UNEP

GREEN economy and TRADE

Ghana Solar Export Potential Study

Citation

UNEP (2015). *Ghana Solar Export Potential Study.* Geneva: UNEP.

UNEP

Disclaimer

UNEP

GREEN economy and TRADE

Ghana Solar Export Potential Study

Acknowledgements

The Solar Export Potential Study (SEPS) was commissioned by the United Nations Environment Programme (UNEP), as represented by its Trade, Policy and Planning Unit of the Economy and Trade Branch. UNEP's Energy Branch and Risø Center have considerably contributed to the process and development of this study.

The overall development and content of this study was responsibly managed by Lennart Kuntze, under the general supervision of Anja von Moltke, Head Trade Policy and Planning Unit. John Maughan significantly contributed to the management and development of the study. Martina Otto, as former head of Energy Policy Branch, and Emmanuel Ackom (UNEP Risø Center) provided significant contributions to the development and content of the study. The initial idea for this study was guided by Lawrence Agbemabiese (former UNEP Energy Branch), in discussion with Prof. Abeeku Brew-Hammond, Akua Akuffo, Anja von Moltke, Martina Otto and Lennart Kuntze.

Authors: This report was authored by The Energy Center (TEC) of the Kwame Nkrumah University of Science and Technology, KNUST, as represented by Lena Dzifa Mensah, David Ato Quansah, Emmanuel Narh, Ebenezer Nyarko Kumi, Anthony Osei-Fosu, and ably supported by Samuel Yeboah and Triumph Tetteh.

UNEP and TEC are grateful to the following individuals and their host institutions for their input into the execution and review of the Solar Export Potential Study:

SEPS Consultative Team: Rose Mensah Kutin (ABANTU for Development), Fred Akuffo (Aekosolar), Richard Addo (ARB APEX Bank), Samuel Adu Asare (Association of Solar Ghana Industries), Julius Ahiekpor (Centre for Energy and Sustainable Development), Oumar Bangoura (ECOWAS Regional Electricity Regulatory Authority), Godfred Mensah (Electricity Company of Ghana), Norbert Anku (Ghana Grid Company), Simon Bawakyillenuo (ISSER), Ishmael Ejekumhene (Kumasi Institute of Technology and Environment), Peter Dery (MESTI), Seth Agbeve and Gifty Tettey (MoEP), Magdalene Apenteng and Osei Oteng Asante (MoFEP), Papa Bartels (MoTI), Amadu Mahama (New Energy), Elvis Demuyakor (Northern Electricity Distribution Company), Oscar Amonoo-Neizer (Public Utility and Regulatory Commission), George Amegashie (Takoradi Thermal Plant), Ahmad Addo, Kwaku Anto, Edward Awafo, Eric Osei Essandoh, Robert Kyere and Edward Quarm (TEC), Daniel Serme (SONABEL), Lennart Kuntze, John Maughan, Martina Otto and Rhoda Wachira (UNEP), Emmanuel Ackom (UNEP Risø Centre), Linus Abenney-Mickson and Ekow Sam (VRA), and Agyenim Boateng (Wilkins Engineering).

Reviewers: Fred Akuffo (Aekosolar), Seth Agbeve (MoEP), Papa Bartels (MoTI), Kwaku Anto (TEC), Lennart Kuntze, Simon Lobach and John Maughan (UNEP), and Emmanuel Ackom (UNEP Risø Center).

Special Thanks: The SEPS Team is also eternally grateful to the late Professor Abeeku Brew-Hammond, who, through his belief in the potential of solar power in West Africa, sparked the initial ideas and dialogue towards the development and execution of the SEPS. Last but not least, the SEPS Team is grateful to Akua Afuffo, who started developing the initial ideas of this study with Prof. Abeeku Brew-Hammond, but had to travel abroad to further her education.

UNEP and the authors would like to thank the European Commission for the financial support provided by the EU to the Green Economy and Trade Opportunities Project.

List of Acronyms

AC	Alternating Current
ADF	African Development Fund
ADFD	Abu Dhabi Fund for Development
AFD	Agence Française de Développement
AfDB	African Development Bank
AGSI	Association of Ghana Solar Industries
AICD	Africa Infrastructure Country Diagnostic
ATSE	Academy of Technological Sciences and Engineering
B-C	Benefit-Cost
BOS	Balance of System
BRIC	Brazil, Russia, India and China
CEB	Communauté Electrique du Benin
CEESD	Centre for Energy, Environment and Sustainable Development
CEET	Compagnie d'Energie Electrique du Togo
CEO	Chief Executive Officer
CIE	Compagnie Ivoirienne d'Électricité
C-Si	Crystalline Silicon
DC	Direct Current
DSCR	Debt-Service Coverage Ratio
EC	Energy Commission
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EDF	Electricité de France
EEA	European Environment Agency
EIA	Energy Information Administration
EPIA	European Photovoltaic Industry Association
ERERA	ECOWAS Regional Electricity Regulatory Authority
ESEI	ECOWAS Solar Energy Initiative
EU	European Union
EUR	Euro
FIT	Feed-in Tariff
FTE	Full-Time Employees
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GE	Green Economy
GEI	Green Economy Initiative
GEF	Global Environment Facility
GE-TOP	Green Economy and Trade Opportunities Project
GHG	Green House Gas
Gh₵	Ghana Cedi
GIS	Geographic Information System
GPRS	Ghana Poverty Reduction Strategy
GRIDCo	Ghana Grid Company

GSGDA	Ghana Shared Growth and Development Agenda
GTZ	Gesellschaft für Technische Zusammenarbeit
GWp	Gigawatt peak
HV	High Voltage
IEA	International Energy Agency
IEC	International Electrochemical Commission
IFF	Infrastructure Finance Facility
ILO	International Labour Organisation
IPP	Independent Power Producers
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
ISO	International Organization for Standardization
ISRIC	International Soil Reference and Information Centre
ISSER	Institute of Statistical, Social and Economic Research
KNUST	Kwame Nkrumah University of Science and Technology
kTOe	Kilo Tonnes of Oil Equivalent
LCO	Light Crude Oil
LCR	Local Content Requirements
MA	Millennium Ecosystem Assessment
MESTI	Ministry of Environment, Science, Technology and Innovation
MoEP	Ministry of Energy and Petroleum
MoFEP	Ministry of Finance and Economic Planning
MoTI	Ministry of Trade and Industry
MWp	Megawatt Peak
NA	Not Applicable
NDPC	National Development Planning Commission
NEDCo	Northern Electricity Distribution Company
NEP	National Energy Policy
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
OECD	Organization for Economic Co-operation and Development
PPP	Public-Private Partnership
PSEC	Power Systems Energy Consulting
PURC	Public Utilities Regulatory Commission
PV	Photovoltaic
RCREEE	Regional Center for Renewable Energy and Energy Efficiency
RE	Renewable Energy
RE & EE	Renewable Energy and Energy Efficiency
REN21	Renewable Energy Policy Network for the 21st Century
SADA	Savannah Accelerated Development Authority
SAUR	Société d'Aménagement Urbain et Rural
SEPS	Solar Export Potential Study
SNEP	Strategic National Energy Plan
SONABEL	Societé Nationale d'Electricité du Burkina Faso
SWERA	Solar and Wind Energy Resource Assessment (UNEP)
TBT	Technical Barriers to Trade

TEC	The Energy Center
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNCSD	United Nations Conference on Sustainable Development
UNEMG	United Nations Environment Management Group
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
US$	United States Dollar
VAT	Value Added Tax
VGS	Viability Gap Scheme
VRA	Volta River Authority
WAPP	West African Power Pool
WTO	World Trade Organization

CONVERSION FACTORS AND DECIMAL MULTIPLIERS

1kTOe = 11,627.91 kWh[1]
1 kWh = 3.6 x 10^6 joules (J)
Kilo (k) - 10^3
Mega (M) – 10^6
Giga (G) - 10^9
Tera (T) – 10^{12}

1 Based on Ghana Energy Commission's conversion factor.

Table of contents

List of Figures

List of Tables

Executive Summary

Traditional models of economic development, which, in pursuit of achieving economic growth, prioritize investments in physical and human capital at the expense of natural resources, are yielding increasingly negative environmental, social and economic externalities. The traditional mode of allocating capital contributes to challenges related to energy, climate, economic growth, poverty and biodiversity, among others.

There is a general consensus among governments, private sector and civil society that green economy (GE) is an important tool for achieving sustainable development and poverty eradication. The United Nations Environment Programme (UNEP) defines GE as an economy that results in improved human well-being and social equity, whilst significantly reducing environmental risks and ecological scarcities.

As a fast-growing lower-middle-income economy, Ghana seeks to develop an export-led economic model that promotes, among others, employment creation and economic growth. This vision also emphasizes regional trade, in accordance with the mission of the Economic Community of West African States (ECOWAS). ECOWAS promotes economic integration in "all fields of economic activity […] including energy." (ECOWAS, 2007)

Ghana and its neighbours have had cross-border electricity supply arrangements for decades. With the development of large hydro-electric power plants in Ghana, in the 1960's and 1980's, Ghana has for many years been trading electricity with its neighbours through special arrangements, mainly at the political level. In 2011, for example, Ghana exported over 5 per cent (610 GWh) of all nationally produced electricity.

Since 2011, Ghana has enacted legislation that has created the legal and regulatory framework for the development of renewable energy. In August 2013, feed-in-tariffs were implemented for the first time. Although the country has had to grapple with power supply difficulties in recent years, it remains an active exporter of electricity to its neighbours (Togo, Benin and Burkina Faso) and intends to increase its participation in regional power trade. These conditions, together with the generally positive investment climate, as indicated by the World Bank's Doing-Business reports, have made Ghana more attractive for renewable energy trade and investment.

This study, the Ghana Solar Export Potential Study (SEPS), assesses the green economy and trade potential of solar power in Ghana. It establishes the legal, technical and financial feasibility of solar electricity exports in the near term, as well as Ghana's current and future capabilities to contribute to the global solar Photovoltaic (PV) value chain in the medium-to-long term. Finally, it assesses the environmental, social and economic impacts that increased solar energy trade may bring to Ghana and the sub-region.

Methodology

In this study, a variety of tools and techniques have been used for both data collection and analysis, including archival research and stakeholder consultations. For all major sections of the study, archival documents facilitated the capture of the current situation of Ghana, Burkina Faso and other relevant country data. These documents were drawn from reputable institutions such as the Ministry of Energy and Petroleum (MoEP) of Ghana, UNEP and the European Photovoltaic Industry Association (EPIA). Analytical tools included ArcGIS and the RETScreen Clean Energy Analysis Software, which were used to estimate the amount of land available for solar PV power generation and Ghana's solar radiation profile, respectively. RETScreen was also used for the financial analysis. Two national stakeholder workshops were organized to obtain key stakeholder inputs to the design and completion of the study. In addition, interviews were conducted with government, civil society and industry actors.

Regional electricity trade initiatives and renewable energy

ECOWAS has formed sub-regional organizations that provide the institutional basis for regional power trade. These include the West African Power Pool (WAPP), the ECOWAS Regional Electricity Regulatory Authority (ERERA) and the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE).

WAPP develops cross-border interconnection infrastructure, fosters power exchanges between Member States, harmonizes legislation and standards and creates an open and competitive regional electricity market. ERERA is mandated to regulate interstate electricity exchanges and gives targeted support to national regulatory bodies. ECREEE's objective is to increase access to modern, reliable and affordable energy services, as well as create a favourable framework and enabling environment for renewable energy and energy efficiency markets. ECREEE also supports activities directed at mitigating existing barriers. Together, WAPP, ERERA and ECREEE, with their various mandates, are creating and improving conditions for an efficient sub-regional power market based on renewable energy.

Ghana's policy and regulatory framework on renewable energy

In recent years, Ghana's policy and regulatory landscape has seen a number of significant initiatives that fostered the development of national renewable energy capacity. Starting with the Strategic National Energy Plan (SNEP) of 2006, Ghana has put in place a National Energy Policy (NEP), intended to facilitate the development and effective management of the energy sector, which would ultimately lead to the realization of Ghana's vision of becoming an energy economy, with a significant contribution of renewables. The country is aiming to become a major exporter of power to the West African sub-region by 2015. To ensure that this aim is achieved, Ghana plans to increase power generation capacity to 5,000 MW by 2015.

In 2011, Ghana passed the Renewable Energy Law (Act 832) to provide the framework for a sustainable, low-carbon energy economy, with reliable power for industry and households, as well as green jobs. Ghana's energy strategy has set a target of generating 10 per cent of electricity from renewable energy (RE) sources (excluding large hydropower installations) by 2020. Also in 2011, Ghana developed a Public Private Partnership (PPP) policy to encourage a wide variety of efficient, high-quality public infrastructure and services. Ghana's initiatives have provided a strong legal basis for supporting increased regional trade in renewable energy.

Ghana's solar energy generation potential

Ghana, like many countries in Africa, is blessed with abundant solar radiation. In the northern regions where exposure is highest, Ghana receives an average of up to 6.5 $kWh/m^2/day$ of solar radiation. This is also a region where lands remain relatively little developed, leaving vast space for solar capacity additions. By restricting the analysis to the 10 per cent of lands in the northern regions that are within 20 km of transmission infrastructure, and after having eliminated the lands that are already in use for competing purposes such as agriculture and protected areas, an estimated 2,965.7 km^2 of Ghana's land remains available for solar energy development. This land area could theoretically generate up to 167,200 GWh of electricity annually with an installed capacity of 106 GWp.

Ghana plans to increase its generation capacity to 5,000 MW by 2015, with at least 10 per cent renewable energy (excluding large hydropower). MoEP has recently announced a cap of 550 MW on intermittent renewable energy generation capacity, of which 150 MW are allocated to solar PV capacity and 300 MW to wind. It is not certain whether this 150 MW of solar power can easily be integrated into the upgraded grid system. For the purposes of this study, it is assumed that this near-term goal of 150 MW in installed solar generation capacity will largely be installed within 20 km of the grid in Ghana's northern regions and that ample land should be available.

Additional potential: participation in the global solar PV value chain

In order to create an export-led economic model, the most feasible way to participate in the global solar PV value chain appears to be upstream, manufacturing components and parts. Specifically, Ghana could concentrate on the balance of system segments of the chain, such as charge controllers, cables, mounting frames and conductors. Some existing local manufacturers already have the expertise to provide such components for national electrification projects. These manufacturers could be integrated into the global value chain with minimal adaptation. Based on the existing expertise, the manufacturing of cells, modules and inverters is among the probable goals for the medium to long term.

Key Results

Ghana's technical and financial potential for solar electricity exports

On the technical side, Ghana's grid is currently at or near maximum load capacity. Ghana's transmission infrastructure, which comprises 161 kV lines as the primary backbone, is a significant constraint to the integration of high levels of intermittent renewable energy, considering that the country's installed capacity in 2012 was 2,280 MW. However, Ghana's target of doubling generation capacity from current levels to 5,000 MW by 2015, as well as current plans to expand the grid, increases the prospect of the grid being able to accommodate larger volumes of solar electricity for export. As projected, Ghana's grid expansion should provide the technical capacity to support a 150 MW installation of intermittent, solar-generated power, but the technical details are beyond the scope of this study.

On the financial side, with a typical installed cost of US$ 3,000/kW and other financial input parameters as detailed in this study, an energy production cost of US$ 208.27/MWh is estimated for a 20 MW solar installation running 25 years. This cost is just covered by Ghana's current feed-in tariff rate of US$ 210/MW. Through grid expansions and continued financial support, in conjunction with Ghana's institutional and regulatory support mechanisms, the economy could be set to support more solar electricity exports at cost price, but additional financial support is probably needed to attract investment.

However, when the installed cost falls to US$ 2,000/kW, the energy production cost decreases to US$ 144.5/MWh. This compares favourably with the prevailing electricity generation cost of US$ 250/MWh in a neighbouring country such as Burkina Faso, and becomes competitive with traditional energy exports at today's relatively low cross-border bulk supply tariff rate of around US$ 150/MWh. The price of electricity exports could further decline in coming years as WAPP continues to implement projects designed at integrating regional energy markets.

Thus, until the cost of installed capacity falls to US$ 2,000/kW or less, and operational costs for solar PV generation become price-competitive with traditional power sources such as large hydro and thermal power, public commitment and support in Ghana and ECOWAS will be necessary to trigger increasing solar energy trade.

Environmental, social and economic benefits

Although Government sources estimate 150 MW of solar PV, this study adopts a conservative working figure of 100 MW of solar PV in the near to medium-term (by 2020) and finds that several environmental, social and economic benefits could accrue from this estimated national solar PV capacity. These include foreign exchange benefits in the order of up to US$ 38 million annually, an estimated 3,000 direct and indirect jobs, providing livelihoods for over 23,000 people, and an emissions reductions of over 40,000 tCO_2 per year, using Ghana's current emissions factor for the energy sector. The emissions reductions may more than double if the emissions factor of a neighbouring trade partner is used, potentially reaching 700 tCO_2/GWh in Burkina Faso, where power generation is dominated by diesel power systems.

Policy Recommendations and Next Steps

Based on the above conclusions, this study makes the following recommendations:

1. *Regional bodies such as WAPP and ECREEE should engage Member States and/or international stakeholders to develop new financial support mechanisms for solar PV trade.* The cost of electricity generation from solar PV remains relatively high in comparison with current cross-border bulk supply tariff rates of around US$ 150/MWh. Regional or international funds structured to support low-carbon energy production and infrastructure should be engaged in this effort.

2. *Financial and institutional support mechanisms available to investors in the renewable energy sector (particularly solar PV) should be documented and promoted,* for example through an investor reference catalogue. These could include public-private partnership opportunities or concessionary financing arrangements provided by *inter alia* WAPP, the ECOWAS Solar Energy Initiative (ESEI), bilateral or multilateral partners, and the World Bank.

3. *The current capacity of Ghana's grid, including planned expansions, should be investigated with a view to identifying technical and financial needs for incorporating new solar electricity supplies into cross-border trade*. The effect of solar intermittency, including the need for base load and load balancing, would be considered for determining the needs for grid improvement. Ghana's grid might also require extension to accommodate new solar PV sites.

4. *Ghana's preferred sites for solar PV installation and grid feed-in should be identified*. Such a study could be undertaken in conjunction with GRIDCo and WAPP to analyse the effect of MW-scale solar PV injection at various locations and various scenarios, and should account for the existing power infrastructure as well as the infrastructure planned under the WAPP initiative.

5. *The Government of Ghana should initiate steps to ease the process of land acquisition for ground-mounted solar PV projects.* MW-scale solar PV projects often require large areas of land. Ghana's current land tenure system faces significant challenges and is often cited as a drawback to investment.

6. *The technical process for adding new solar generation capacity in Ghana and incorporating it into cross-border trade should be documented*. This would facilitate project developers and government policymakers in efforts to improve Ghana's solar trade potential. The process may be mapped out in partnership with the Volta River Authority (VRA) – Ghana's state power generation utility – given its decades of experience in Ghana's cross-border power supply.

1. Introduction

Traditional economic development models, which prioritize investments in physical and human capital at the expense of natural capital, in order to maximize economic growth, are yielding increasingly negative environmental, social and economic externalities. The traditional mode of allocating capital is contributing to challenges in the fields of climate, energy, biodiversity, poverty and economic development, among others (UNEP, 2011a).

The world population is projected to grow from the current 7 billion people to more than 9 billion people by 2050, which amounts to a growth of approximately 28 per cent. Population growth will lead to higher production and consumption (UNEMG, 2011), and increased international trade.

The Millennium Ecosystem Assessment and the United Nations Environment Programme (UNEP) suggest that current populations and consumption and production patterns are already yielding considerable negative externalities on the environment (MA, 2005; UNEP, 2011b). For example, it was found that 15 out of the 24 major ecosystem services are being gradually degraded and/or used unsustainably.

Given the economic models in use, the trend of environmental degradation, and the projected world population growth, future trends are not promising. However, the anticipated negative externalities can be averted if current approaches to socio-economic development are fundamentally transformed in order to make a more efficient use of resources and energy. In order to enhance environmental protection, it should also be ensured that consumption patterns are oriented towards goods and services that are less resource and carbon-intensive (UNEMG, 2011).

The green economy (GE) is generally regarded among governments, private sector and civil society as an important tool for achieving sustainable development and poverty eradication. The United Nations Environment Programme (UNEP) defines a GE as an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP, 2011a). The GE concept provides an approach to sustainable development that moves away from resource-intensive economic growth models, stewards sustainable production and consumption, and enhances the creation of value added and reinvestment in resource-rich supplier communities in developing countries (UNEMG, 2011). At the operational level, a green economy fosters growth in income and employment, driven by investments that reduce carbon emissions and pollution, enhance resource efficiency, and prevent the loss of biodiversity and ecosystem services (UNEMG, 2011).

Since 1989, when the term "green economy" first appeared in the report "Blueprint for a Green Economy" (Pearce et al., 1989) interest in GE transitions have evolved and intensified at all levels: global, regional and national. A number of international initiatives and support programmes to foster green economy transitions at the national level have been launched, including initiatives to foster international trade in environmental goods and services.

The United Nations (UN), as a collective institution, raises awareness at the global level on key issues such as sustainable development, through a variety of mechanisms: international summits and conferences, like the United Nations Conference on Environment and Development (UNCED, 1992), and the United Nations Conference on Sustainable Development (UNCSD, 2012). Through its Regional Commissions, the UN stimulates regional dialogue and consensus, which can often lead to coordination of regional and sub-regional activities and partnerships to drive ahead the green economy agenda.

1.1 UNEP's Green Economy and Trade Opportunities Project (GE-TOP)

The UNEP-led Green Economy Initiative (GEI), launched in late 2008, consists of several components whose collective overall objective is to provide the analysis and policy support for investing in green sectors and in greening environmentally unfriendly sectors.

The GEI includes three sets of activities:

1. promoting findings from the GE Report and related research materials, which analyse the macroeconomic, sustainability, and poverty reduction implications of green investment in a range of sectors, from renewable energy to sustainable agriculture, and providing guidance on policies that can catalyse increased investment in these sectors;
2. providing national-level advisory services to create the enabling conditions to move towards a green economy in specific countries and economic sectors, and enhancing the sustainability of international trade; and
3. engaging a wide range of research institutions, non-governmental organizations, businesses and UN partners in implementing the Green Economy Initiative.

To contribute to this effort, UNEP's Trade, Policy and Planning Unit is undertaking the Green Economy and Trade Opportunities Project (GE-TOP). GE-TOP, which is financially supported by the European Commission, aims to (UNEP, 2013):

1. identify a range of international trade opportunities in various key economic sectors associated with the transition to a green economy;
2. identify policies and measures that may act as facilitators and overcome hindrances to seizing trade opportunities arising from the transition to a green economy; and
3. assist governments, the private sector and other stakeholders to build the capacities needed to take advantage of sustainable trade opportunities at the national, regional or international level.

