibilities may constrain women's available time, mobility, and capacity to engage in technically demanding or field-based roles within the solar PV value chain.

These inequalities are mirrored in firm-level leadership structures. AfDB's survey further shows that only 14.9% of firms have female managers, indicating significant gender disparities in decision-making and leadership positions. While women account for 37.9% of all business owners, demonstrating notable entrepreneurial presence, the majority operate within the informal economy. Informal employment accounts for 86.1% of total employment in Ghana, with women disproportionately represented: 90.9% of employed women are in informal employment, compared with 81% of employed men. This overrepresentation in informal employment often leads to lower earnings stability, limited access to finance, reduced social protection, and weaker integration into formal production networks, such as large-scale solar PV projects.

These patterns suggest that gendered household responsibilities, occupational segregation, and informality structurally shape women's participation in Ghana's solar PV sector. Without deliberate interventions to address unpaid care burdens, leadership gaps, and the formalisation of women-led enterprises, existing social norms and labour market inequalities are likely to be reproduced within the RE transition rather than transformed by it.

Rural-urban cultural differences further shape societal embeddedness. The majority of electricity-sector employment is concentrated in urban areas, yet urban living entails high housing costs and social pressures (Ghana Statistical Service, 2023). Migrants from rural areas entering urban solar employment must adapt to different social norms, higher living expenses, and often precarious rental arrangements. At the same time, strong ties to rural hometowns are typically maintained, reinforcing obligations to transfer income and patterns of seasonal mobility. These dual attachments influence labour stability and workers' willingness to relocate permanently.

Energy use itself reflects entrenched cultural and gender norms. While national electricity access has improved substantially (Energy Commission, 2025), affordability and social practices influence how electricity is used within households. In many low-income or rural households, cooking and other traditionally gendered tasks continue to rely on traditional fuels (such as firewood, charcoal, crop residues, or animal waste) rather than electricity, even where grid access exists (Ali, E., et al., 2024). This reflects not only economic constraints but also embedded cultural practices around food preparation and domestic roles (Asibey, 2024). Thus, the benefits of expanded electricity generation do not automatically translate into transformed gender relations or reduced unpaid labour burdens.

Community expectations also shape firm behaviour. Community-firm interactions through corporate social responsibility initiatives are often interpreted as philanthropic rather than strategic (Blay et al., 2021). Communities may expect visible contributions to local development. However, when CSR interventions are perceived as tokenistic or externally imposed, they can generate mistrust (Mohammed et al., 2022). The social legitimacy of firms, therefore, depends not only on regulatory compliance but also on their responsiveness to local cultural expectations and participatory practices.

Generally, societal embeddedness in Ghana's solar PV sector is defined by strong kinship systems, gendered household divisions of labour, rural-urban social ties, and culturally embedded energy

practices. These conditions shape labour participation, mobility, skill acquisition, and firm-community relations. Any new entrant into the sector, whether a worker or a firm, must navigate these social norms and expectations, which both enable and constrain the development of an inclusive, locally rooted solar PV industry.

7. CONCLUSION

Ghana stands at a strategic juncture in its clean energy transition. While much attention has been placed on the deployment of solar PV systems as a route to increase energy access and diversify the generation mix, a more transformative opportunity lies in positioning Ghana within GPNs in ways that support localisation, job creation and other forms of economic and social development. This means looking beyond the mere reduction in the cost of imported solar panels, towards using the clean energy transition as a platform for industrial development, decent job creation, and technological capability building.

Localising elements of Solar PV value chains also offers opportunities to mitigate new challenges associated with the global energy transition. For example, as millions of solar panels reach end-of-life over the next two decades, Ghana could position itself as a regional hub for recycling and material recovery, especially for valuable metals such as silver, copper, and aluminium. This would support a circular economy, while enhancing raw material security and generating green jobs in secondary industries.

The labour-intensive nature of module assembly is particularly suited to the skill profile and employment needs of developing countries. This opportunity presents a strong case for Ghana to expand vocational training, invest in technical universities, and integrate local labour into solar PV panel manufacturing. Moreover, Ghana's civil society actors can play a critical role in ensuring that the localisation agenda remains inclusive, socially responsive, and gender-sensitive.

The actors already discussed can be better coordinated to unlock these opportunities. For instance, the Ministry of Energy's recent rebranding to include "Green Transition" should not be merely symbolic; it must drive the implementation of holistic green strategies that promote localisation across clean energy value chains. The Energy Commission and Ghana Standards Authority can collaborate to strengthen certification systems and technical standards for locally produced modules.

Ghana can learn from India's localisation model and explore how regional trade agreements, like the African Continental Free Trade Area (AfCFTA), and industrial incentives could attract investment into its own PV sector. The assessment by the Africa Centre for Energy Policy (ACEP) of the solar PV value chain shows that the AfCFTA could facilitate intra-continental trade in goods across the solar PV value chain, as they largely satisfy rules of origin requirements (Boakye and Ofori, 2022). Targeted interventions such as providing concessional financing for R&D, developing recycling infrastructure, and establishing industrial clusters linked to regional trade hubs could help Ghana build a competitive niche in the global solar PV production network.

The analysis also shows that Ghana's solar PV sector is not only shaped by market and policy dynamics but also by embedded social, institutional, and network structures. Weakly formalised inter-firm networks, strong dependence on foreign technology and finance, gendered household divisions of labour, and community expectations together condition how value is created and captured locally.

These layered forms of embeddedness both enable incremental learning and constrain deeper industrial upgrading. As such, any meaningful localisation strategy must move beyond deployment targets to address the institutional alignment, social norms, and network relationships that ultimately determine who participates in, benefits from, and advances within Ghana's RE transition.

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