Under the umbrella of the GE-TOP initiative, UNEP conducts a national-level project in Ghana, in cooperation with The Energy Center (TEC), at the College of Engineering of the Kwame Nkrumah University of Science and Technology (KNUST). The project has been endorsed by Ghana's Ministry of Environment, Science, Technology and Innovation (MESTI) and the Ministry of Finance and Economic Planning (MoFEP), and benefited from substantive inputs from experts at the Ministry of Energy and Petroleum (MoEP) and the Ministry of Trade and Industry (MoTI).

Besides the development of the Solar Export Potential Study (SEPS), the GE-TOP Ghana project entails three stakeholder group workshop meetings and the development of a national-level Strategy Proposal for implementing selected findings from the SEPS.

1.2 Study Rationale

As a fast-growing lower middle-income economy, Ghana is seeking to develop an export-led economic model that promotes economic growth and employment creation. This vision also emphasizes regional trade, in accordance with the mission of ECOWAS (see Figure 1 for a map of the sub-region), which seeks to promote economic integration in "all fields of economic activity, particularly industry, transport, telecommunications, energy, agriculture, natural resources, commerce, monetary and financial questions, social and cultural matters" (ECOWAS, 2007).[2] Within the context of regional cooperation, Ghana and its neighbours have had cross-border electricity supply arrangements for decades. With the development of large hydro-electric power plants in Ghana in the 1960's and 1980's, Ghana has developed into a supplier of renewable electricity to its neighbours Côte d'Ivoire, Togo, Benin and Burkina Faso. For example, Ghana exported over 5 per cent (610 GWh) of all nationally produced electricity in 2011 (Energy Commission, 2013).

2 See URL: www.comm.ecowas.int/sec/index.php?id=about_a&lang=en.

Despite recent power generation deficits (due to difficulties with natural gas supplies from Nigeria) the Government of Ghana envisions becoming a major exporter of electricity by 2015. This goal was repeatedly announced, for example in the National Energy Policy (NEP) 2010, which aims to "secure a reliable supply of high quality energy services for all sectors of the Ghanaian economy, and also to become a major exporter of power by 2015" (Energy Commission, 2006). In spite of the significant market potential to increase generation capacity and strengthen existing inter-state transmission infrastructure, there is no detailed strategy to implement Ghana's electricity export objectives, including under the umbrella of the West African Power Pool (WAPP).

Figure 1. Map of the West African sub-region

The authors are not currently aware of any studies that have sought to investigate the potential contribution of renewable energy to a regional power market in West Africa, and its socio-economic and environmental benefits for the region. It is against this background, and within the context of UNEP's GE-TOP, that this study is undertaken.

The passage of the national Renewable Energy (RE) Law (Act 832) in 2011 set the government's goal to ensure a contribution of renewable energy to Ghana's total energy mix of at least 10 per cent by 2020, and increased investor interest in the RE sector (particularly solar energy). Currently, over 2,000 MWp in provisional licenses for renewable energy projects have been issued by regulators (Ahiataku-Togobo, 2014).

Ghana features an average annual solar radiation of up to 2,000 kWh/m^2 (for comparison: Germany's territory features 1,200 kWh/m^2), and a transmission system that runs across the entire country while interconnecting with its neighbours, Côte d'Ivoire, Togo, Burkina Faso and Benin. Additionally, Ghana's business and investment environment is one of the best in Africa – Ghana is ranked 64 out of 185 economies (globally) in the World Bank's "Rankings on the ease of doing business" (World Bank, 2013a). This rank is the fifth highest in Sub-Saharan Africa, and the highest in the ECOWAS sub-region.

Based on the opportune conditions for solar energy generation and transmission, and the friendly business environment, Ghana can be a frontrunner for solar energy trade in West Africa. In this vein, this study sets out to re-shape thinking on power trade in West Africa, which has been largely based on fossil fuels and large hydropower plants.

1.3 Objectives

The main objective of the SEPS is to assess the export potential from solar power (including solar PV value chain participation) in Ghana. The technical and financial feasibility of renewable electricity exports in the near term will be established, and Ghana's current and future capabilities to contribute to the solar PV value chain in the medium to long term ascertained. The study includes policy reviews and recommendations that can facilitate the development of Ghana's capacity in order to benefit from the identified trade opportunities in the solar energy sector.

Thus, the specific objectives of the study can be summarized as:

- *Section 2* discusses both existing and on-going initiatives being implemented by ECOWAS to meet regional electricity needs and boost sub-regional electricity trade. The section also gives a brief overview of the WAPP initiative and the institutions and mechanisms that were introduced in regional electricity trade. An overview of the policy and regulatory environment in Ghana is also presented in this section, particularly focusing on the country's Strategic National Energy Plan (SNEP), the National Energy Policy (NEP) and the Renewable Energy Law (Act 832, 2011).
- *Section 3* presents the results of the assessment of Ghana's technical potential for generating and transmitting solar electricity.
- *Section 4* presents the results of the financial feasibility assessment of PV plants.
- *Section 5* draws on global value chain literature to assess Ghana's potential to participate in the global solar PV value chain. The section gives a brief overview of the global solar PV industry, discusses the governance structures in global value chains and concludes with a discussion on the opportunities for Ghana to participate in the global solar PV value chain.
- *Section 6* presents estimates of the positive externalities in terms of greenhouse gas (GHG) emission reductions and socio-economic benefits that could potentially accrue from the generation and export of solar power from Ghana.
- *Section 7* recaps the key objectives of the SEPS, and draws a set of conclusions based on the work done in previous sections. These form the basis for the policy recommendations presented in the same section.

This study yields insights into the contribution of green electricity trade to economic growth, employment creation (as per Ghana's trade policy), GHG emissions reductions and other environmental benefits.

1.4 Methodology

This section provides an overview of the methodology used in this study. The primary objective of the study is to assess the potential of Ghana to export solar energy (including solar components) to neighbouring countries.

A variety of tools and techniques have been used for both data collection and analysis. For all sections of the study, relevant country data on Ghana and Burkina Faso were gathered through a desk study. These documents were drawn from reputable institutions such as ECOWAS, ECREEE, and the International Renewable Energy Agency (IRENA).

Analytical tools included the Solar and Wind Energy Resource Assessment (SWERA) toolkit and the ArcGIS software. These two software packages were used to estimate the amount of land available for solar PV power generation. The SWERA toolkit is a map-based software application that integrates resource data and other geographic information system (GIS) data for analysis. It can be used for decision-making and policy analysis, in addition to planning for future projects on solar and wind energy. Due to the limitations of the SWERA toolkit in providing the desired outputs for analysis, resource data from the SWERA toolkit was analysed extensively using the ArcGIS desktop tool. The ArcGIS software package is a GIS for handling maps and geographic information. It is a tool used for creating and using maps, compiling geographic data, analysing mapped information, and managing geographic information in a database. The ArcGIS tool enables users to view data and perform analysis spatially and visually.

Financial analysis and analysis of the solar radiation profile of the three Northern Regions in Ghana was done using the RETScreen software. The RETScreen Clean Energy Analysis tool, developed by Natural Resources Canada/CANMET Energy is a widely used tool for conducting pre-feasibility analyses on clean energy projects and investments.

Two national stakeholder workshops were undertaken to inform the development of SEPS. The first national stakeholder workshop sought to form a consultative group, and initiate stakeholder dialogue. A consultative team known as SEPS team was drawn from relevant institutions in the energy sector. This team was made up of representatives from academia, private and public sector institutions, and non-governmental sector institutions. The second national stakeholder workshop sought to present the SEPS findings, and to receive feedback on the analysis underlying the SEPS from stakeholders. It offered an opportune platform to coordinate and synthesise contributions from the national stakeholders involved in SEPS. Key stakeholders in this study included representatives from the Public Utilities Regulatory Commission (PURC), MoEP, the Ministry of Trade and Industry (MoTI), the Association of Ghana Solar Industries (AGSI), KNUST, the Volta River Authority (VRA), MoFEP and the Centre for Energy, Environment and Sustainable Development (CEESD). The full list of institutions represented at the first and second national workshop can be found in the Appendices A and B. In addition to the inputs from workshop presentations and discussions, the research team held interviews with key stakeholders in both Ghana and Burkina Faso to update data gaps, and to collect additional data to aid analysis. The final output of the study was also shared with key stakeholders for review to ensure the accuracy of data collected, and ascertain the soundness of analytical approaches adopted and recommendations made.

2. Ghana's Electricity Trade in the ECOWAS Region: Initiatives, Policies and Authorities

2.1 ECOWAS Electricity Trade Initiatives and Authorities

Electricity exchanges between countries in the West African sub-region have been a common phenomenon over the years, with Ghana exporting electricity to neighbouring Togo, Benin and Burkina Faso, and importing from Côte d'Ivoire in case of national shortage. ECOWAS has been instrumental in the efforts to boost sub-regional electricity trade, by spearheading a number of initiatives aimed at removing barriers and providing the enabling environment for electricity trade and investment in the sub-region. In 1999, ECOWAS adopted the principle of setting up the WAPP system with the vision to (Adenikinju, 2008):

- develop interconnection and power exchanges between member states;
- harmonize legislation and standards for power sector operations;
- promote and protect private investment in energy projects;
- use flare-gas in Nigeria to feed power stations in neighbouring countries; and
- create an open and competitive regional electricity market.

Although the decision to establish WAPP was already taken in 1999, it was in 2006 that the Heads of State and Government of ECOWAS adopted the Articles of Agreement for the establishment and functioning of WAPP, granting the WAPP Secretariat the status of a specialized institution of ECOWAS. The vision of WAPP is to harmonize the operations of national power systems into a unified regional electricity market, which will, over the medium to long term, assure the citizens of ECOWAS Member States of a stable and reliable electricity supply at competitive cost. WAPP also has the mission to ensure the promotion and development of power generation and transmission facilities, as well as, the coordination of power trade between ECOWAS Member States. WAPP has begun efforts to build regional transmission lines to interconnect major load centres in the sub-region.

The ECOWAS Energy Protocol, modelled on the European Energy Charter, was adopted in 2003 to establish a legal framework to promote long-term co-operation in the energy field, based on complementarities and mutual benefits, with a view to achieving increased investment in the energy sector, and increased energy trade in the West Africa region. The objective of the Protocol (ECOWAS, 2003) is to:

- ensure free exchange of power, equipment and energy products among Member States;
- define non-discriminatory rules for energy exchanges and conflict resolution;
- protect private investments; and
- safeguard the environment and foster energy efficiency.

According to the Protocol, the Contracting Parties shall work to promote access to international markets relating to Energy Materials and Products as well as Energy-Related Equipment on commercial terms and, generally, to develop an open and competitive energy market.

In order to ensure compliance with the electricity provisions under the Protocol, Member States of ECOWAS established in January 2008 the ECOWAS Regional Electricity Regulatory Authority (ERERA) within the framework of the Energy Protocol and the WAPP Programme. ERERA's main objective is to regulate interstate electricity exchanges, and to give appropriate support to national regulatory bodies or entities of the Member States.

ERERA's organisation and monitoring of regional markets is being carried out in two stages. The first stage (2010-2013) involved the enhancement of the current state of the market and prepared for its opening through the implementation of the following actions:

i. reliability and rationalization of existing exchanges through the adoption of harmonized technical and commercial rules;

ii. market definition and preparation of Directives of the ECOWAS Commission, based on a planned schedule for institutional and regulatory harmonization and market opening; and

iii. expansion of power exchanges, through the organization of a short-term market.

In the second stage (2014-2019), ERERA is responsible for the oversight of the existing market, and for coordinating the organisation of the regional wholesale market.

The ECOWAS Energy Protocol envisages the improvement of energy efficiency and increased use of RE sources in the sub-region. To this end, the ECOWAS Commission has taken significant steps to mainstream Renewable Energy and Energy Efficiency (RE & EE) into its regional activities and policies, drawing on the experience of the European Union (EU).

ECREEE was formed in 2008, at the 61st Session of the ECOWAS Council of Ministers, to contribute to the sustainable economic, social and environmental development of West Africa by improving access to modern, reliable and affordable energy services, energy security and reduction of negative environmental externalities of the energy system. ECREEE also aims to create favourable framework conditions and an enabling environment for renewable energy and energy efficiency markets by supporting activities directed at mitigating existing barriers - technological, financial, economic, legal, policy, institutional, in terms of capacities, etc. The ECOWAS Renewable Energy Policy was developed by ECREEE in September 2012, to ensure increased use of renewable energy sources such as solar, wind, small-scale hydro and bio-energy, for grid electricity supply and for the provision of access to energy services in rural areas.

2.2 Energy Situation and Demand in ECOWAS Member Countries

2.2.1 Overview of Energy Situation in Ghana

Ghana's electricity supply comes from two major sources: hydroelectric and thermal. Historically, Ghana has been heavily dependent on hydroelectric power. Two hydroelectric plants, located at Akosombo and Kpong on the Volta River, represent the core of Ghana's generation system, accounting for 1,180 MW of generation capacity,[3] and almost 70 per cent (8,071 GWh)[4] of total generation in 2012 (EC, 2013).

Ghana has a relatively high electricity access rate, which stood at 72 per cent, in 2011, and the government has a long-running vision to achieve universal (100 per cent) electrification by 2020. This electrification rate is much above the ECOWAS sub-regional average of 40 per cent, and the rates of less than 20 per cent in various countries in the sub-region (ECREEE, 2012a).

Ghana's energy consumption in 2012 was estimated at 7,718.9 kTOe, up from 5,740.1 kTOe in 2002, an increase of almost 35 per cent over a 10-year period (EC, 2013). By the end of 2012, total installed electricity generation capacity stood at approximately 2,280 MW, with the Ministry of Energy and Petroleum (MoEP) estimating a total of 1,190 MW of power plants at various stages of construction, including a 2.5 MWp Solar PV system at Navrongo in the Northern part of Ghana (MoEP, 2012), which has since been commissioned.

Electricity consumption in 2012 was 9,258 GWh, up by 35.6 per cent from 6,829 GWh in 2002, averaging 3.5 per cent growth per annum. This, however, does not include the unmet demand occasioned by generation capacity shortages in 2006/2007 and 2012/2013, among other factors. National demand is expected to grow at 6 per cent per annum (World Bank, 2013b) over the next decade. Together, these trends necessitate significant investments in power generation capacity to satisfy national needs and meet export objectives.

The reforms and liberalisation of Ghana's power sector over the years have resulted in some private-sector-led investments in power generation. Starting with CMS Energy Corporation of Michigan in 1997, there are currently over 30 Independent Power Producers (IPP)[5] who have been granted provisional licenses to supply power to the grid. Following the passage of the Renewable Energy Law (Act 832), up to 15 companies have acquired provisional licenses to generate electricity from solar energy.[6] These are major steps towards the achievement of the country's vision for the energy sector.

3 A 400 MW hydroelectric plant at Bui was commissioned in 2013, although is yet to be officially added to national energy statistics.
4 The remaining 30 per cent is generated from thermal sources.
5 See URL: energycom.gov.gh/Licenses-Register/electricity-wholesale-supply-licence-register.html.
6 See URL: energycom.gov.gh/Renewable/provisional-wholesale-supply-and-generation-licenses.html.

2.2.2 Overview of Energy Situation in Burkina Faso

This study relies on the case of Burkina Faso as an exemplary regional export market for many of its simulations. Burkina Faso is to the north of Ghana, with a population of 16.5 million (2012 est.), and a Gross Domestic Product (GDP) of US$ 10.5 billion. The country had an annual GDP growth rate of 10 per cent in 2012 (World Bank, 2013c). Its total installed electricity generation capacity was 250 MW (as of January 2012), and net generation 670 GWh. Net electricity consumption stood at 770 GWh, exceeding electricity generation in 2012 (EIA, 2013). However, the country has far advanced plans of increasing its installed electricity generation capacity. There is currently a planned 33 MWp solar PV plant in Ouagadougou, near the Zagtouli substation, which has attained financial closure and is, therefore, supposed to commence in 2015. The project is estimated at US$ 70 million, and is financed by the European Union, the European Investment Bank and the African Development Bank. There are also plans to develop a 14 MW hydropower plant downstream of the Bagre dam - feasibility study yet to commence -, as well as 100 MW and 150 MW thermal (diesel) plants in Ouagadougou, dubbed Ouaga East and Ouaga North-West respectively.

The national electricity access rate in Burkina Faso is currently at 29 per cent (ECREEE, 2013), up from 17 per cent in 2008, when the rural access rate was as low as 4 per cent. The country aims to achieve an electrification rate of 60 per cent by 2015 (ADF, 2009).

As ECOWAS countries aim at accelerated economic growth, reliable and secure energy supply is key to creating the enabling environment for investments. As a result, sub-regional electricity demand is expected to grow from 10,659 MW in 2011 to 30,731 MW by 2025, of which "non-large" hydro[7] renewable energy is set to contribute 8 per cent (WAPP, 2011). In Burkina Faso, for example, analysis of energy supply and demand balances indicates that the system's peak demand, which was 131 MW in 2009 will reach 426 MW in 2020 (ADF, 2009), although studies by the WAPP forecast a lower demand - of 345 MW - in the reference scenario, by 2020 (WAPP, 2011) (see Table 1).

Burkina Faso is a country with limited natural energy resources, and is projected to continue importing power from its neighbours to support its economic growth (Ghana Business News, 2010).

Table 1. Electricity demand forecast in Burkina Faso

	Base Scenario [GWh]	Low Scenario [GWh]	Base Scenario [MW]	Low Scenario [MW]
2011	873	873	178	178
2012	934	929	190	189
2013	1 006	987	205	201
2014	1 087	1 048	222	214
2015	1 173	1 112	239	227
2016	1 265	1 179	258	240
2017	1 362	1 250	278	255
2018	1 466	1 324	299	270
2019	1 576	1 402	321	286
2020	1 694	1 484	345	303
2021	1 820	1 570	371	320
2022	1 953	1 661	398	338
2023	2 095	1 755	427	358
2024	2 247	1 855	458	378
2025	2 408	1 959	491	399

Source: (WAPP, 2011)

7 Ghana's Feed-in-Tariff scheme considers "non-large" hydropower as capacities up to 100 MW.

Based on these conditions, the Secretary-General of WAPP recently expressed hope that electricity imports from Ghana can eliminate the shortfall in power demand in Burkina Faso, arguing that: "Burkina Faso is a land-locked country which is not endowed with enough energy resources. Ghana, on the other hand, has hydro-electric power, gas and other available energy resources" (Ghana News Agency, 2010).

Currently, Burkina Faso's power is generated from both thermal and hydro power plants. In 2012, 52 per cent of the country's total electricity consumption of 1.2 TWh, with constituents of 48 per cent thermal and 4 per cent hydro, came from the National Interconnected System, with the remaining 48 per cent coming from imports from Côte d'Ivoire and Ghana. The peak demand in the same year was 205 MW.

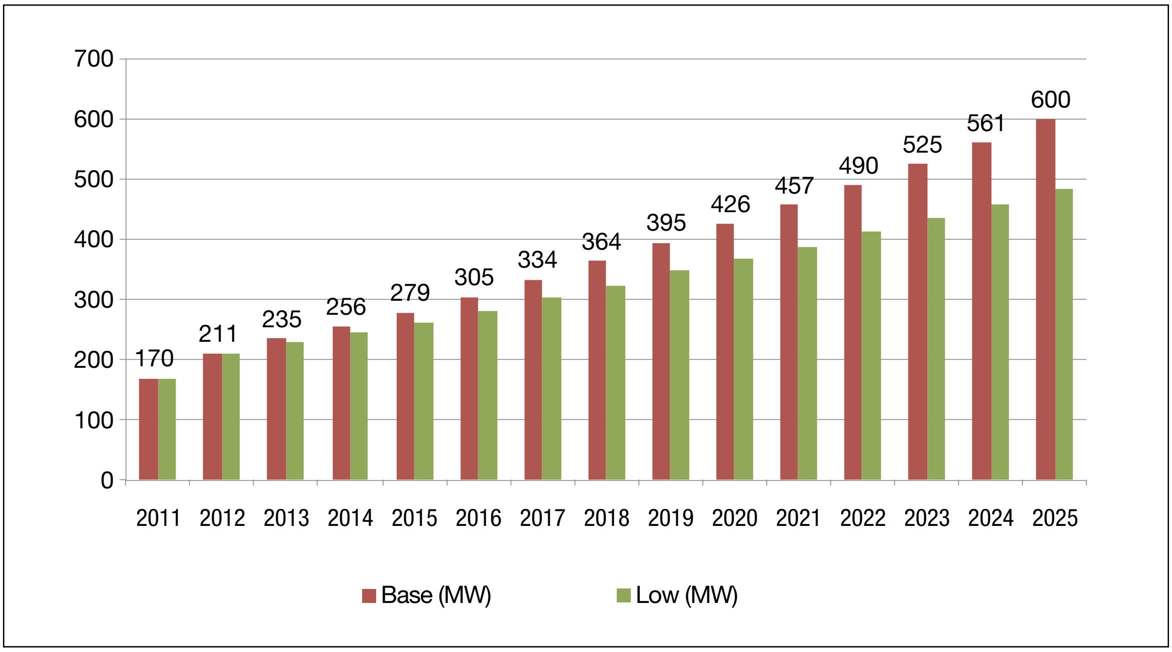
2.2.3 Overview of Regional Demand for Energy

Togo

The Republic of Togo is to the eastern border of Ghana, with a population of 6.6 million in 2012, and a GDP of US$ 3.814 billion in the same year. The country is classified as a low-income country by the World Bank. It has a total electricity generation capacity of 380 MW[8], generating 309,039 MWh in 2011. The national rate of electrification remains low, averaging 25 per cent (32 per cent urban and 5 per cent rural).

The recent addition of 100 MW by Contour Global, an Independent Power Producer (IPP), has been crucial in improving the country's electricity supply and generation capacity. Prior to this, 95 per cent of Togo's electricity was imported from Ghana and Nigeria, through interconnection arrangements, with the jointly owned Benin-Togo utility, Communauté Electrique du Benin (CEB). Electricity distribution is undertaken by Compagnie d'Energie Electrique du Togo (CEET). According to estimates by WAPP, the country's electricity demand is expected to grow from 170 MW in 2011 to 600 MW by 2025 in the reference (business-as-usual) scenario (see Figure 2). The actual peak demand in 2011 was lower, at 135 MW, according to CEET's annual report (2011), as cited by the World Bank (World Bank, 2013d).

Figure 2. Electricity demand scenarios in Togo, 2011-2025



Source: (WAPP, 2011)

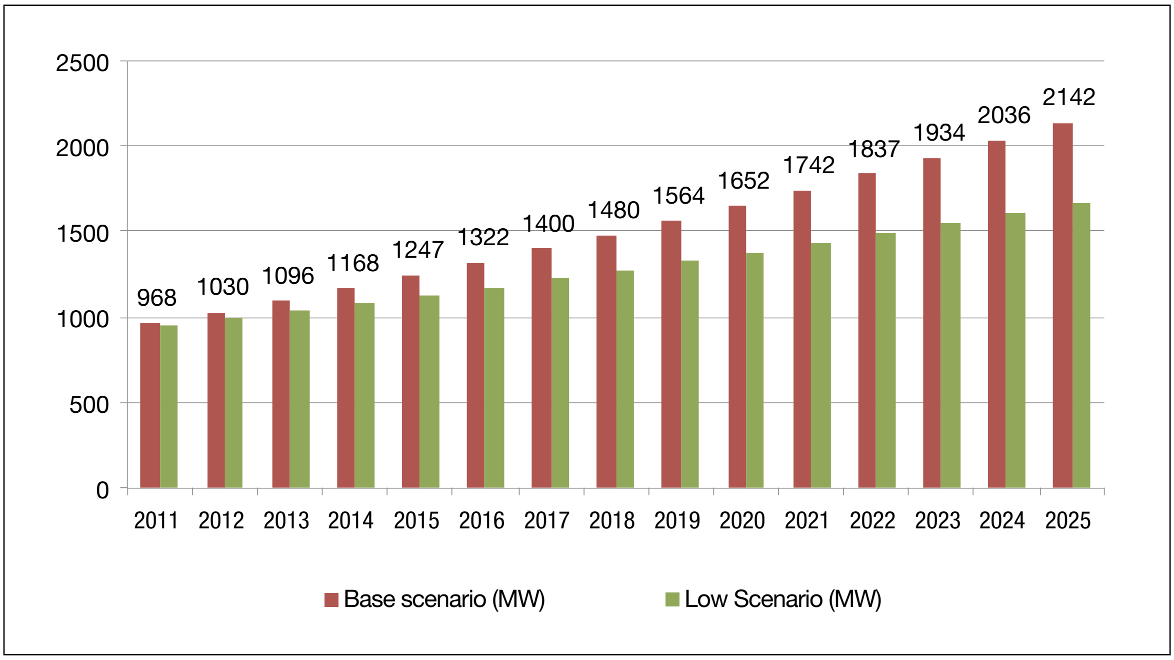
8 Togo and Benin co-own generation assets.

The projected power demand is expected to be exceeded if economic growth picks up. Togo's annual GDP growth forecast, which was factored into the WAPP projection above, averaged 2.5 per cent between 2003 and 2011. The average end-user tariff in Togo is US$ 0.23/kWh (charged by CEET), and is expected to increase until 2017 when a planned 147 MW by CEB is commissioned (World Bank, 2013d). The operating cost of CEB is estimated at US$ 0.13/kWh[9]. The CEET buys electricity from the CEB, and also generates its own electricity from diesel-powered thermal stations. In the medium-to-long term, Togo is expected to increasingly rely on electricity imports from its neighbours.

Côte d'Ivoire

Côte d'Ivoire is classified as a lower-middle-income economy (World Bank) and borders Ghana on its western side. It has a population of 20.32 million, a GDP of US$ 31.06 billion, and a growth rate of 8.7 per cent (World Bank databank, 2013e). Côte d'Ivoire's installed power generation capacity is 1,451 MW, with a generation of 5,987 GWh (ECREEE, 2012b).

Figure 3. Electricity demand scenarios in Côte d'Ivoire, 2011-2025



Source: (WAPP, 2011)

The country is a major player in sub-regional cross-border power supply arrangements, supplying power to Burkina Faso, Togo, Benin, Mali and Ghana (during capacity shortages) (Bloomberg , 2010). Côte d'Ivoire recently signed an agreement to supply 17 MW of power to Benin and Togo, transiting through Ghana (Informa Exhibitions, 2013). Although the country's electricity demand is growing at a rate of 6 per cent annually, compared to 2 per cent in annual capacity expansion (AfDB, 2013), it is poised to increase its participation in sub-regional electricity trade with the construction of a 275 MW hydropower station near the western town of Soubre.[10] The WAPP reference scenario estimates national electricity demand to grow to almost 2,200 MW in 2025, as illustrated in Figure 3.

Electricity generation, transmission and distribution is undertaken by Compagnie Ivoirienne d'Electricité (CIE), which is jointly owned by Electricité de France (EDF) and Société d'Aménagement Urbain et Rural (SAUR) with 51 per cent shares and the state with 49 per cent. CIE is therefore a vertically integrated monopoly (REEGLE, 2013).

9 CFA franc 67/kWh converted at 1 US$ = 500 CFA franc.
10 Ministry of Foreign Affairs, the People's Republic of China. See URL: http://www.fmprc.gov.cn/zflt/eng/zxxx/t1005555.htm.

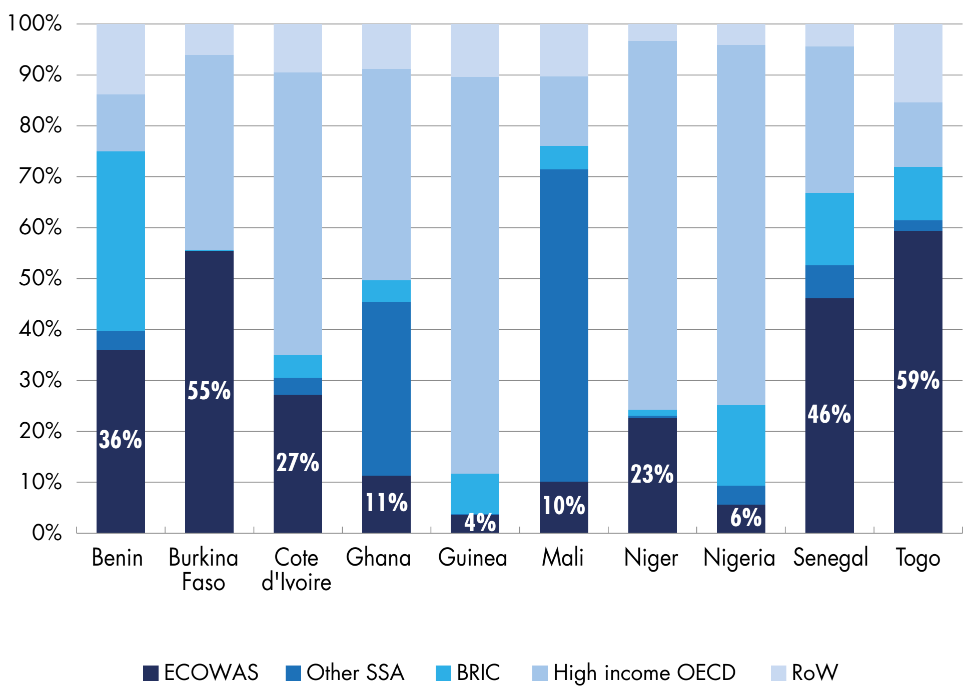
Burkina Faso

Burkina Faso is an important regional export market for Ghana, and serves as a good example of how regional demand could drive solar energy exports. The cost of electricity generation in Burkina Faso was estimated at US$ 0.32 per kWh in 2008, one of the highest rates in the sub-region. Although WAPP forecasts these costs to go down to a value between US$ 0.05 and US$ 0.10 per kWh in the period 2017 to 2025,[11] current downward trends in renewable energy prices (solar and wind) appear to already make RE generation cost effective for countries like Burkina Faso, without any premium pricing.

The prevailing high electricity prices in Burkina Faso, and the general acknowledgement of the need for some electricity imports from Ghana and Côte d'Ivoire, even in the longer term, create an avenue for intra-regional trade. Trade among ECOWAS member countries formed between 10 and 15 per cent of countries' overall trade volume over the past two decades (OECD, 2012), despite political efforts (see Figure 4). This is a rather low share for (sub)regional exchanges.

In harmony with the aspirations of ECOWAS to increase the level of trade among member countries, the MoEP has oriented its energy-sector vision for Ghana to give focus to energy exports to neighbouring countries. This vision is also in alignment with the Government of Ghana's policy on regional and international cooperation, which states that the "Government will vigorously pursue regional integration which will promote regional trade, including investments in energy and other infrastructure, harmonization of trade and investment regulations and policies, removal of non-tariff barriers and trade facilitation with a view to expanding the markets for our goods and services" (Government of Ghana, 2010).

Figure 4. Export shares by region for ECOWAS countries



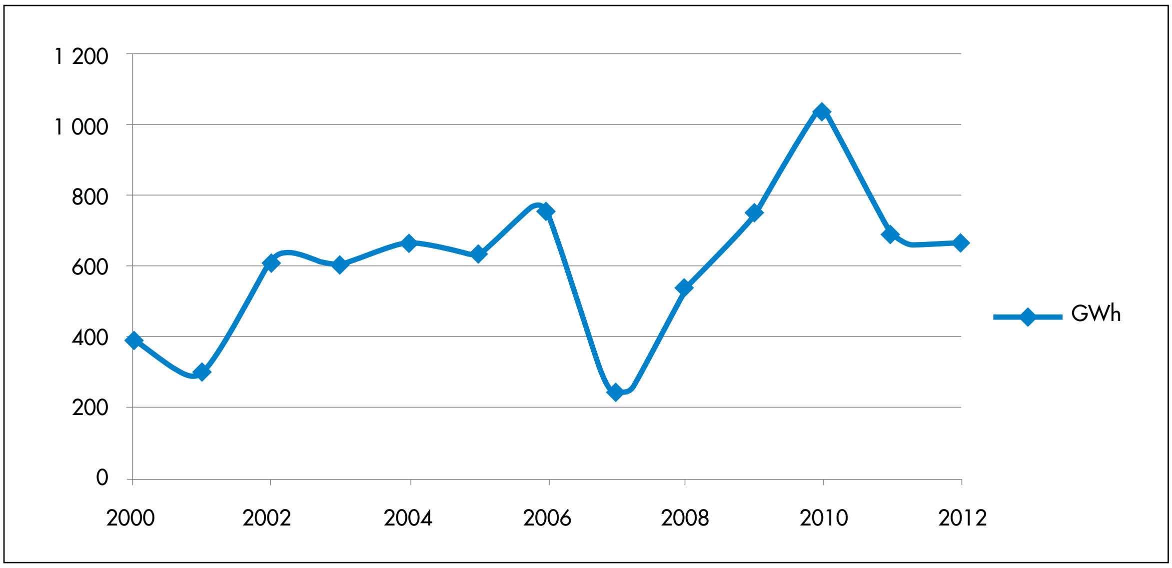
Source: (OECD, 2012)

11 Original estimates were in Euro (EUR). Conversion done using a EUR to US$ rate of 1 : 1.3586.

As mentioned in earlier sections, Ghana considers electricity exports to be an important source of foreign exchange, and has had electricity supply arrangements with Togo, Benin and Burkina Faso. On the other hand, it imports electricity from Côte d'Ivoire when necessary, to augment domestic supply.

Electricity exports from Ghana increased from 392 GWh in 2000 to 1,036 GWh in 2010 (see Figure 5), and then decreased to 667 GWh in 2012 as a result of domestic generation shortages. Net exports (in 2012) stood at 539 GWh as a result of imports of 128 GWh to augment domestic generation (Energy Commission, 2013). In the medium to long term, Ghana will have to increase its generation capacity in order to meet the increasing domestic demand as well as demand for power by its neighbours.

Figure 5. Gross electricity exports from Ghana to neighbouring countries



Source: (EC, 2013)

Box 1. Togo, Benin Request More Power From Ghana

At a high-level meeting on 1 March 2013 between energy ministers from Benin, Ghana and Togo, the delegation from Benin and Togo requested assistance from Ghana to increase their respective power supply. According to current arrangements, Ghana delivers 50 MW on week days (off peak) and weekends as well as 35 MW during peak periods on weekdays (source: OECD and SWAC, 2013).

Against the backdrop of relatively low electricity tariffs of GH₵ 0.232/kWh (approximately US$ 0.11/kWh)[12] in Ghana, electricity exports to neighbouring countries like Burkina Faso, Togo and Benin, where tariffs are much higher, become interesting to analyze.

12 As of September 2013.

2.3 Ghana's Policy and Regulatory Frameworks

Ghana has implemented a number of policies relevant to the energy sector, and aimed at ensuring that adequate, reliable and quality energy is available to its citizenry. This section gives a brief overview of the key policies.

2.3.1 Strategic National Energy Plan (SNEP)

The Strategic National Energy Plan (SNEP) of 2006 was introduced to contribute to the development of a sound energy market that would provide adequate, viable and effective energy services to support Ghana's economic development. The SNEP presents an outlook of energy in Ghana for the period 2006-2020 based on the economic growth rates forecasted in the Ghana Poverty Reduction Strategy (GPRS) II.[13] The plan is based on an assessment of available energy sources and resources in Ghana, and of the ways to exploit them in order to ensure secured and adequate energy supply to support sustainable economic growth for both the present and the future (Energy Commission, 2006).

The vision of the energy sector as captured in the SNEP is to become an *"energy economy"* that ensures the production and distribution of high-quality energy services to all sectors of the economy in a sustainable manner, without compromising the environment (Energy Commission, 2006). The objective to accelerate the development and utilization of renewable energy is complemented with a strategy targeting a 10 per cent renewable energy share in Ghana's total electricity supply mix in terms of installed capacity. The sources of the 10 per cent from renewable energy include solar, wind, and small- and medium-sized hydro plants; solar is to constitute 20 per cent of the quota allocated to renewable energy, amounting to an overall 2 per cent share in Ghana's installed capacity. Private sector participation is key in the realization of the energy sector's vision and targets. Accordingly, interconnection standards that will guarantee open access for independent power producers to electricity transmission infrastructure are to be developed, ultimately facilitating the expansion of electricity supply capacity in the sub-region under the WAPP.

2.3.2 National Energy Policy (NEP)

The National Energy Policy (NEP) of 2010 reiterates the energy sector vision of becoming an "energy economy", and explicitly acknowledges the sector`s vision to export power. The NEP is intended to facilitate the development and effective management of the energy sector. Although Ghana has an installed capacity of 2845.5 MW[14] and peak demand of around 2000 MW, it currently suffers electricity generation inadequacy due to factors such as low water levels in its hydropower facilities, scheduled and unscheduled maintenance of some power plants, as well as fuel supply challenges. The government is confident of overcoming these difficulties by adding 1000 MW of generation capacity in the short term, while working towards additional capacities in excess of 3000 MW from six projects at various stages of consideration. In spite of these challenges, Ghana continues to supply power to its neighbours and aims to become a major power exporter in West Africa (Ministry of Energy, 2010). The government believes that this can be achieved through improving and expanding the capacity of existing energy infrastructure (for generating and transmitting power), and modernising transmission and distribution infrastructure.

The medium term (2010-2015) goal is to increase power generation capacity to 5,000 MW. The NEP outlines a number of policy actions to ensure the realisation of this goal in the medium term, focusing on thermal (natural gas), hydropower and wind. According to the Ministry of Energy (2010),"the implementation of the NEP policy will require a legislative framework for renewable energy resource development as well as the development of a communications strategy to manage public anxiety and expectations, development of procedures and criteria for competitive licensing, and creation of a new institutional framework for the subsector." In this vein, the government in 2011 passed the Renewable Energy Law (Act 832).

13 The population growth rate will not exceed 2.6 per cent per annum (National Development Planning Commission (NDPC), 2010).
14 This figure was given by Ghana's new Minister of Energy, on 2 February, 2015. See URL: http://www.energymin.gov.gh/?p=3395.

2.3.3 Ghana's Renewable Energy Law (Act 832), 2011

As stated earlier in this section, Ghana is aiming to build a sustainable, low-carbon energy economy, with reliable power for industry and households, and green jobs. The country's energy strategy has set a target of generating 10 per cent of electricity from renewable energy (RE) sources by 2020. According to the government, this can only be achieved if incentives are provided to the private sector to invest in renewable energy. To facilitate this process, the Renewable Energy Law (Act 832)[15] was enacted to provide for the development, management, utilization, sustainability and adequate supply of renewable energy for the generation of heat, power and related matters (Section 1 of Act 832).

The Act seeks to, among other things,

- provide a framework to support the development and utilization of renewable energy sources;
- establish an enabling environment to attract investment in renewable energy sources;
- promote the use of renewable energy;
- diversify energy supply to safeguard energy security;
- improve access to electricity through the use of renewable energy sources;
- build indigenous capacity in technology for renewable energy sources; and
- educate the public on renewable energy production and utilization.

The Minister responsible for energy is mandated by the Act to provide policy direction for the achievement of the objectives. The Act also mandates a number of institutions to take responsibility for different aspects of the renewable energy capacity development. Under the Act, the Energy Commission (EC) is, among other functions, responsible for promoting the local manufacture of components to facilitate the rapid growth of renewable energy sources, and promote plans for training and supporting local experts in the renewable energy industry. The EC shares a common mandate with the Public Utilities and Regulatory Commission (PURC) to recommend financial incentives necessary for exploiting renewable energy sources (section 4, subsection e), but also has the sole mandate to recommend exemptions from taxes, levies and other duties on equipment and machinery necessary for fostering the growth of the renewable energy industry (section 4, subsection d).

The Public Utilities Regulatory Commission has the mandate to approve rates to be charged for electricity from renewable energy sources by public utilities, and for wheeling of electricity from RE sources (section 4). The public utilities licensed by the EC, under the Energy Commission Act 1997 (Act 541), to transmit, distribute or sell electricity are also required to comply with the relevant provisions of this Act, and to facilitate the achievement of the Act.

According to the provisions of the Act, a license is required to undertake a commercial activity in the renewable energy industry (section 8, subsection 1). A license is required to undertake the following activities: production, transportation, storage, distribution, sale and marketing, exportation and re-exportation, and installation and maintenance (section 19). Even though section 19 is not explicit about whether "production" includes both electricity generation and the manufacture of components for renewable energy generation, section 20 addresses component manufacture, clarifying the issue that one also needs a license to manufacture renewable energy components. The Renewable Energy Law is not, however, explicit about the validity period of particular licenses (see section 14, subsection 1). As highlighted under sub-section 2.2.1 of this report, over 30 Independent Power Producers (IPP) have been issued with licenses to generate power to the grid, and 15 companies have acquired licenses to generate power from solar energy.

To ensure private sector participation in reaching the 10 per cent renewable energy target in Ghana's total electricity mix, and to guarantee that a market is available for the energy generated from renewable energy sources, operational measures and schemes have been outlined in Act 832.

15 Available at: energycom.gov.gh/files/RENEWABLE%20ENERGY%20ACT%202011%20(ACT%20832).pdf.

A feed-in-tariff (FIT) scheme has been established, comprising three components (Section 25):

- a renewable energy purchasing obligation;
- a feed-in-tariff rate; and
- a connection to transmission and distribution systems.

PURC is required to prepare and provide public utilities with guidelines on the level of rates that may be charged by the public utility for electricity generated from renewable energy sources (section 27). The FIT rate is to be guaranteed for a period of ten years, and subsequently every two years, subject to review in the regulated market (Section 27, subsection 4). The provisions of the Act also allow a public utility to set a FIT rate (higher than the rate set by PURC) to be agreed upon between the public utility and the customer, with the permission of the PURC (Section 28, subsection 3). The setting of tariffs under this provision does not, however, include tariff setting for purposes of power exports (section 28, subsection 4).

Section 26 of the Act requires an electricity distribution utility or bulk customer to purchase a specified percentage (to be specified by the PURC in consultation with the Energy Commission) of the total electricity purchase from renewable energy sources. The Renewable Energy Act also establishes a Renewable Energy Fund, to be managed by the Energy Commission, which aims to provide financial resources for the achievement of the key objectives of the Act. The fund shall be utilised to provide, among other things, financial incentives, capital subsidies and product-based subsidies.

In addition, the fund is available to support capacity building activities and for the development of renewable energy infrastructure. Furthermore, the fund is also instituted to promote the following:

- programmes to adopt international best practices;
- research into the establishment of standards for the utilization of renewable energy; and
- innovative approaches to the development and use of renewable energy sources.

The Renewable Energy Act also mandates the Energy Commission to issue guidelines for the development, efficient management and utilisation of renewable energy sources and technical standards for the use of renewable energy sources, among other things (Section 49).

2.3.4 Ghana's Policy on Public Private Partnership Policy (PPP)

A Public Private Partnership (PPP) is a contractual arrangement between a public entity and a private sector party with clear arrangement on shared objectives for the provision of public infrastructure and services that traditionally were the responsibility of the government or the public sector. In return, the private sector receives a benefit/financial remuneration according to predefined performance criteria. The government of Ghana, through its numerous energy-related policy documents, recognizes the role that the private sector can play in the development of the energy sector, particularly to increase generation capacity and upgrade energy transmission infrastructure.

In 2011, the government developed a national policy for PPPs to "encourage the provision of a wide variety of quality and timely public infrastructure and services" (Ministry of Finance and Economic Planning, 2012). In order to provide the assurance to the private sector that the government is committed to the initiative, a range of instruments are to be introduced. These include the development of a Viability Gap Scheme (VGS), aimed at providing rule-based incentives for PPP projects. With the establishment of an Infrastructure Finance Facility (IFF) to raise the required long-term financing, the government will support the private partner for the PPP for on-lending at commercial rates. A Project Development Facility is also to be implemented, which will, among other things, finance upstream investment appraisal, value for money assessments and other feasibility and safeguard studies. The government, with the support of the World Bank, is now developing its capacity to fully implement the requirements of the policy. This is a strong start that could give rise to a number of opportunities for energy infrastructure development and upgrades through PPPs.

3. Technical assessment of solar electricity potential in Ghana

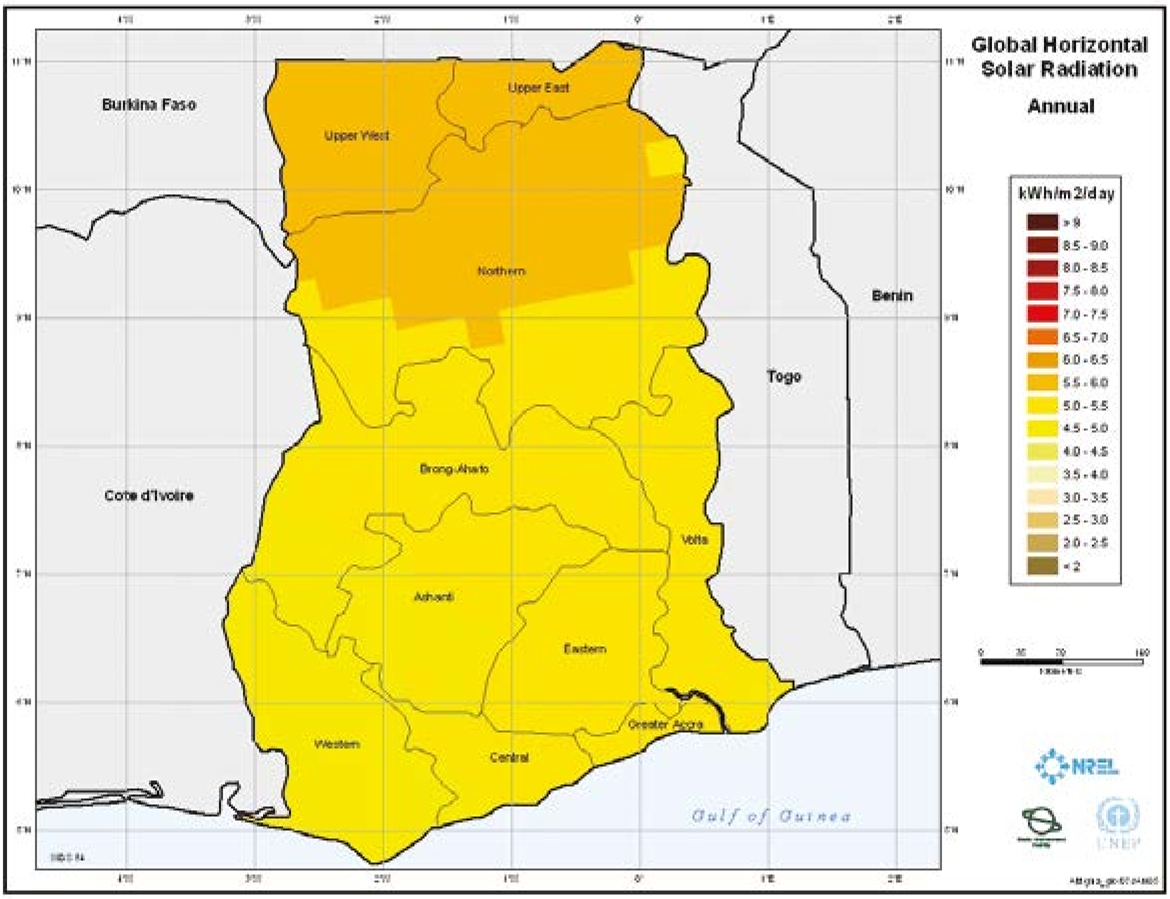
To assess Ghana's technical potential for solar PV power generation and exports, various pertinent factors were considered. First, a review of solar resources in Ghana was carried out using climatic data from RETScreen. The land available in Ghana for solar PV power generation was then assessed in the light of other competing uses of land using the SWERA toolkit and ArcGIS software. These two activities enabled a determination of the technical potential of solar PV power generation. Documents on the grid infrastructure and installed capacity of Ghana and its neighbouring countries were also reviewed, in order to establish the capacity for transmitting solar-sourced power.

3.1 Solar Resource Availability

Ghana receives high amounts of sunshine across the entire country. The average duration of sunshine in Ghana varies from a minimum of 5.3 hours per day in Kumasi, which is in a cloudy semi-deciduous forest region, to 7.7 hours per day at Wa**,** which is in a dry savannah region. The monthly average solar irradiation also varies in different parts of the country, ranging between 4.4 and 5.6 kWh/m^2/day (16-20 MJ/m^2/day) (Energy Commission, 2009). Some regions receive very high irradiation levels, with monthly averages between 4.0 and 6.5 kWh/m^2/day. Ashanti, parts of Brong Ahafo, Eastern, Western and parts of Central and Volta regions have monthly average irradiation levels of 3.1-5.8 kWh/m^2/day. As noted by Arku (2011), the monthly total irradiation is higher during the dry season than the rainy season. Also, the total irradiation is generally higher in Northern Ghana as compared to Southern Ghana.

The results of the RETScreen analysis of locations in Ghana with the highest and lowest irradiation levels, and the monthly variations for those locations, reveals that Navrongo has the highest average annual irradiation, and Tafo the lowest. The RETScreen software was used to acquire daily solar radiation levels for a town in each of the three solar belts in Ghana: Navrongo in the northern belt, Kete-Krachi in the middle belt, and Bibiani in the south-western belt. The radiation belts are shown in Figure 6. The data for the three towns is shown in Table 2. As seen in Figure 6, the northern regions and the northern parts of Brong Ahafo and Volta have the highest average solar radiation.

Figure 6. Annual global horizontal solar radiation for Ghana



Source: (NREL, 2005)

Data in Table 2 was used to plot a graph comparing radiation levels in Bibiani, Kete-krachie and Navrongo (see Figure 7). Figure 7 shows that radiation levels for all three towns follow a similar rise and fall pattern across the various months of the year. Navrongo, which represents the northern belt, receives the highest solar radiation, followed by Kete-Krachi in the middle belt, and finally Bibiani in the south-western belt, which has the lowest radiation. On average, the annual solar radiation for Navrongo is 6.07kWh/m^2/day.

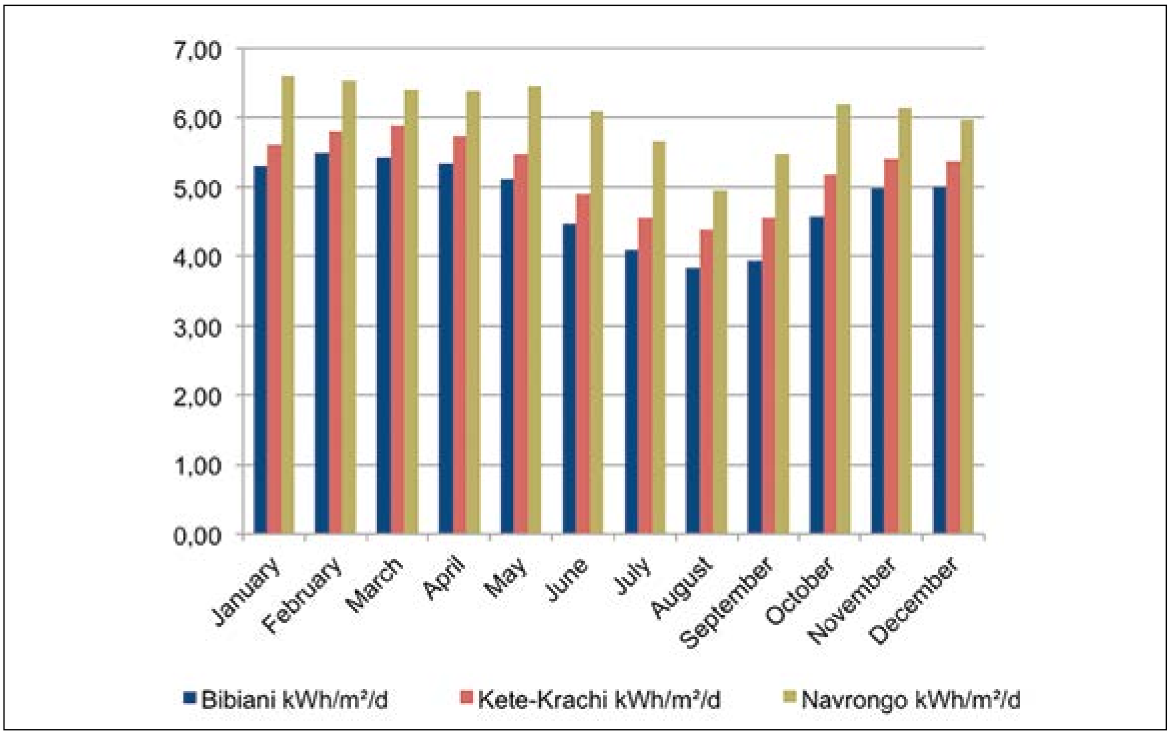
Overall, the assessment shows that Ghana has good solar potential for PV power generation across various parts of the country. The average solar radiation in Burkina Faso is 5.5kWh/m2/day (GTZ, 2012). According to ECREEE, the average solar radiation is 5-6 kWh/m2 per day across many countries in the West African sub-region (Kappiah, 2013). While Ghana has typical solar radiation resources for a West African nation, these levels are still highly favourable for solar PV power generation. Other economic and institutional factors make Ghana the right choice for utility-scale solar PV development in the region. By way of illustration, Germany, one of the leading countries in solar PV power generation, has much lower average radiation levels of 2.73kWh/m^2 (Sealite, 2014).

Table 2. Monthly variation of solar radiation for three towns across three solar belts in Ghana

	Monthly variation of solar radiation for three towns across the three solar belts in Ghana		
Month	**Bibiani**	**Kete-Krachi**	**Navrongo**
	kWh/m²/d	kWh/m²/d	kWh/m²/d
January	5.30	5.61	6.61
February	5.49	5.80	6.53
March	5.43	5.88	6.40
April	5.34	5.74	6.38
May	5.12	5.47	6.46
June	4.47	4.89	6.09
July	4.09	4.55	5.66
August	3.83	4.38	4.94
September	3.94	4.55	5.47
October	4.57	5.19	6.19
November	4.98	5.40	6.15
December	5.00	5.38	5.98
Annual average	**4.79**	**5.23**	**6.07**

Source: RETSCREEN Climate Database (extracted 2014)

Figure 7. Annual global horizontal solar radiation for three towns in Ghana



Source: RETSCREEN Climate Database

3.2 Land Availability and Competing Issues

3.2.1 General Overview of Land Use in Ghana

The pressing question is how to meet the growing human demands for living space, food, fuel, and other materials while sustaining ecosystem services and biodiversity. Due to the competing demands for land usage, acquiring land for large-scale projects such as solar PV projects needs serious consideration. The total land area of Ghana is 238,539 km^2. The designated agricultural land area, comprising of cultivated and irrigated lands, accounts for 57.8 per cent. Areas classified under inland water make up 8.0 per cent, while forest reserves, savannah and woodland form 38.3 per cent of the total land area (Ministry of Food and Agriculture, 2010).

In order to be used for PV projects, land has to be both available and accessible, for which the question of land tenure is critical. Land ownership in Ghana can be categorized into two broad classes: customary lands and public lands. Customary lands are lands owned by traditional tribal arrangements, families or clans and usually held in trust by the chief, head of family, clan, or priests for the benefit of members of that group. Private ownership of land can be acquired by way of a grant, sale, gift or marriage. Public lands are lands that are vested in the president for public use. Ownership is by way of purchase from customary landowners or private individuals, or headed over from colonial governments (Sittie, 2006). The large majority of land in Ghana comes under the category of customary lands. Such lands are also mostly sold and held by individuals. This makes the acquisition and aggregation of large tracks of land for large-scale projects difficult. Hence, the land tenure system in Ghana can be said to pose significant challenges to investment for construction and infrastructure projects that require large tracks of land.

The 1992 constitution[16] vested all public lands in the President in trust for the people of Ghana (Article 257) and also freed all pre-existing public lands in the three northern regions from state control. It recognizes that the managers of public, tribal and family lands are fiduciaries charged with the obligation to discharge their functions for the benefit of, respectively, the people of Ghana and the tribal or family concerned and are accountable as fiduciaries in this regard. This prohibits the creation of freehold interest out of stool land in favour of a grantee (Article 267.5).

The Ghanaian Government is mindful of the implications of large-scale land acquisitions and, in February 2012, the national Lands Commission developed guidelines for large-scale land acquisitions for agriculture and other purposes, with the view to operationalizing the principles of responsible agricultural investments (Lands Commission, 2012). Since large solar energy farms cannot be installed on rooftops, they compete with other land uses. However, properly managed land can be used both for alternative purposes and for solar PV generation, which should lead to the provision of sustainable energy and a green economy.

3.2.2 Assessment of Land Available for Solar PV Power Generation in Ghana

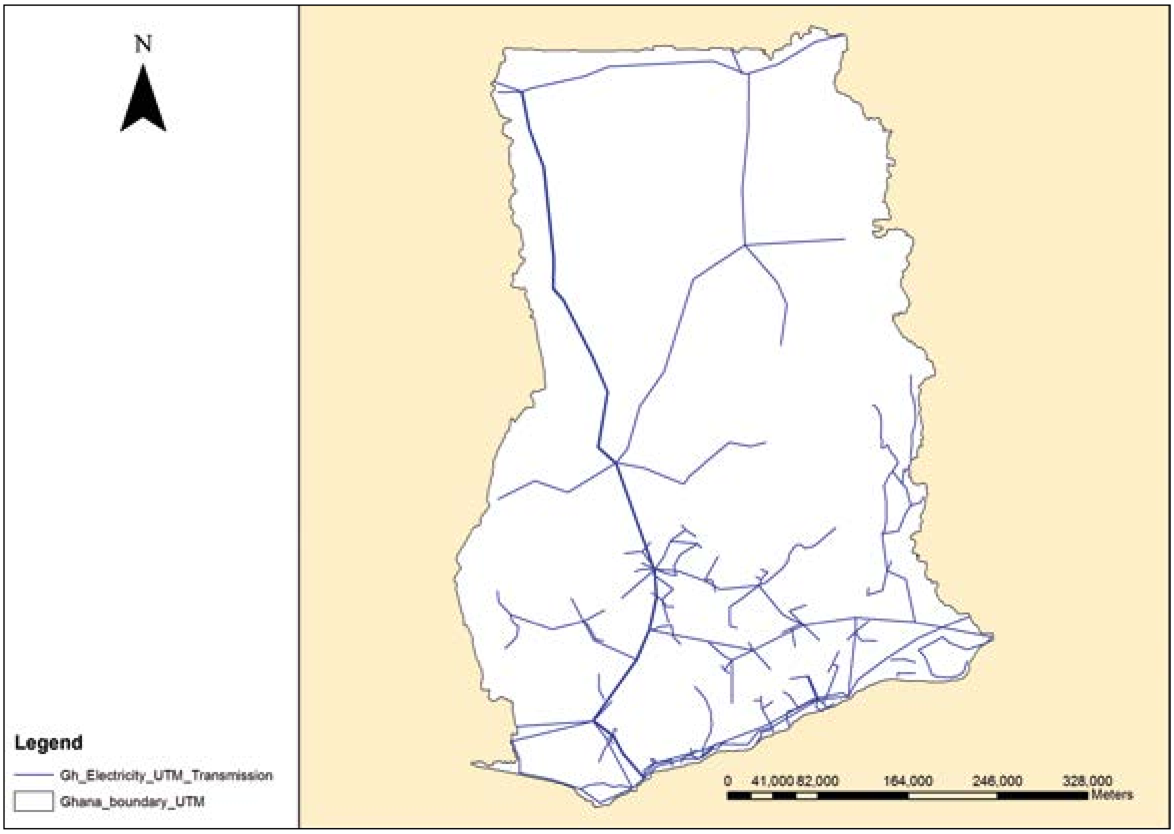
The technical viability of Solar PV generation depends, among other factors, on the available land resource that can be utilized from the geography of Ghana. Land data from the SWERA toolkit coupled with the ArcGIS desktop tool was used to determine the available land. A validation assessment of the tool was carried out at the preliminary stage by comparing the published actual total land area to the total land area obtained by the use of the ArcGIS desktop tool.

Four scenarios were simulated to determine the potential land availability for solar PV generation in Ghana. The third scenario looked at the available land for the entire nation of Ghana. An initial constraint was placed on the other three scenarios in order to minimize transmission losses. In the first scenario, only land areas that were within 20km from the transmission network were considered. The second scenario looked at land that was within 50km from the transmission network in Ghana. The final scenario looked at land that was within 20km from the transmission network for the three northern regions using proximity as a benchmark and Burkina Faso as a target destination for exports. The country boundary data together with the transmission network shown in Figure 8 was used for all the case scenarios.

16 Available at: www.politicsresources.net/docs/ghanaconst.pdf.

All lands within 20km from the transmission network were mapped[17], as shown in Figure 9. Land within the 20km buffer which was determined as unsuitable because of its competitive use was subtracted from the region. Land in Ghana is subject to several competing uses. Protected areas should and cannot be utilized because of their recognized natural, ecological and cultural values. Lakes, rivers and water bodies were also categorized as unsuitable for solar PV. Public infrastructure such as roads and other land uses such as forest belts rendered those areas not suitable for solar PV. All the above subtracted lands shall be referred to as "*first subtracted*" henceforth. The regions *first subtracted* from the 20km land buffer are shown in Figure 10.

Figure 8. Map of transmission network and boundary of Ghana



17 The eligible land area was restrained to 20km within reach of transmission networks, to limit accruing expenditure for prospective investors on transmission infrastructure to a reasonable and feasible level.

Figure 9. Map of land within 20km from transmission network

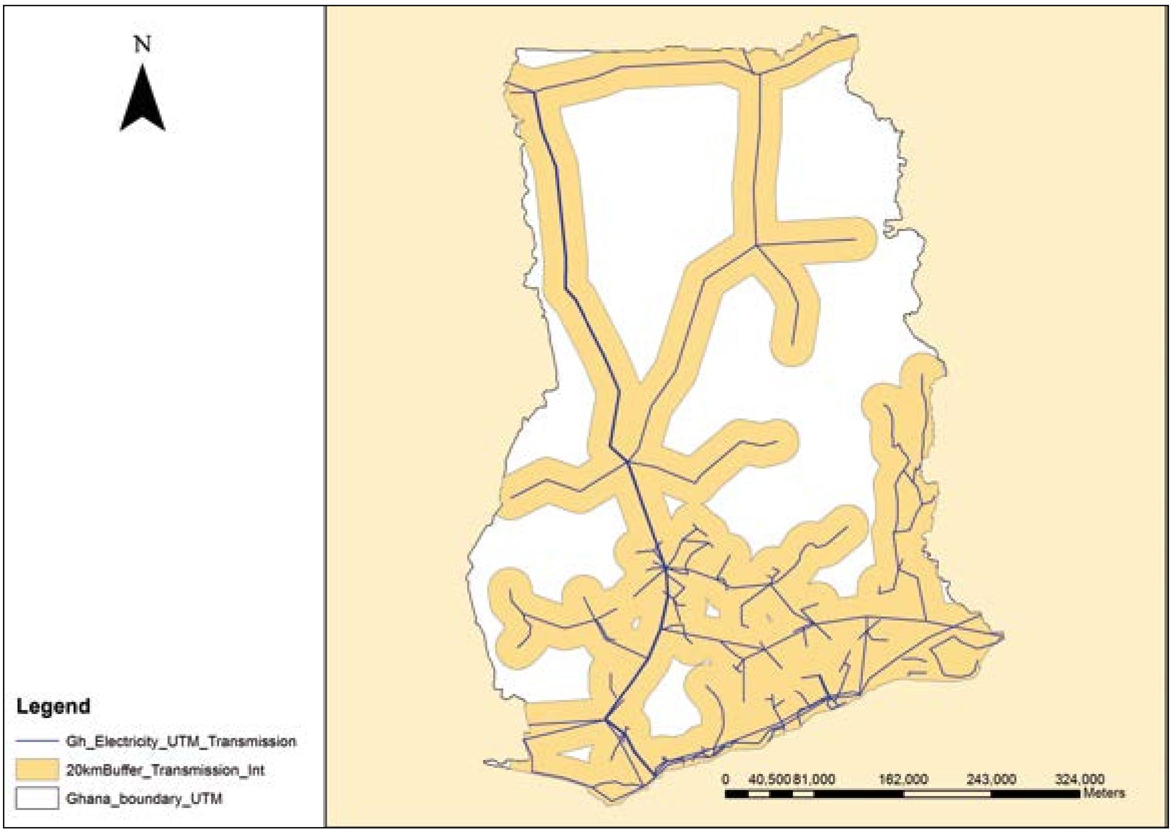
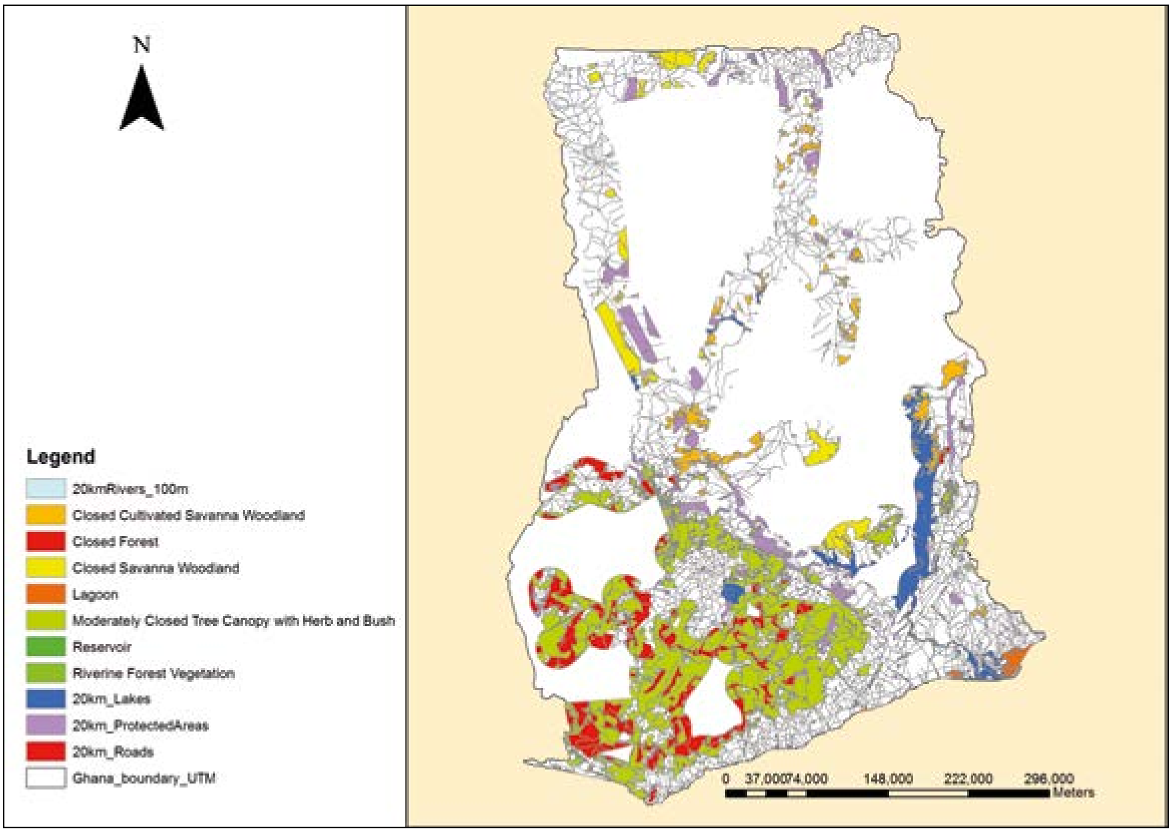


Figure 10. Map of first subtracted areas from land within 20km from transmission network



Land that is suitable for agricultural purposes was then excluded from the land shown in Figure 10. Figure 11 shows the land area deemed not suitable for agricultural purposes. Suitability of land for solar PV generation was determined on the basis of selection criteria from soil type data, to avoid conflicting use with agricultural purposes (see Table 3). Figure 12 depicts the final land available for solar PV generation. This land area is the same as in Figure 11 but without the land classifications. The procedure was repeated for the other three scenarios. Figures 13, 14 and 15 illustrate the final land available for the 50km land buffer, the whole Ghana, and the 20km land buffer for the three northern regions, respectively.

Table 3. Suitable land for solar PV generation from soil data

Type of Soil	Soil Data	Solar PV Generation
Acrisols	Not very productive soils; perform best in un-demanding acidity-tolerant crops	Suitable
Alisols	Used for agriculture in the tropics	Not Suitable
Arenosols	Varying possibility for agriculture; best left under their natural vegetation in the humid tropics	Suitable
Cambisols	Make good agricultural land	Not Suitable
Ferralsols	Not good for agriculture at all	Suitable
Fluvisols	Such soils pose problems for agricultural use	Suitable
Gleysols	Adequately drained gleysols are good for arable cropping, dairy farm, horticulture	Not Suitable
Leptosols	Unattractive soils for rain-fed agriculture	Suitable
Lixisols	Perennial crops or forestry are suitable land uses	Suitable
Luvisols	Luvisols with a good internal drainage are potentially suitable for a wide range of agricultural uses because of their moderate stage of weathering	Not Suitable
Nitosols	Nitosols are highly suitable for agricultural land use at all levels of farming	Not Suitable
Planosols	Planosol areas are not used for agriculture	Suitable
Plinthosols	Many are unsuitable for agriculture and are left idle	Suitable
Regosols	In desert areas, have minimal agricultural significance; used for extensive grazing	Suitable
Solonchaks	Have limited potential for cultivation of salt tolerant crops; many are used for extensive grazing or not used for agriculture at all	Suitable
Solonetz	Problem soils when used for arable agriculture	Suitable
Vertisols	Suitable for rice; good for agriculture	Not Suitable

Source: Compiled from ISRIC (www.isric.org/), n.d.

Figure 11. Map of non-agricultural land within 20km from the transmission network

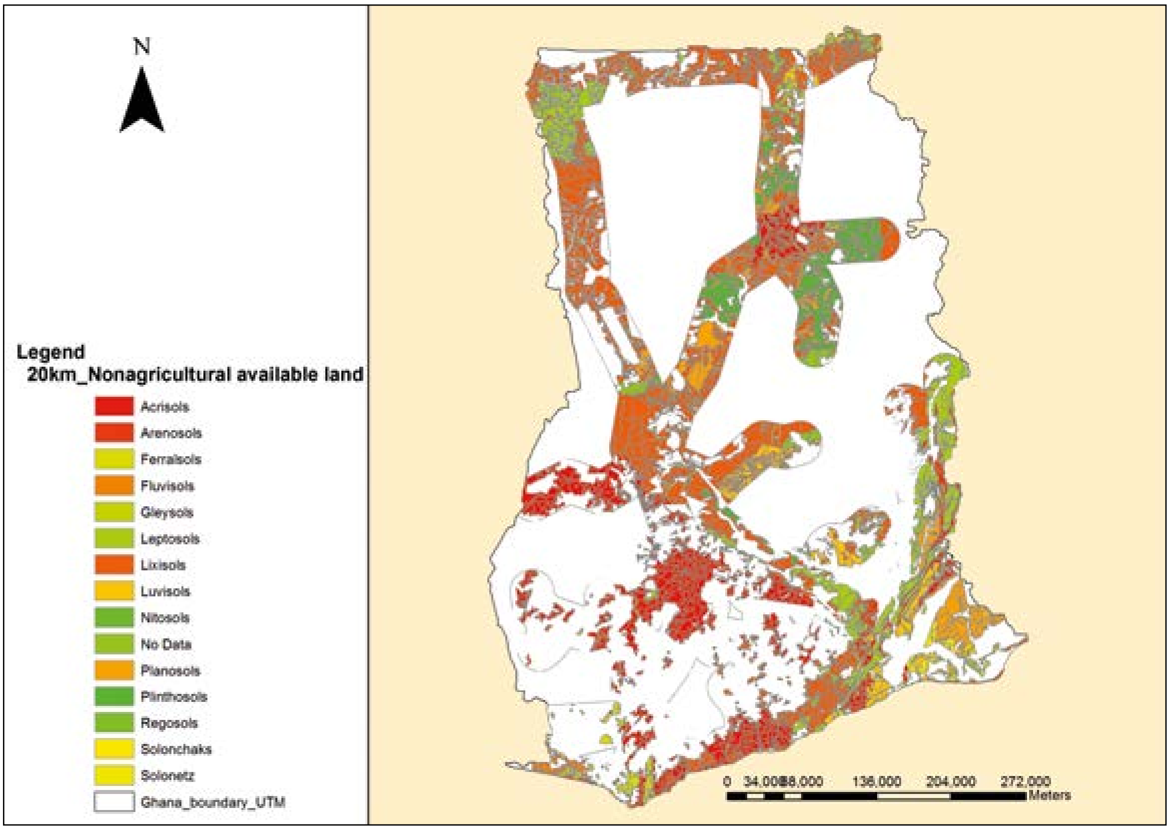


Figure 12. Map of final available land in the zone within 20km from the transmission network

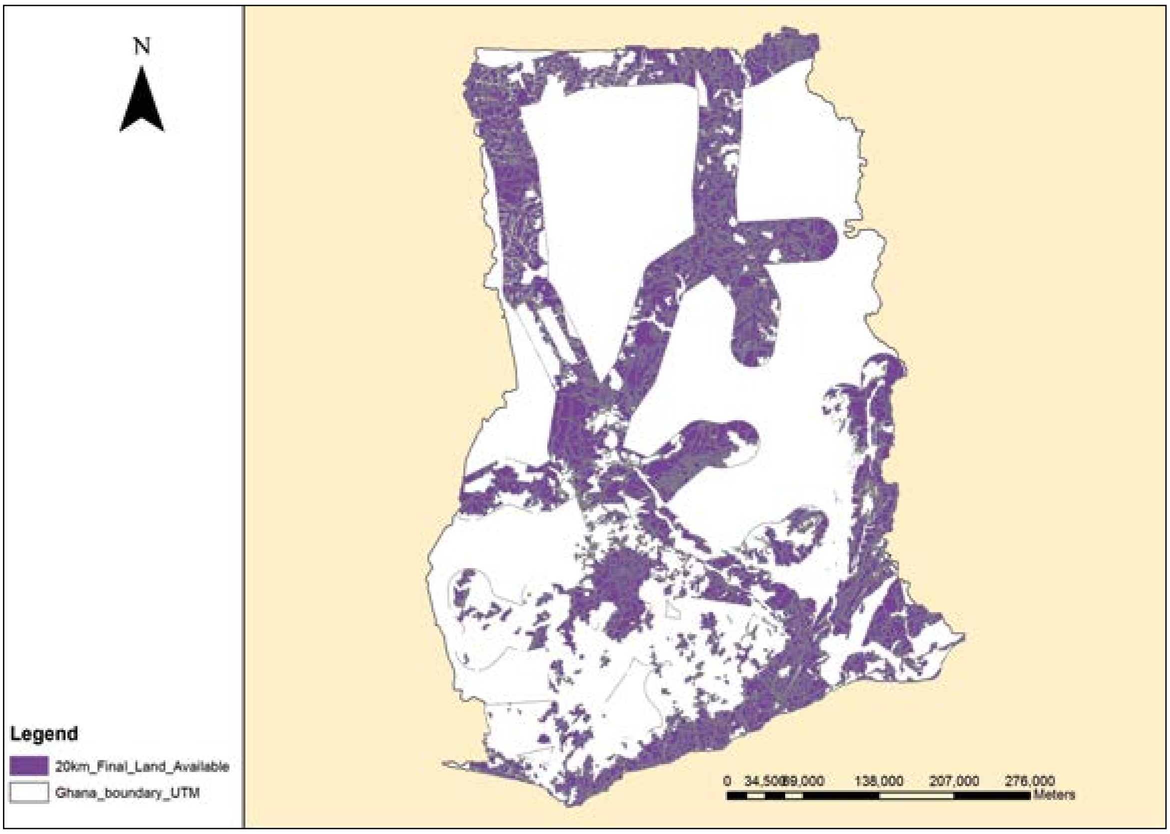


Figure 13. Map of final available land in the zone within 50km from the transmission network

Figure 14. Map of final available land in Ghana

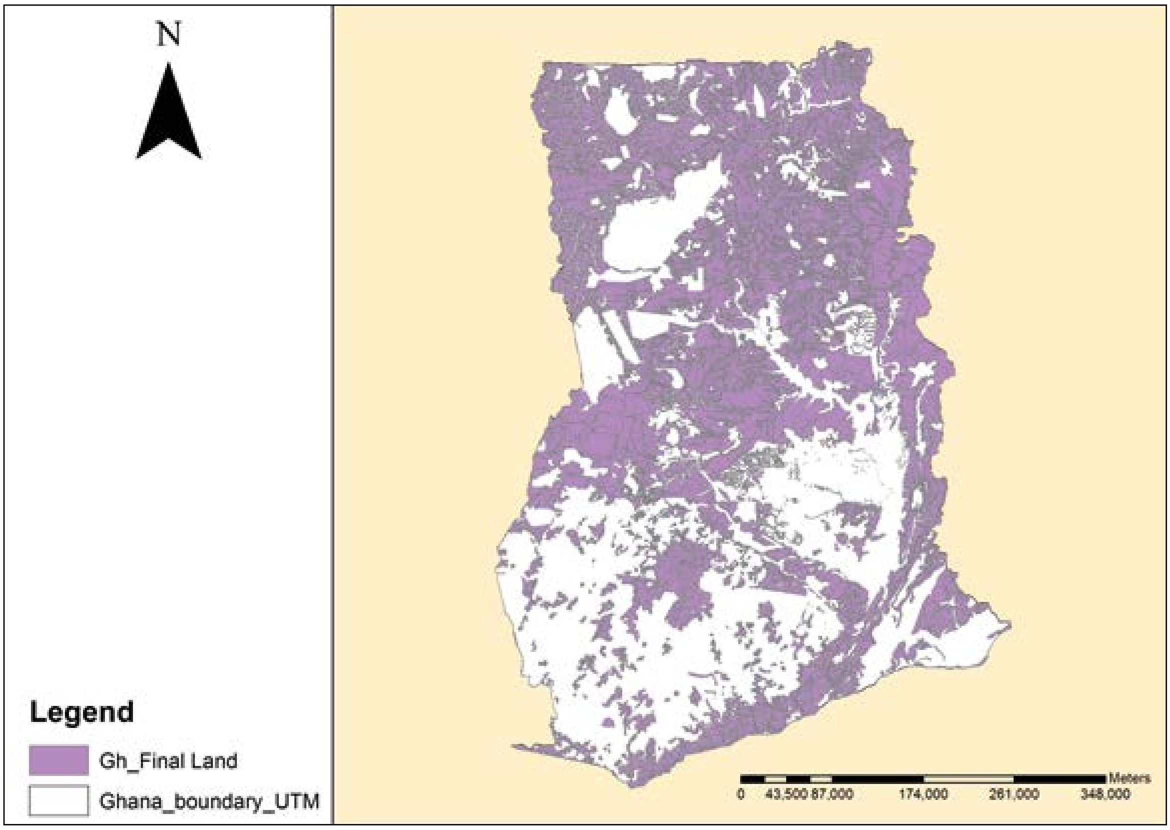
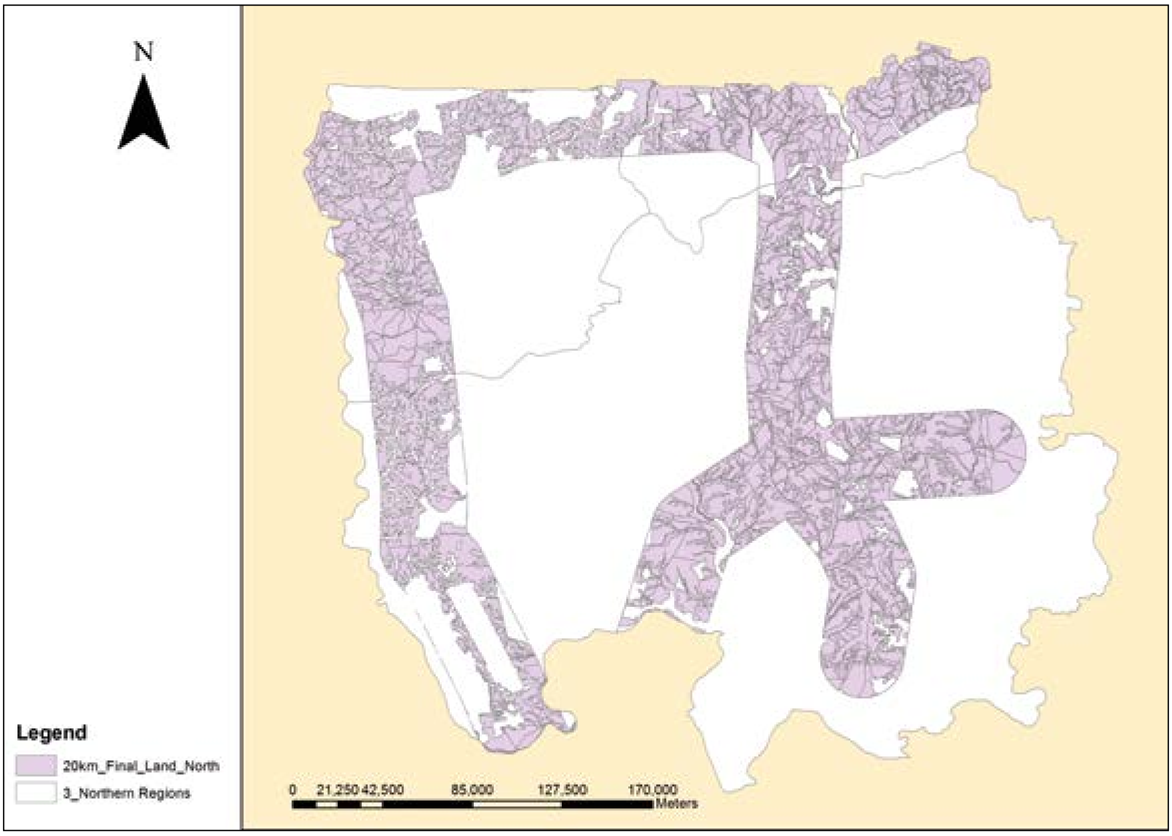


Figure 15. Map of final available land within 20km from the transmission network in the 3 northern regions



The available land area obtained for each of the four scenarios is shown in Table 4.

Table 4. Estimated land areas for solar PV generation in Ghana

Scenario Number	Scenario	Available Land Obtained from Analysis (km²)	Estimated Land Area for Solar PV Generation (10 per cent of Available Land (km²)
1	20km Land Buffer from Transmission Network	76 898.4	7 689.8
2	50km Land Buffer from Transmission Network	112 505.9	11 250.6
3	Entire nation of Ghana	127 644.1	12 764.4
4	20km Land Buffer from Transmission Network for the 3 Northern Regions	29 656.7	2 965.7

3.3 Technological Potential for Electricity Generation (GWh) and Export

Ghana is planning to increase its national generation capacity to above 5,000 MW by 2016, and to reach universal access to electricity by 2020 (from currently 72 per cent of the population), while becoming a major net exporter of electricity to the ECOWAS sub-region. In 2011, Ghana generated 11,200 GWh of power, of which 7,561 GWh (67.5 per cent) was from hydropower and 3,134 GWh (32.5 per cent) from thermal power plants (Energy Commission, 2012). The net power exported was 610 GWh (5.45 per cent of national power generation).

The Ministry of Energy and Petroleum (MoEP) estimates installed solar PV capacity in Ghana at 5.8 MWp (Ahiataku-Togobo, 2013)[18]. This constitutes less than 1 percent of the country's installed capacity. Some documented grid-connected installations in the country include: 50 kWp at MoEP, 6 kWp at the Energy Commission, 90 kWp at Gyau Towers in Tema, 42 kWp at the Akosombo House in Akwamufie, 24 kWp at KNUST, 315 kWp at the Noguchi Memorial Research Centre, and 2.5 MWp from a solar farm in Navrongo (TEC, 2009).

The remainder of this chapter discusses the limits to the achievable technical potential of solar PV power in Ghana and explains how the national solar PV power and energy yield potential were estimated.

3.3.1 Limits to Achievable Technical Potential

A. Technology Constraints

i) Solar Cell Efficiency

An important limiting factor to the potential of electricity generation from solar PV technology is the efficiency of solar cells. Table 5 shows the current solar cell technologies, cell efficiencies and module efficiencies.

Module efficiencies are expected to increase over time due to breakthroughs in new materials with higher conversion efficiencies. For the purposes of this study, we assume that solar PV installations will rely on mono-c-Si technologies at a realistic, relatively low efficiency rate of 12.2 per cent.

Table 5. Performance of commercial PV technologies

	Cell Efficiency (per cent)	Module Efficiency (per cent)	Record Commercial and (Lab) Efficiency (per cent)	Area/kW (m^2/kW)	Life time (year)
c-SI					
Mono-c-SI	16-22	13-19	22 (24.7)	7	25 (30)
Multi-c-SI	14-18	11-15	20.3	8	25 (30)
Thin-Film					
a-Si	4-8		7.1 (10.4)		25
a-Si/μC-Si	7-9		10 (13.2)		25
CdTe	10-11		11.2 (16.5)		25
CI(G)S	7-12		12.1 (20.3)		25
Organic Dyes	2-4		4 (6-12)		15
CPV	Na	20-25	>40	Na	Na

Source: (IEA-ETSAP and IRENA, 2013)

18 Presentation by Mr. Wisdom Ahiataku-Togobo, Director of Renewable Energy of Ghana, at Workshop "Opportunity Africa: Sustainable Energy Investments in Africa - Engaging the Private Sector" - UNEP DTU, Copenhagen, 24-25 June 2014. Available at: http://www.unepdtu.org/PUBLICATIONS/Workshop-Presentations/Workshop-Presentations–Sustainable-Energy-Investments-in-Africa.

ii) Solar Inverter Efficiency

Inverter systems are not 100 per cent efficient in the conversion process, so the maximum expected power output cannot be achieved. Furthermore, due to anti-islanding features, inverter systems are programmed to shut down during grid disturbances hence contributing to system downtime. The data sheet of inverter manufacturers generally lists the efficiency of the conversion of DC to AC power in the 92-95 per cent range. Peak efficiencies are not maintained over the whole time of operation, but inverters generally operate at greater than 90 per cent efficiency over much of the operation (Vignola et al., n.d).

iii) Solar PV Capacity Factor

The "Capacity Factor" is the ratio of the electrical energy generated for the period of time relative to the energy that could have been generated at continuous full-power operation during the same period. The Capacity Factor of solar PV systems is dependent on solar resource availability at different locations, different PV configurations (fixed system, single and double axis tracking), PV orientations and tilt, and conversion losses (inverter efficiency). For most currently available solar PV panels with conventional inverters and no mechanical tracking systems, the Capacity Factor is usually from 0.125 to 0.135 (Cleland & Leverton, 2010). Higher capacity factors are obtained in regions with higher solar resource availability.

iv) Solar PV De-rate Factor

The maximum achievable energy from solar PV systems is limited by the conversion factor, also known as the "de-rate factor". The DC to AC de-rate factor (see Table 6) is the potential energy lost as energy is converted from the panels to grid electricity.

Table 6. PVWATTS[19] DC to AC de-rate factors

Component De-rate Factors	Component De-rate Values	Range of Acceptable Values
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and transformer	0.92	0.88 - 0.98
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.3 - 0.995
System availability	0.98	0.00 - 0.995
Shading	1	0.00 - 1.00
Sun tracking	1	0.95 - 1.00
Age	1	0.70 - 1.00
Overall DC to AC De-rate Factor	0.769	0.769

Source: (NREL, 2013)

B. Electricity Grid Constraints

To achieve the possibility of transmitting and exporting power above 1 GW, the voltages of transmission lines have to be increased significantly. The highest transmission voltage in Ghana currently is 330 kV, but such voltage lines are not available in most of Ghana's territory. To enable the transmission network to haul more power, higher transmission voltages are required to minimize the power lost when transmitting power from Ghana to neighbouring countries. Since loss is a critical factor in determining power generation facilities, proximity to electric transmission infrastructure is another important factor for selecting solar PV sites, as it minimizes transmission losses. Thus, the availability and proximity of transmission infrastructure places a limit on the amount of solar PV power that can be generated in Ghana.

19 PVWatts is a tool by the National Renewable Energy Laboratory (NREL) used to estimate the energy production and energy cost of grid-connected photovoltaic (PV) energy systems.

3.3.2 Review of Land Requirement per Megawatt for Solar PV Power Generation

Many studies have sought to assess the land requirements for solar PV installations, using different methods and techniques for different technologies. There is currently no generally accepted methodology for estimating solar PV potential, but some literature has put forward compelling calculations for land requirements per achievable installed capacity. Literature suggests that array spacing, also known as Packing Factor, must be considered in assessing land per MW constraints. Typical spacing considered during installation for service vehicles is 4-5 meters (Denholm & Margolis, 2008).

IRENA proposed a formula for estimating the extractable solar PV energy (IRENA, 2014). However, IRENA's formula is not further considered in this study, since it does not account for module spacing (the packing factor).

Denholm and Margolis (2008) estimated solar electric footprint to be 48 MW per square kilometer (MW/km^2) for 1-axis tracking collectors with 0° tilt and 65 MW/km^2 for 25° tilt, south facing (ground-based). To estimate the energy production from solar sites, the authors performed hourly simulations using the PVWATTS/PVFORM[20] model. Jacobson (2009) estimated that the area required for a 160 MW PV panel and walking space is about 1.9 km^2, or 1.2 km^2 per 100 MW installed.

In a technical report published by NREL, a complete assessment of solar land-use requirements for various technologies and system configurations with capacities greater than 1 MW was provided (Ong et al., 2013). Land use data was obtained from 166 projects completed or under construction, and 51 proposed projects representing 12.8 GWac of capacity. Direct land-use requirements for small and large solar PV installations were found to range from 2.2 to 12.2 acres/MWac, with a capacity-weighted average of 6.9 acres/MWac.

Given that Ghana has no large-scale solar PV installations of capacities greater than 1 MW, estimates of land use requirements cannot be done by the method of data collection from actual projects and land occupied. The only large-scale installation in the country is a 2.5 MW installed plant in Navrongo, which began generation in May 2013. Hence, there still is insufficient accumulated data on plant yield, capacity factor and project fact sheets for the Navrongo plant. After evaluating the reviewed methods for robustness, this study adopted a land requirement of 6.9 acres/MWac, as used by Ong et al. (2013). Table 7 contains a compilation of estimates of land requirements for solar PV installations, suggested by some authors.

Table 7. Land requirement estimates used in Solar PV technical potential studies

Author	Land requirement per installed capacity	Land requirement per energy yield	Location
Ong et al. (2013)	6.9 acres/MWac	3.1 acres/GWh/yr	USA
Denholm & Margolis (2008)	65 km^2/MW	PVWATTS/PVFORM	USA
Jacobson	1.2 km^2 per 100 MW	PVWATTS	Worldwide
IRENA	Formula	Formula	Not Considered
SEPS	6.9 acres/MWac	RETScreen	Ghana

20 PVFORM is a system design tool developed by the Sandia National Laboratories.

3.3.3 Estimation of Solar PV Power and Energy Yield Potential of Ghana

In order to estimate the technical potential for electricity generation and exports, Ghana was divided into five solar regions: Region A, Region B, Region C, Region D and Region E, based on differences in the available solar resource radiation levels. Details of the radiation range for each region are presented in Table 8. As discussed in Section 3.2.2, the land requirements suggested by Ong et al. (2013) were used in estimating the solar power and energy yield potentials for Ghana. The potential energy yield was estimated using RETScreen. Input parameters used in the RETScreen analysis are shown in Table 9.

Table 8. Solar regions in Ghana

Region Name	Radiation Range (kWh/m²/day)
A	4.862 – 5.100
B	5.106 – 5.319
C	5.326 – 5.518
D	5.522 – 5.710
E	5.718 – 6.019

Source: RETSCREEN 4 Climate Database (extracted 2014)

Table 9. Input Values used for Analysis in RETScreen

Parameters	Inputs
Solar tracking mode	Fixed
Slope	15
Azimuth	0
Photovoltaic type	Mono-si
Manufacturer	Apin Solar
Model	Mono-si- SPP200
Efficiency	12.20 %
Nominal operating Cell temperature	45°C
Temperature Coefficient	0.40 %
Miscellaneous losses	5.00 %
Inverter efficiency	0.92 %

Table 10. Power and energy yield for the various scenarios[21]

Scenario	Land Area (km²)	Potential Power (GW)	Potential Energy (GWh/yr)
Scenario 1	7 689.7	275.4	411 060
Scenario 2	11 250.5	402.9	606 230
Scenario 3	12 764.1	457.1	689 360
Scenario 4	2 665.6	106.2	167 200

21 Only 10 per cent of the available land obtained for each scenario was used in determining solar PV power and energy yield estimates for Ghana.

Table 10 presents the results of Ghana's potential for solar PV electricity generation under the four scenarios. From the results of the analysis, the maximum power and energy yield for solar PV in Ghana are 457.1 GW and 689,360 GWh/yr (689.4 TWh/yr) respectively, occurring under Scenario 3. In Scenario 4, when a constraint of only the three Northern Regions in Ghana, within 20km to the grid is used as a constraint, the results are 106.2GW of power and 167.2 TWh/yr of energy. The area of land required under this scenario (2665.6 Km^2) is approximately 1 per cent of Ghana's total land area. 1 per cent of Ghana's land area has the potential to generate up to 167 200 GWh (106.2 GW) of electricity annually, which is 13 times the national electricity generation in 2012 (12,024 GWh) and 140 times the energy consumed in neighbouring Burkina Faso in 2012 (1,200 GWh).

3.4 Electricity Transmission and Interconnection Systems

This section reviews the transmission network and interconnection systems within Ghana and also within West Africa, under the WAPP.

3.4.1 Electricity Transmission Network of Ghana

Ghana's power system, like many others, is separated into generation, transmission and distribution segments. Generation of electricity is the responsibility of the Volta River Authority (VRA). Transmission is administered by the Ghana Grid Company (GRIDCo). The distribution of electricity to customers in Southern Ghana is done by the Electricity Company of Ghana (ECG), and in Northern Ghana by the Northern Electrification Distribution Company (NEDCo), a subsidiary of VRA.

In 2011, 11,200 GWh of electricity was generated in Ghana, up from 10,167 GWh in 2010. Net power exported decreased by about 64 per cent in 2010. Total power transmission losses in 2011 were 4.9 per cent of electricity transmitted, compared with the previous years' value of 4.6 per cent (see Table 11) (Energy Commission, 2012).

Table 11. Transmission losses and net power exports, 2008-2011

Year	2008	2009	2010	2011
Net exports (GWh)	263	555	930	610
Transmission losses (as % of gross transmission)	6.3	5.5	4.6	4.9

Source: (Energy Commission, 2012)

The transmission system in Ghana is a web of interconnected networks that supports the bulk transfer of electricity over long distances from generation facilities to bulk power distribution substations. The transmission network connects generation points in Akosombo (hydro), Kpong (hydro), Aboadze (thermal), Tema (thermal) and, most recently, Bui (hydro). There are about 53 switching substations and about 4,315.5 km of transmission lines.

The primary backbone of Ghana's transmission system is a network of 161 kV lines and substations. This primary network is supplemented with a sub-transmission system of 34.5 kV lines and a single 69 kV line in the lower Volta Region – the 34.5 kV network is sometimes classified as distribution (PSEC, 2010).

Assessment of the transmission infrastructure shows that a 161 kV closed-loop grid serves the concentrated load of the southern part of Ghana. A 161 kV radial line from Techiman to Sawla serves the north-western part of the country. Also, a 161 kV radial line from Kumasi serves the relatively lightly-loaded northern part of Ghana. The Upper West Region is supplied at Wa by an extension of the Techiman-Sawla line at 34.5 kV (GRIDCo, n.d.). Under the Bui power project, four transmission lines are being constructed from Bui to Sawla, Kintampo, Techiman and Sunyani.

Figure 16. Transmission network infrastructure in Ghana

Source: (GRIDCo, n.d.)

Currently under construction are a 330 kV Aboadze-Prestea-Kumasi-Han transmission system and a 330 KV Tumu-Han-Wa transmission line project. A 330 kV loop between Tema and Takoradi is currently in operation. Figure 16 shows Ghana's transmission network infrastructure.

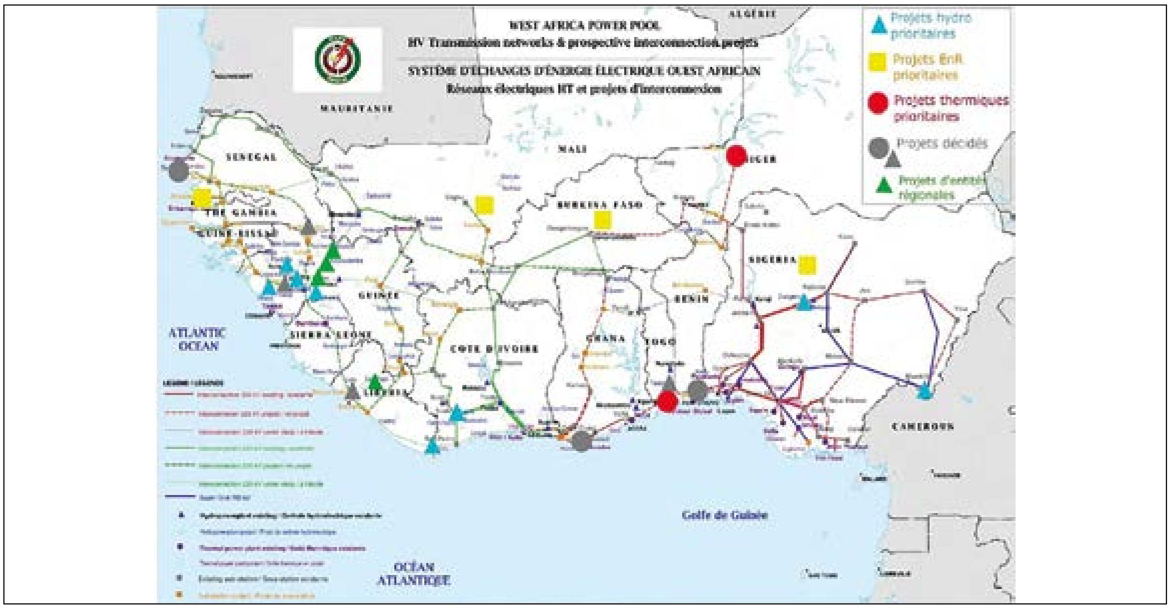
3.4.2 West African Power Pool (WAPP)

The WAPP, a specialized institution of ECOWAS, is the institutional framework of the regional electric system. The WAPP's strategic objective is based on a vision of integrated operations of national electric networks and a unified regional power market. This unified regional market has to ensure, in the medium and long term, an optimal and reliable electricity supply at an accessible cost for the population of the different Member States. WAPP aims to ensure common economic welfare, leveraging on long-term cooperation in the energy sector, including through the promotion of trans-border electricity exchanges.

WAPP facilitates power trading amongst the ECOWAS member states. To achieve its goal, WAPP marked two zones, namely Zone A and Zone B. Zone A includes Benin, Burkina Faso, Ghana, Niger, Nigeria, Niger and Togo, while Zone B includes Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Senegal and Sierra Leone. Côte d'Ivoire is part of both zones.

The transmission system of Ghana is interconnected to the power system of its neighbours Côte d'Ivoire, Togo, Benin and Burkina Faso for power trading (see Figure 17). Owing to the long distance of these interconnecting lines, as well as the bulk power to be delivered, transmission of power is implemented on high voltage (HV) transmission lines, namely 161 kV, 225 kV and 330 kV, and the planned 760 kV super grid, which is expected to run across Nigeria, covering a distance of 7,200 km and entering service between 2017 and 2019.

Figure 17. Current and planned interconnection of West African states under WAPP



Source: (WAPP, 2011)

Power Imports and Exports under WAPP

In 2010, power imports by West African countries increased by 63.5 per cent as compared to 2009. The increase was accounted for as follows:

Togo/Benin – 45%
Mali – 15%
Niger – 15%
Burkina Faso – 10.5%
Senegal – 6.9%
Côte d'Ivoire – 3.9%
Ghana – 2.9%

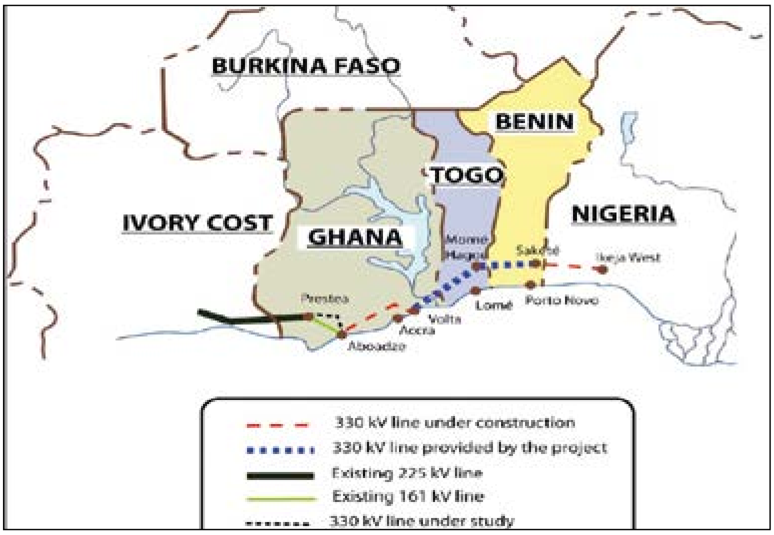
Conversely, energy exports[22] by West African countries declined slightly (by 1 per cent), as compared to 2009. The major energy exporters were, respectively, Nigeria (47 per cent), Ghana (36 per cent) and Côte d'Ivoire (17 per cent). Out of a total of 47,073 GWh of electricity consumed by WAPP Member States in 2010, 3,278 GWh was exported, and 3,247 GWh was imported. Hence, 6.9 per cent of electricity produced in the WAPP region was traded (Infrastructure Consortium for Africa, 2011).

Network Interconnection between Ghana, Togo and Benin

Togo and Benin are highly dependent on power imports from Ghana to supplement local electricity generation. Power trading between these countries is administered by two power authorities, namely VRA (Ghana) and Communauté Electrique du Bénin (Benin). CEB is co-owned by the governments of Togo and Benin and in charge of developing the electricity infrastructure of the two countries.

A proposed 330 kV costal backbone interconnection line is under construction and intended to link Ghana with the power systems of Togo, Benin and Nigeria (see Figure 18). It comprises nearly 192 km of power lines: 82.2 km in Togo and 109.7 km in Benin (both 330 kV lines). This line begins in Tema-Tornu at the Ghana-Togo border (an additional distance of 140 km)[23], runs to Mome Hagou (Togo), through to Sakete in Benin, and continues to Ikeja West, Nigeria (ADF, 2006). In the Upper East region of Ghana, a 161 kV line connects Bawku to Dapaong (Togo), to provide electricity to neighbouring towns and villages. Another line, which has been in operation since 1972, is the 205-km long 161 kV line from the Akosombo hydro plant to Lomé (Togo) (ISSER, 2005).

Figure 18. Coastal backbone interconnection



Source: (ADF, 2006)

Network Interconnection between Ghana and Côte d'Ivoire

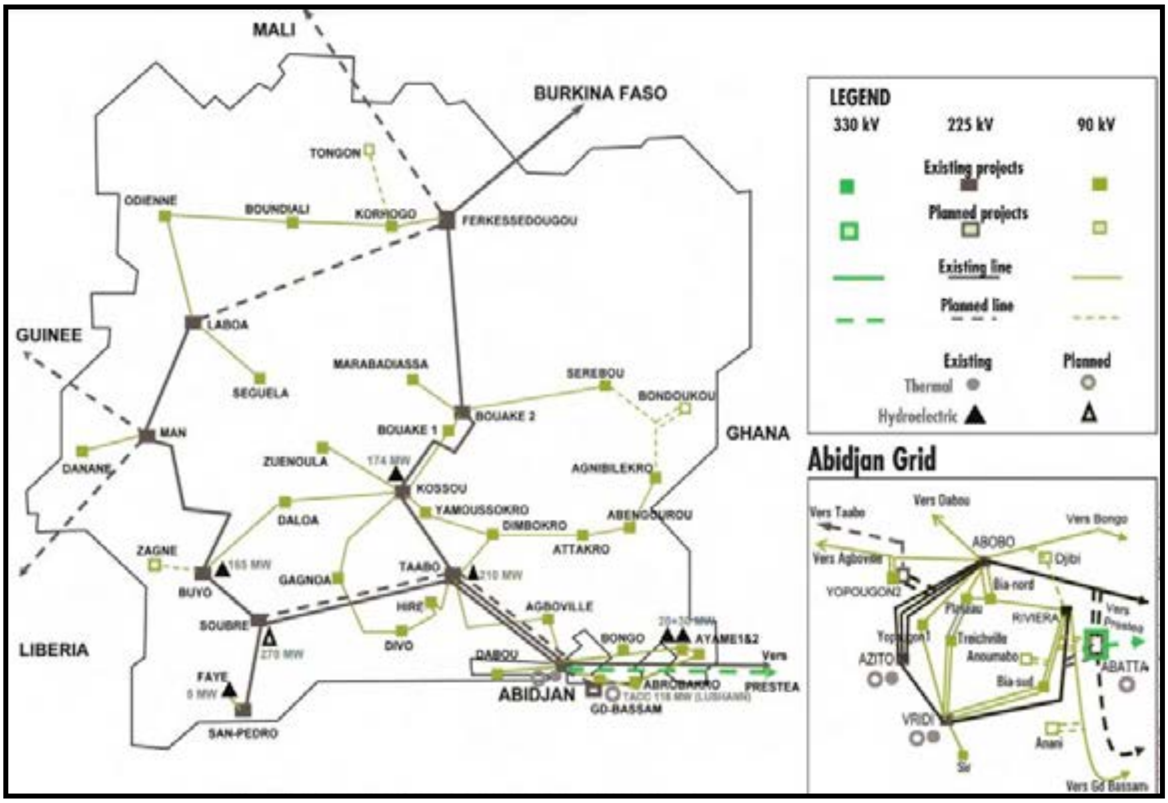
The generation, transmission and distribution of electricity in Cote d' Ivoire are managed by the Compagnie Ivorienne d'Électricité (CIE), which is jointly owned by EDF and SAUR. Côte d'Ivoire exports power to Ghana, Togo, Burkina Faso, Liberia, Guinea, Mali and Benin, making it a major electricity exporter in the sub-region.

In 1983, a single circuit 225 kV line of 220 km between the substation Prestea (Ghana) and the substation Abobo near Abidjan was commissioned to supply power to Côte d'Ivoire (see Figure 19). However, the line's construction demand has since reversed, and Ghana is now a net importer of power from Côte d'Ivoire (African Energy Journal, 2012).

22 Measured as percentage of total electricity generation.
23 A specific procurement notice was issued by the AfDB in August 2010 for the Ghana component of the line. For more information, see URL: www.afdb.org/fileadmin/uploads/afdb/Documents/Procurement/Project-related-Procurement/AOIGhanaPower%208-10.pdf.

Connecting Aboadze (Ghana), Prestea and Riviera (Côte d'Ivoire) is a section of the 330kV coastal backbone that is intended to connect Côte d'Ivoire and Ghana with Togo, Benin and Nigeria. This section of the transmission line is expected to be completed in 2015 (WAPP, 2010).

Figure 19. Côte d'Ivoire's transmission network (showing interconnection with Ghana)



Source: (African Energy Journal, 2012)

Network Interconnection between Ghana and Burkina Faso

Electricity in Burkina Faso is supplied solely by the state-owned Société Nationale d'Electricité du Burkina (SONABEL). The electricity demand in most parts of Burkina Faso is primarily met through thermal power generation. Burkina Faso imports almost 15 per cent of the electricity it consumes, through interconnections with power systems of neighbours (AICD, 2011). Increasing demand for power prompted Burkina Faso to import additional power to supplement peak demand, through interconnections with its neighbours like Ghana and Côte d'Ivoire. In 2009, maximum power imports from Côte d'Ivoire equalled 120 MW and imports from Ghana were 30 MW (ADF, 2009).

Plans are underway to construct a 225 KV transmission line from Bolgatanga in the Upper East Region of Ghana to Ouagadougou in Burkina Faso to transmit high-tension electric power between the two countries. This Interconnection is comprised of approximately 210 km of 225 kV transmission line to a 225/161 kV substation in Zagtouli in Burkina Faso (VRA, 2005). A procurement notice for this project was published by the Agence Française de Développement (AFD) in January 2014[24], and the Ministers responsible for Energy in Ghana and Burkina Faso met in Accra in March 2014 to reaffirm their commitment to the interconnection project (MoEP, 2014).

Another transmission line of 20 km connects the Bawku substation in the northern part of Ghana through an outdoor 34.5 kV switchyard to Bittou in Burkina Faso.

24 See URL: tenders.afd.dgmarket.com/tenders/np-notice.do?noticeId=10505747.

3.4.3 Integration of Solar PV Power into the Grid

Ghana has an extensive network of 161 kV transmission lines. The country is also connected to its immediate neighbours for power trading. According to a source at Ghana's Ministry of Energy, the current transmission network, which distributes power from plants in the southern part of the country, is operating at near maximum capacity[25]. The addition of 330 kV transmission networks could potentially quadruple the transmission capacity of the current 161 kV lines. WAPP has also planned several transmission network upgrades.

Ghana plans to increase its generation capacity to 5,000 MW by 2015 (see Section 2.3.2), with a 10 per cent share of renewable energy excluding large hydropower (see Section 2.3.1). The Public Utilities Regulatory Commission in November 2014 announced a cap of 550 MW on capacities of intermittent renewables that will be permitted in the National Interconnected System. Solar PV is capped at 150 MW while wind is capped at 300 MW.

It remains to be seen whether the 150 MW of solar power can easily be integrated into the upgraded grid system. Generally, increased base load and dispatchable generation capacity enables a greater integration of intermittent renewable into the grid. Therefore, Ghana's target of increasing generation capacity to 5,000 MW in the short-to-medium term increases the prospect of the grid being able to accommodate greater quantities of intermittent solar power.

Literature on grid integration of variable and intermittent renewables emphasizes the need for electricity grid flexibility. Such flexibility is particularly necessary with high penetration levels (OECD and IEA, 2011). Bahar and Sauvage (2013) proposed some techniques for attaining flexibility, which include:

- improving load management,
- using energy-storage systems,
- diversifying variable energy sources geographically and technologically, and
- trading with other electricity grids.

It should be noted, however, that all these measures come with additional costs that need to be considered. In light of the discussions above, further research needs to be done to ascertain the actual effect of intermittency and the amount of power from variable renewables that can be injected into Ghana's grid. Base load options such as small hydro, natural gas fired plants, etc. must be considered, taking Ghana's peculiarities into account. Using the dispatchable generation capacities of neighbouring countries could also facilitate greater penetration of solar PV (and other intermittent renewables).

The theoretically estimated potential of 106.2 GW of power and 167.2 TWh/yr of electricity under the scenarios adopted by this study would require significant infrastructure upgrades, for example conscious efforts to match up grid infrastructure with the anticipated growth in generation capacity (especially from variable sources), and a corresponding increase in dispatchable base load generation capacity to be able to harness. While these estimates must be seen as merely theoretical potential under the practical scenarios and constraints adopted, it shows the extent to which solar electricity could play a role in meeting national and sub-regional energy needs.

25 Source: meeting with GridCo officials on 13 November, 2014, in Tema.

4. Financial assessment of utility-scale solar PV power plants in Ghana

Financial analysis was conducted on a typical 20 MWp solar PV power plant located around Navrongo in the northern part of Ghana (10.9° N, 1.1° W), where solar radiation is one of the highest in the country, with a daily average solar radiation of 6.07 kWh/m^2.[26] This capacity of 20 MWp is chosen for analysis based on the assumption that it represents a realistic investment for a single investor. Typical projects are most likely to be under 50 MWp, as reflected in Table 12 showing the solar PV projects registered at the Energy Commission (as of January 2014). Large-scale (i.e. 50 MW and above) projects will likely be rolled out in phases, with each phase requiring financial justification. An example is the joint venture agreement between China's Solargiga Energy Holdings and the Savannah Accelerated Development Authority (SADA) of Ghana (Bloomberg, 2013). Although the partners plan to install up to 400 MWp (see Table 12), it will be implemented in phases, with the first phase being 40 MWp.

It is important to note that, although over 2000 MWp of Solar PV projects have been provisionally registered (as of April 2014) (Ahiataku-Togobo, 2014), the overall solar PV generation for national use underlies the cap of 150 MW, as appended to the national FIT rates (PURC, 2014) and only VRA has gone ahead to implement and commission a grid-connected 2.5 MWp solar plant in Navrongo, in northern Ghana.

The RETScreen Clean Energy Analysis tool developed by Natural Resources Canada/CANMET Energy is used to conduct/perform/execute this analysis. RETScreen is widely used as a tool to perform pre-feasibility analyses on clean energy projects and investments.

Table 12. List of solar PV projects in Ghana (compiled as of January 2014)[27]

No.	Name of Company	Proposed Plant Capacity (MWp)	Location of Plant
1	Mere Power Nzema Limited	155	Awiaso-Akpandue, Western Region
2	Siginik Energy Limited	50	Bodi, Northern Region
3	Orion Energy Ghana Limited	75	Tsopoli, Greater Accra Region
4	Savannah Accelerated Development Authority (SADA)	40	Nabogu, Northern Region
5	Selexos Power Ghana Limited	30	Tarkwa, Western Region
6	Scatec Solar Ghana Limited	50	Tamale, Northern Region
7	Turkuaz Energy Limited	50	Navrongo, Upper East Region
8	Savanna Solar Limited	400	Kusawgu, Northern Region_
9	Volta River Authority (VRA)	2.5	Navrongo,Upper East Region
10	Volta River Authority	4	Kaleo, Upper West Region
11	Volta River Authority	2	Lawra, Upper West Region
12	Avior Energy Ghana Ltd	70	Jema, Brong Ahafo Region
13	Energy Resources Projects Ghana Ltd	10	Prampram, Greater Accra Region
14	Wilkins Engineering Ltd	5	Yendi, Northern Region
15	Reroy Energy Limited	50	Kpone, Greater Accra Region
16	Sun Investment Ghana Limited	100	Osudoku City, Eastern Region
17	TFI Power Limited	30	Mahe-Obom Shai
18	Alpha Power Ghana Limited	10	Buipe, Northern Region
19	Solaris Kage Ghana Limited	5	Koforidua, Eastern Region
19	BXC Company (Ghana) Limited	20	Gomoa Onyadze, Central Region
TOTAL (MWp)		1 158.50	

26 Data Source: RETScreen Climate Database.
27 See URL: energycom.gov.gh/Renewable/provisional-wholesale-supply-and-generation-licenses.html.

a) Input Parameters for Financial Analysis

Key input parameters into RETScreen are summarized in Table 13 below. The data used were obtained from benchmark data, publications of the PURC of Ghana, authors' assumptions, etc.

Table 13. Summary of input parameters into RETScreen

Parameter	Value	Remarks
Solar resource data	See Table 3	Obtained from RETScreen Climate database
Tracking mode	Fixed	Slope of 15° due south
Module specifications	Mono-Crystalline Si (see Table 7)	Efficiency of 12.2 per cent is quite a conservative value considering current efficiency numbers for this technology.
Electricity export rate	US$ 210/MWh	Using Ghana's FIT rate for Solar PV.
Inverter Efficiency	95 per cent	Typical inverter efficiency
Installed cost	US$ 3 000/kW	Includes Balance Of System (BOS) components. An optimistic assumption based on US$ 4000/kW (approximately) of solar PV plant installed by Ghana's VRA in 2013.
Transmission line	US$ 80 000/km	Personal communications with GRIDCo and from RETScreen user-guidelines (analysed for 20 km scenario), 161 kV lines.
Access roads	US$ 80 000/km	RETScreen user-guidelines – for projects > 5 MW
Sub-station	US$ 2 000 000	
Feasibility study	1 per cent of project cost	Authors' assumption
O&M as per cent of Capital Cost	2 per cent	PURC Ghana guidelines, authors' assumptions considering scale of project
Variable cost as per cent of energy cost	0.23 per cent	PURC Ghana guidelines
Discount rate	10 per cent	Based on World Bank rate of 5 per cent plus margin for non-concessional facilities.[28]
Inflation rate	3 per cent	US$ -denominated
Debt ratio	90 per cent	Authors' assumption
Debt term	10 years	Authors' assumption
Debt interest rate	5 per cent	Authors assume concessional facility such as the IRENA/ADFD.[29]
Electricity export escalation rate	0 per cent	Tariffs are usually predetermined by long-term contracts.
Project life	25 years	Typical for solar PV projects

With these input parameters, RETScreen reports an annual electricity output of 36,783 MWh, with a capacity factor of 21.0 per cent. Incorporating tracking (1-, 2-axis) improves the system output, although the initial cost also increases.

28 See URL: www.worldbank.org/ida/grant-element-calculations.html.
29 The Abu Dhabi Fund for Development (ADFD) charges between 2-6 per cent interest rate. See URL: climatefinanceoptions.org/cfo/node/3337.

b) Summary of Financial Metrics

On the basis of the input data summarized in Table 13, the financial indicators presented in Table 14 are obtained.

Table 14. Summary of Financial analysis based on input parameters from Table 13

Indicator	Unit	Value
Pre-tax Internal Rate of Return	per cent	10.3
Simple Payback	Yr	10.3
Equity payback	Yr	13.8
Net Present Value (NPV)	US$	578 374
Benefit-Cost (B-C) ratio		1.09
Debt Service Coverage Ratio (DSCR)		0.77
Energy Production Cost	US$/MWh	208.27
Annual Energy Production	MWh	36 783
Annual Income	US$	7 724 492
Annual Cost	US$	7 660 78

c) Financial Viability Indicators – Explanatory notes

Internal Rate of Return on equity (IRR- Equity) - *Represents the true interest yield provided by the project equity over its life before income tax. If the internal rate of return is equal to or greater than the required rate of return of an organization, then the project will likely be considered financially acceptable. If it is less than the required rate of return, the project is typically rejected.*

Net Present Value (NPV) *of the project is the value of all future cash flows, discounted at the discount rate, in today's currency. Positive NPV figures are an indicator of a potentially feasible project.*

Benefit-Cost (B-C) ratio *is the ratio of the net benefits relative to costs of the project. B-C ratios greater than 1 are indicative of profitable projects. Net benefits represent the present value of annual income and savings minus the annual costs, while the cost is defined as the project equity.*

The Debt Service Coverage (DSCR) *is the ratio of the operating benefits of the project over the debt payments. This value reflects the capacity of the project to generate the cash liquidity required to meet the debt payments. RETScreen outputs the lowest ratio encountered throughout the term of debt.*

Simple Payback *represents the length of time that it takes for a proposed project to recoup its own initial cost, out of the income or savings it generates. The more quickly the cost of an investment can be recovered, the more desirable is the investment. It is useful as a secondary indicator to indicate the level of risk of an investment.*

Source: www.RETScreen.net

With an equity payback of 13.8 years, an NPV of US$ 578,374, a Benefit-Cost ratio of 1.09 and an IRR of 10.3 per cent, this project appears to be financially viable only with special financial support. A DSCR of 0.77, however, gives an indication that the project may have liquidity constraints. Additionally, the Ghanaian feed-in-tariff conditions, which guarantee prices for a period of 10 years, may pose concerns for potential investors, as there is some uncertainty after the first 10-year period. The annual income for this typical 20 MWp plant is estimated at US$ 7.7 million, with a corresponding operating cost of US$ 7.66 million (see Table 14). The annual income could increase to almost US$ 40 million if 100 MWp was allowed by grid operators – with a corresponding increase in annual costs. Investment requirements are estimated at US$ 200 million for the typical 20 MWp plant, and US$ 380 million for an installed capacity of 100 MWp. Thus, preferential financing will be required until the costs of installation fall, as shown by the sensitivity analysis below.

d) Sensitivity Analysis

Various input parameters and the underlying assumptions are subject to some variability, particularly the cost/kW installed, which makes up over 80 per cent of the initial cost. Therefore, sensitivity analyses were undertaken to see the effect of the potential changes on the initial costs and the other financial viability indicators. The installed cost, which was initially assumed at US$ 3,000/kW, is varied (see Table 13) up to US$ 3,500/kW and US$ 2,000/kW. This range of sensitivity is informed by project cost of VRA's 2.5 MW plant in the North of Ghana (US$ 4,000/kW) and a KfW loan facility of EUR 22.8 million to the Government of Ghana for a 12 MWp Solar PV project (ADF, 2014) – this amounts to EUR 1,900/kW. The results are presented in Table 15 below.

Table 15. Sensitivity of financial indicators to cost per installed kW

US$/ kW	IRR – Equity	Payback – Equity (yr)	B-C Ratio	Debt Service Coverage Ratio	Energy Production Cost, US$/MWh	NPV (US$)
3500	5.7 per cent	16.8	-0.33	0.64	240.14	-10 062 889
3000	10.3 per cent	13.8	1.09	0.77	208.3	578 374
2500	18 per cent	11.1	3.01	0.96	176.4	11 219 637
2000	35.4 per cent	3.2	5.79	1.26	144.5	21 860 900

The financial indicators become strongly positive at an installed cost of US$ 2,000/kW. At this level (and holding other parameters constant), the electricity production cost is estimated at US$ 145/MWh.

e) Issues to Consider/Challenges

From a financial point of view, Ghana's current feed-in-tariff of US$ 210/MWh effectively sets a lower limit in terms of tariff expectation for any investor who is setting up a plant in Ghana - even for export. Although officials at SONABEL[30] (in Burkina Faso) put the cost of electricity production at US$ 250/MWh (for diesel power plants), they currently buy power from Ghana and Côte d'Ivoire at around US$ 150/MWh. Meeting the minimum tariff expectation of a Ghana-based PV power producer will mean having to pay at least 40 per cent more for wholesale electricity. Additional charges by the national grid operator for power transmission will also apply.

Financial mechanisms will have to be put in place to address this issue, making the returns from investment more attractive while not overburdening cross-border off-takers. Climate and carbon finance schemes could play an important role in this context.

30 Source: interview with SONABEL officials on 26th November, 2013.

5. Assessment of Ghana's potential to participate in the solar PV value chain

The global solar PV value chain is complex, and its activities transcend domestic boundaries. This section presents an overview of the global solar PV value chain, and examines the prospects for Ghana's participation using solar PV components.

5.1 Governance in the Global Solar PV Value Chain

A PV system is formed from a number of components. The PV cell is the basic building block that converts solar energy into direct current (DC) electricity. PV cells are interconnected to form a PV module, and the modules are combined with balance of system (BOS) components (e.g. inverters, batteries, electrical components, and mounting systems) to form a PV system.

The global solar PV value chain is organized around the components of solar PV systems. Upstream suppliers provide inputs to other businesses midstream, which further transform these inputs, before passing them downstream to the next actor in the chain and, eventually, the product is passed on to the consumer (Normann & Ramirez, 1994).

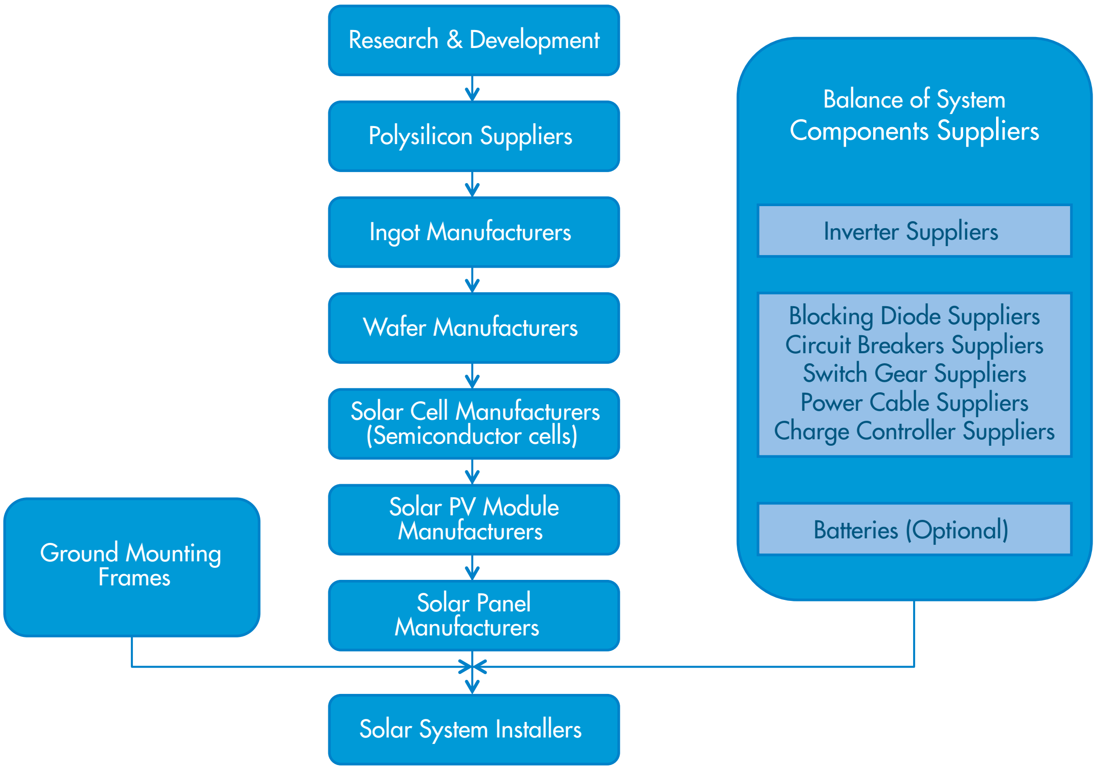
Accordingly, solar businesses are strategically positioned along the global value chain to take responsibility for various value-added functions within the chain (see Figure 20). The linkages existing within value chains, beyond national boundaries of the parent enterprise, prescribe a global view on value chains (hence, "global value chains").

Lead enterprises manage access to and integration into value chains. They employ a variety of governance structures (e.g. vertical integration[31] and modular value chains[32]) and mechanisms, which have implications for the roles played by subordinate actors in the chains, often from developing countries.

Some lead enterprises are vertically integrated and, therefore, there is less opportunity for the participation of new actors. These enterprises have expanded their operations to cover the major phases of the PV value chain in order to control costs and lead times. However, global sourcing is a common practice in the competitive PV solar value chain. The manufacture of solar PV system components is both capital and technology-intensive.

31 Almost all value chain activities, from research and development, to design and production, are done in-house (Gibbon et. al., 2008).
32 Suppliers in such chains manufacture products or provide services to customer's specification, while taking responsibility for process technology and investments in equipment (Gibbon et. al., 2008).

Figure 20. A typical solar PV value chain



Lead enterprises with the largest market shares have invested in large-scale and high-technology production and assembly facilities, which are used as leverage to generate economies of scale, thereby driving costs down. These capital-intensive facilities can create barriers of entry for new market actors. Consequently, lead enterprises often have the market power and capacity to integrate other actors to undertake value-added functions or, alternatively, to exclude other actors.

Through, for example, modular structures, some suppliers are integrated into value chains to take charge of the manufacture of full components or subassemblies for particular lead enterprises. Lead enterprises specify their requirements to suppliers, and suppliers must have the capability (process technology and capital) to meet specified requirements.

Local PV manufacturers may have the opportunity to be integrated into value chains, and occupy functional positions that lead enterprises cannot fulfil, based on their demonstration of capability to deliver low-cost products that meet production requirements.

The decision to integrate particular actors into the chain is made upon a consideration of a variety of factors. Lead enterprises make initial decisions based on actors' demonstration of compliance with pre-specified requirements known as order qualifiers (e.g. social, environmental and quality standards and non-tariff barriers) of the international market. Compliance with these requirements is verified by a variety of recognized conformity assessments[33] (1st party, 2nd party and 3rd party conformity assessments). The second decision-making criterion then focuses on order winners, e.g. reputation, price, reliability and geographical position. The integration of subordinates along the chain is partly based on the core competence of lead enterprises and their functional investments. These lead enterprises and their various tier-suppliers are in turn subject to a wider institutional framework of governance executed by public and private sector regulators, which are external to the value-adding activities.

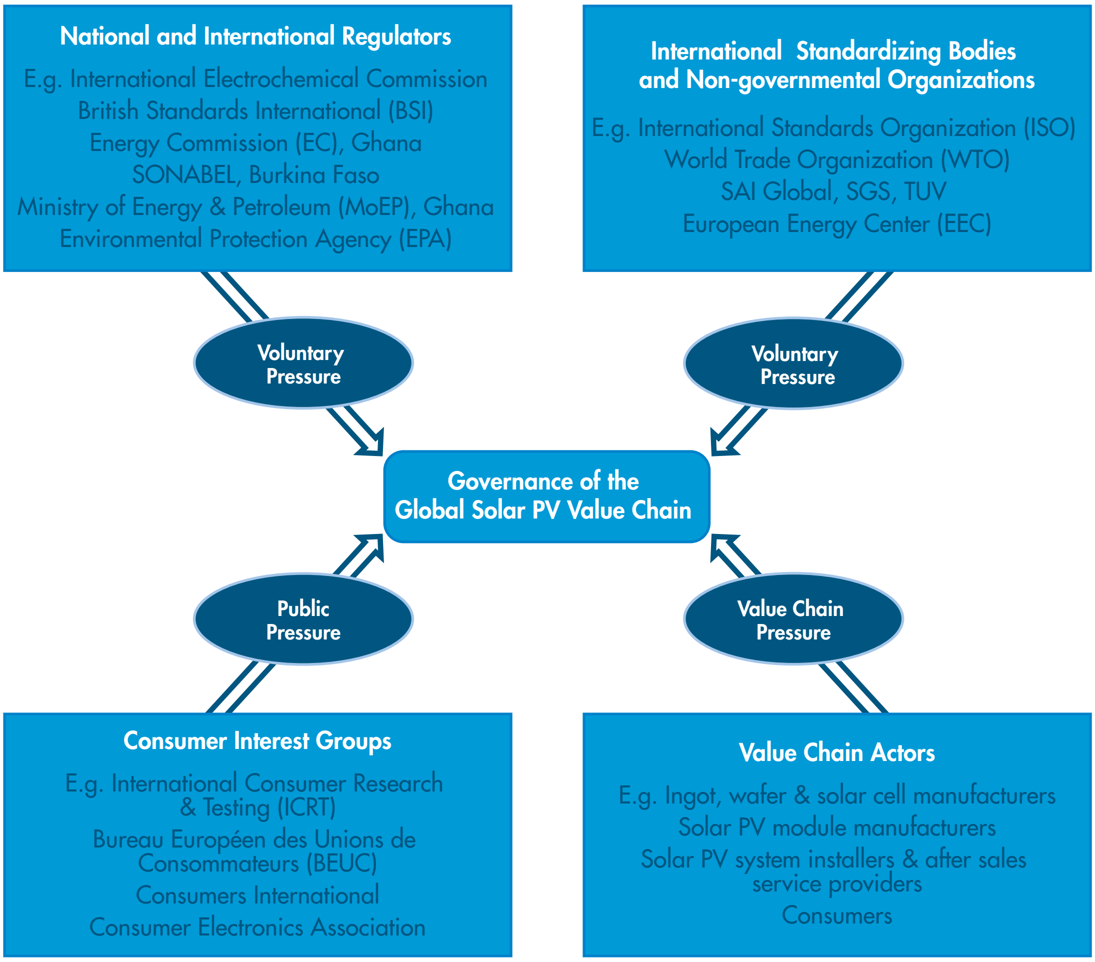
33 A conformity assessment entails checking whether products, services, materials, processes, systems and personnel measure up to the requirements of standards, regulations or other specifications.

Lead enterprises and the suppliers they govern are tied into regional and global structures that develop rules that govern international trade. These are implemented at the regional and national levels through a variety of mechanisms that influence how manufacturing and assembling is organized within domestic contexts. The Technical Barriers to Trade (TBT) Agreement, for example, establishes a framework of rules and disciplines that guides Member States in reference to the preparation and adoption of technical regulations, standards and conformity assessment procedures[34] (WTO, 2008). All Member States of the WTO are expected to comply with the requirements of the TBT Agreement. The TBT Agreement is envisaged to foster an international trade system that is more open, fair and non-discriminatory to all involved.

5.2 Key Stakeholders

The global solar PV value chain is governed by four categories of stakeholders: non-governmental sector bodies, intergovernmental and national government ministries and agencies, consumer interest groups and value chain actors (see Figure 21). These stakeholders play different roles in the value chain, and use different mechanisms both to govern and influence the value chain in diverse ways. All efforts are geared towards realizing a safe and reliable high-quality product that yields higher margins for chain actors.

Figure 21. Key stakeholders in the governance of the solar PV value chain



34 There are 159 Member States and 30 Observers to the TBT Agreement. Normally, observers are expected to start accession negotiations within five years of becoming observers.

National and Intergovernmental Regulators

These are stakeholders who are not directly involved in the value adding functions of the solar PV value chain, but have significant input into the ways in which production processes and services are organized to meet various objectives: to protect the environment, and to yield social and economic benefits. These institutions and agencies are mandated by law to regulate value chain activities through mandatory global, regional and national frameworks at the institutional, regulatory and policy level. Intergovernmental institutions (e.g. the International Electrochemical Commission (IEC) and the WTO), which are often made up of country representatives of Member States, collectively enact global and regional binding policies, agreements, regulations and standards (e.g. TBT Agreement and IEC 61215:2005). National Government Ministries and Agencies also enact policies and regulations to make global and regional operational requirements, in addition to context specific requirements. Additionally, some stakeholders at this level also develop codes of best practice, both to guide and facilitate the compliance of relevant commercial institutions with the relevant requirements.

International Standardizing Bodies and Non-governmental Organizations

There are limits to the extent to which governments can control and intervene in value chains, and this makes the role of non-governmental sector institutions very important. This group of stakeholders, even though they are not direct value chain actors, develops standards and codes of practice (e.g. ISO 14000 and ISO 9000), which inform the design of plants, processes and products, and the content of training programmes at different functional positions in the solar PV value chain.

Unlike public standards, which often set the basic minimum requirement for chain actors, private standards are often more stringent. In theory, private standards are supposed to be voluntary in nature; however, over the years, some have become *de facto* mandatory. The lack of compliance with one or more of the private standards means that enterprises will be excluded from participating in the respective value chain. Non-governmental sector institutions also assist manufacturing and service providers in the value chain to comply with both public and private standards, and serve as third-party conformity assessment bodies, which provide third-party certification and registration services, and training to the industry in order to further develop its capacities.

Consumer Interest Groups

This group of stakeholders acts on behalf of consumers to influence institutional, policy and regulatory frameworks. Consumer interest groups act as the voice of consumers in the governance process to protect them from potential corporate abuse. These interest groups exert public pressure in relevant institutions responsible for the governance process, to ensure that the consumer interest is taken into account in decision-making. This stakeholder group also educates and informs consumers, and addresses (with regulators, where necessary) consumer complaints (Tansey & Worsley, 1995; Simmonds, 2002). Furthermore, consumer bodies also participate in international and national technical committees during the standards development process, to ensure that regulations are developed in conformity with the standards that address issues of real concern to consumers.

Consumer interest groups are established in two ways: by non-governmental sector bodies, or through the formal institutional arrangement of government. In the latter case, interest groups have specific statutory status (Simmonds, 2002). In some contexts, particularly in developing countries, consumer groups are ad hoc; they are formed for particular purposes and disband afterwards. Such ad-hoc practice does not allow due consideration of consumer issues over time to get an understanding of the issues of true concern to consumers, and of what scopes of action are open to addressing such concerns effectively.

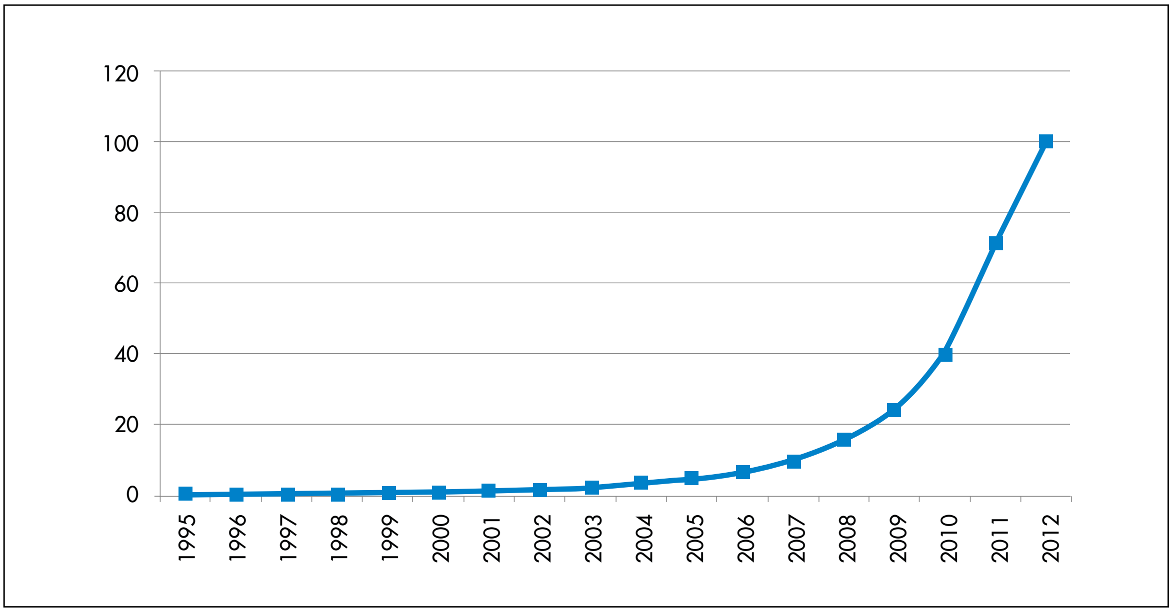
Other Value Chain Actors

This group includes raw material suppliers, manufacturers, distributors, retailers and arbitrageurs. These stakeholders are the primary actors in ensuring that solar PV components and services are safe, of high quality and reliable. The actors receive all kinds of pressure (including mandatory, voluntary and public pressure) from actors external to the value chain. Research and development organisations and consumers are also part of this group.

5.3 Overview of the Global Solar PV Industry

The global solar PV industry has experienced significant growth over the past few decades. In terms of global installed capacity in renewable energy systems, it is third to hydro and wind power (EPIA, 2012). The total installed PV generation capacity on a global scale has been increasing progressively from approximately 0.6 GW at the beginning of 1995 to 100 GW in 2012 (see Figure 22) (REN21, 2013). It is estimated that the cumulative, grid-connected capacity will grow to 230 GW in 2017 (IEA, 2012), and up to 3,000 GW by 2050 (IEA, 2012).

Figure 22. Solar PV global capacity in GW from 1995-2012



Source: (REN21, 2013)

While many developed countries, particularly in Europe, are taking advantage of the opportunities provided by the growing solar power industry, and some Asian countries are gathering momentum to compete in particular segments of the global PV system value chain, it is forecasted that the African region has potential for growth only in the medium- to long-term (IEA, 2010). The solar market is expected to shift from the North to the South, and this is expected to give Africa some share of installed capacity between 4.1 per cent and 5.7 per cent, relative to the total global installed capacity by 2030 (EScience Associates et al., 2013).

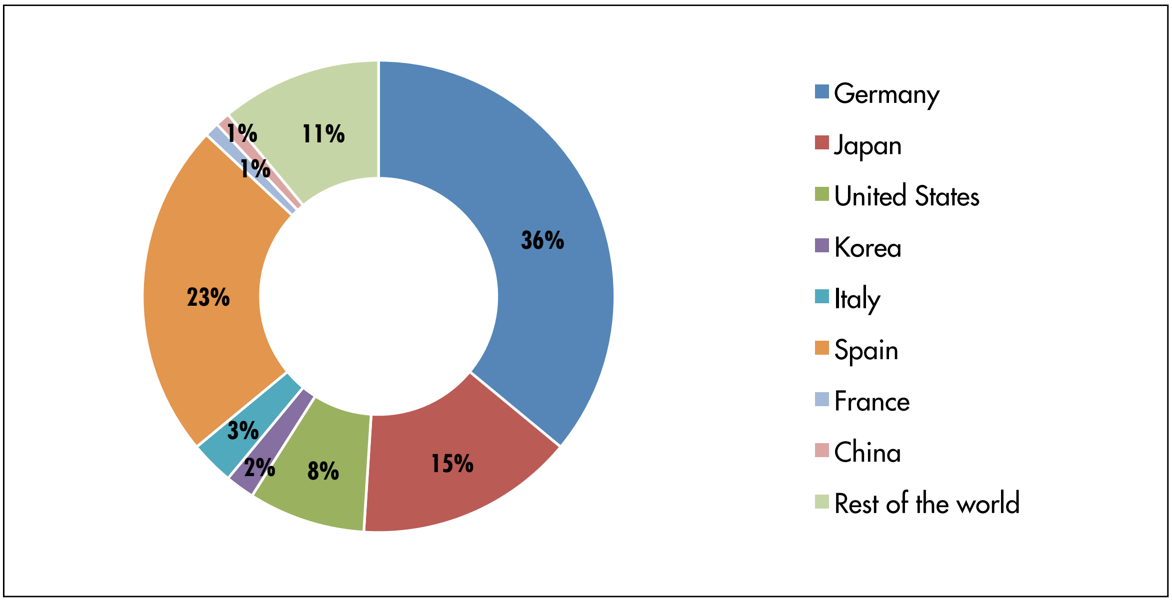
Africa is currently last on the list of solar PV development per region. The region's contribution, even to the upstream segments of the value chain, is still not significant. Africa, and West Africa in particular, currently participates at the far end of the chain, primarily as consumers of the PV technology. Solar PV technology and services are primarily imported into Africa, and this makes retail prices far higher than cost prices (UNIDO, 2009). Yet, the deployment of the technology for power generation in many Member States, relative to global trends, is quite negligible.[35] According to experts in the field of renewable energy, the current trends in energy supply and demand in Africa will worsen unless a stronger commitment is reached, and a concerted effort and effective measures are taken at the national and regional levels, in order to reverse the overdependence on imported solar PV systems and components.

Some argue that with diminishing tariff barriers to international trade, the West African region, and developing countries in general, faces greater opportunities for sustainable green growth and development. Mechanisms implemented by global institutions such as the WTO's GATT and TBT Agreements attempt to ensure that no country is unduly restricted from participating in global value chains (WTO, 2008).

35 Some studies record a total cumulative installed capacity of less than 1 per cent (EScience Associates et al., 2013).

According to the IEA (2010), PV power will continue to grow in the next four decades, providing 11 per cent of global electricity supply by 2050, and this will have positive impacts on the security of energy supply and the socio-economic development of producer countries. The global solar industry is projected to grow from revenues of currently US$ 80 billion to around US$ 1 trillion, and has the potential to create 10 million additional green jobs globally, in the coming decades.

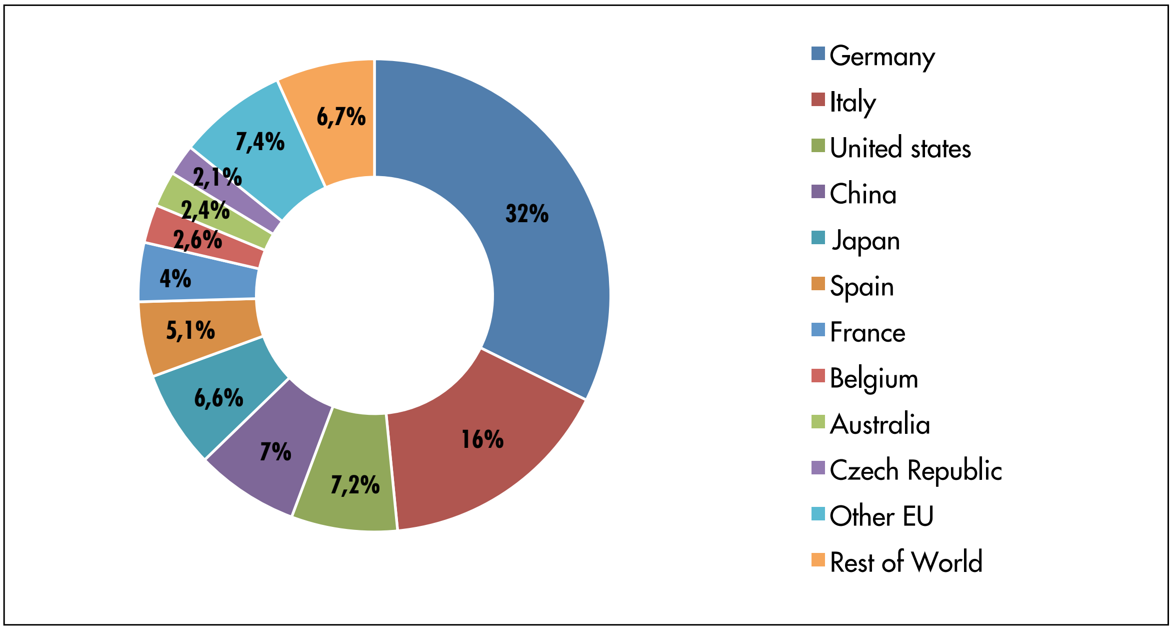
Figure 23. Share of countries in global installed solar PV in 2008



Source: (IEA, 2010)

The global landscape for solar PV is changing rapidly. For instance, in 2000, three countries (Germany, Japan and United States) dominated the global solar PV market, accounting for approximately 77 per cent of total global installed PV capacity. By 2008, Spain had become a significant player in the solar PV market, with market shares surpassing even Japan and the United States (See Figure 23). In 2010, four countries dominated the market of PV installed capacity: Germany (5.3 GW), Spain (3.4 GW), Japan (2.1 GW) and the United States (1.2 GW), accounting for 80 per cent of the total global installed capacity (IEA, 2010). Since then, new players continue to emerge; countries like Korea, China, France, Italy, India and Portugal are gradually increasing their share in the global solar PV installed capacity due to new policy and economic support schemes. These countries also identify functional positions along the global PV value chain to contribute their value offering. Established actors are also expanding their total installed capacity, and this is significantly changing the rankings of countries with regards to their holdings in market shares in the industry (see Figure 24). Germany, Italy, the United States and China are currently the leading countries while, regionally, Europe still has the largest share in terms of installed capacity (approximately 70 per cent).

Figure 24. Share of top 10 countries in solar PV global capacity in 2012

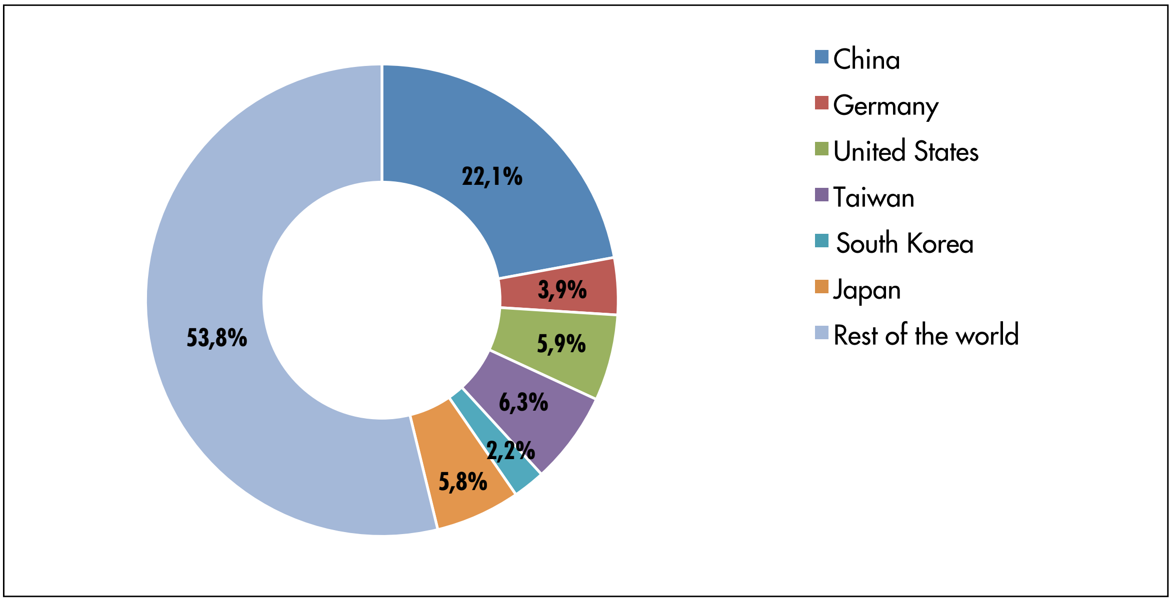


Source: (REN21, 2013)

The production side of the solar PV industry is equally changing. Countries like India and China are increasingly expanding their production capacities across the different PV value chain segments. India has a mission to make the country a global leader in solar energy, with an installed generation capacity of 20 GW by 2050, 100 GW by 2030 and 200 GW by 2050. China, in particular, has become a major contender in the global context, holding the largest share in both silicon cell manufacturing and PV modules globally (see Figure 25 and Figure 26). The country is also continuing to strategically expand its production shares across other segments of the value chain. Production of cells in China has risen from just 3 MW in 2001 to 107 MW in 2007; production capacity increased to 50 GW in 2012.

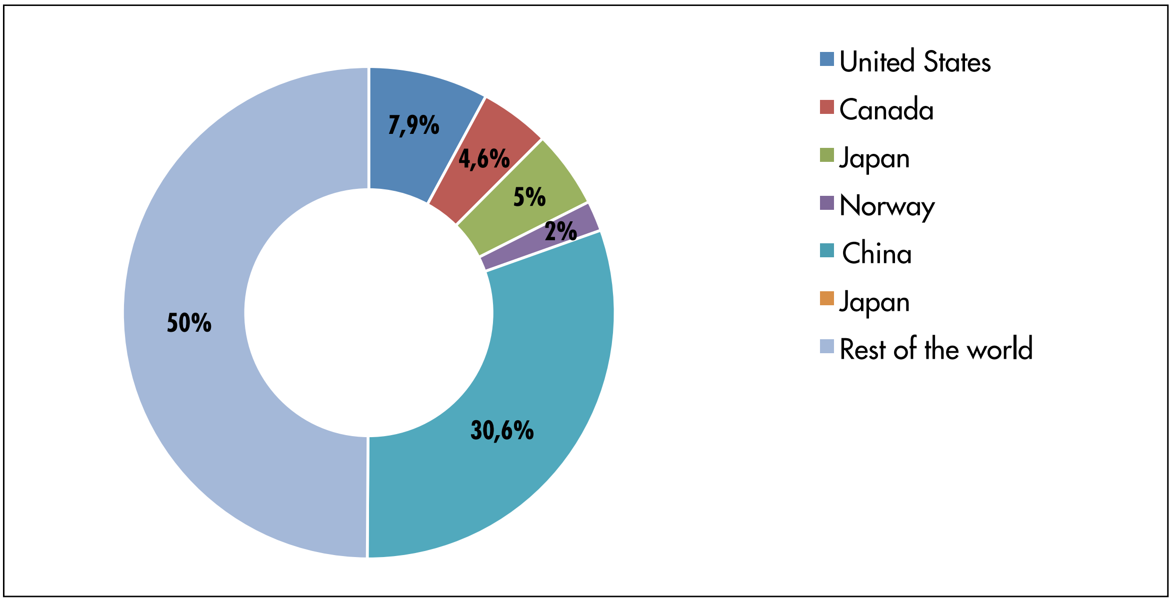
The significant growth in both installed and production capacities in China is pumping huge investments into the sector and incentivizing enterprises to move into manufacturing industries through support schemes, including tax incentives. This is a result of stringent national regulatory requirements decided by the Chinese Ministry of Industry and Information Technology. For instance, China ramped up capacity by using its own raw material (polycrystalline silicon) and tightened the regulation on both old and new market entrants. The efforts from individual countries have put the Asia region on the global landscape. Currently, Asia has the largest share in cell production, with countries like China, Taiwan, and Japan being the market leaders (REN21, 2013). However, Germany and the United States also continue to feature prominently in solar PV cell production.

Figure 25. Top solar PV cell manufacturers in 2010



Source: (Platzer, 2012)

Figure 26. Global solar PV module manufacture in 2012, by country



Source: (REN21, 2013)

The regional distributions of solar PV components for a number of technologies for the year 2012 are shown in Figures 27 to 31 (EPIA, 2013). In the figures, the outer circle represents global production capacity and the inner circle the actual production from the region. These signify different utilisation rates. The figures indicate that the share of the Asian region in all of the featured technologies is rather significant. Asia has significant market share in wafers, c-Si cells, and c-Si modules, and China plays a key role in realizing these market shares for the region. The production capacity for Europe still remains competitive, particularly in polycrystalline silicon, with the annual capacity share reaching 17 per cent, and the actual production share reaching 20 per cent due to higher utilization rates. With respect to thin film production capacities, Europe also played an important role in 2012 with over 20 per cent share in the actual production of thin film. The Asia Pacific region, with Japan and Malaysia as leading producers, covered more than 60 per cent of the actual production of thin film in 2012.

Figure 27. Regional production vs. actual production capacity of poly silicon

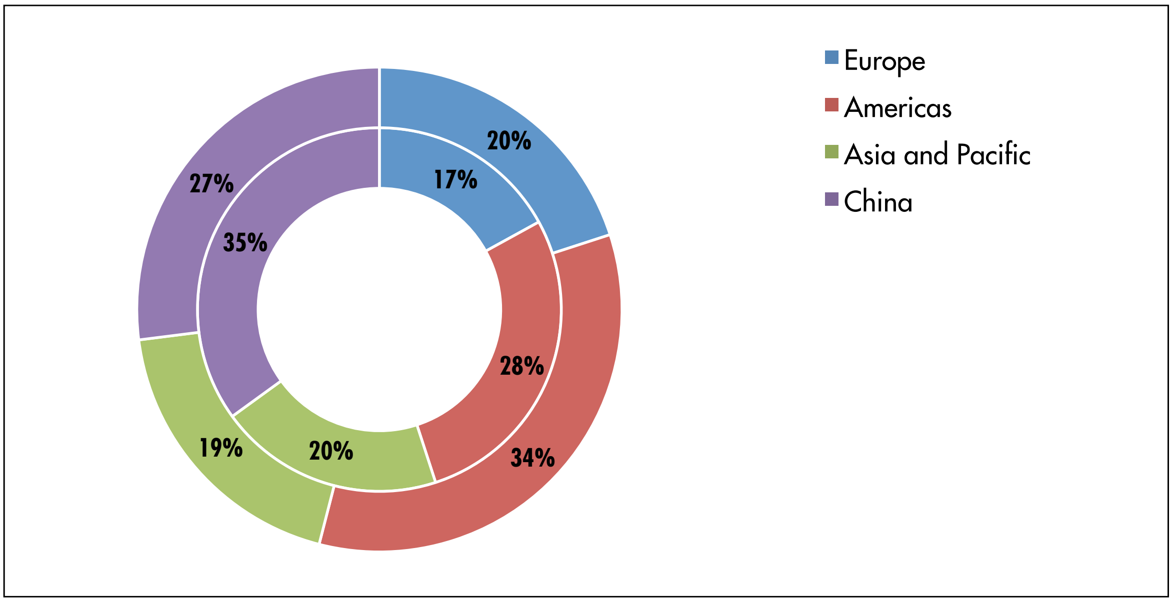


Figure 28. Regional production vs. actual production capacity of wafer

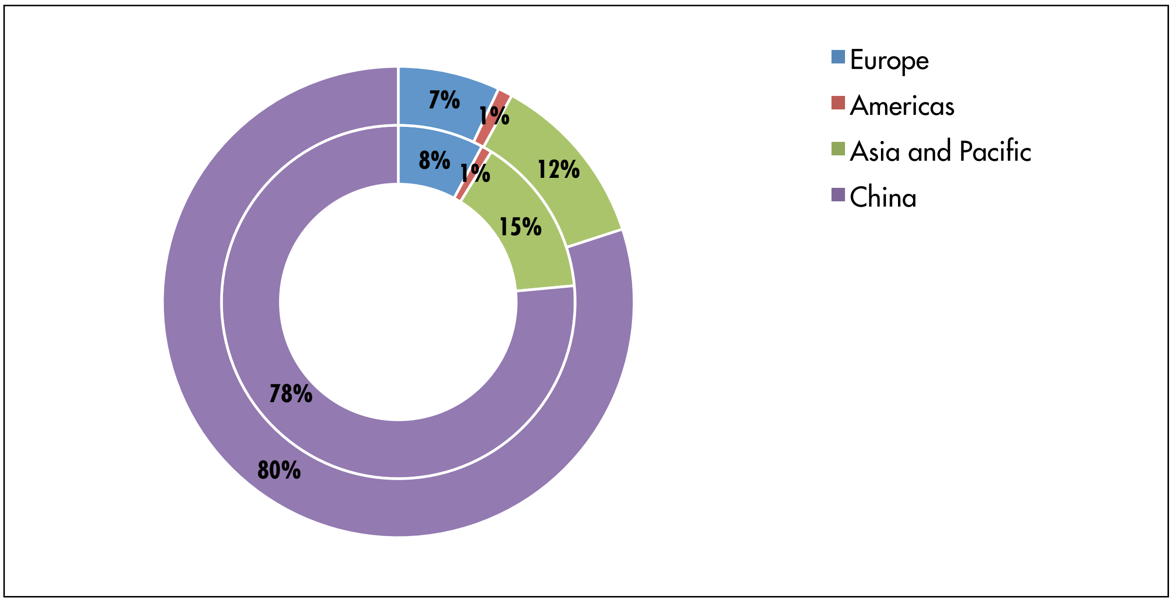


Figure 29. Regional production vs. actual production capacity of C-Si cells

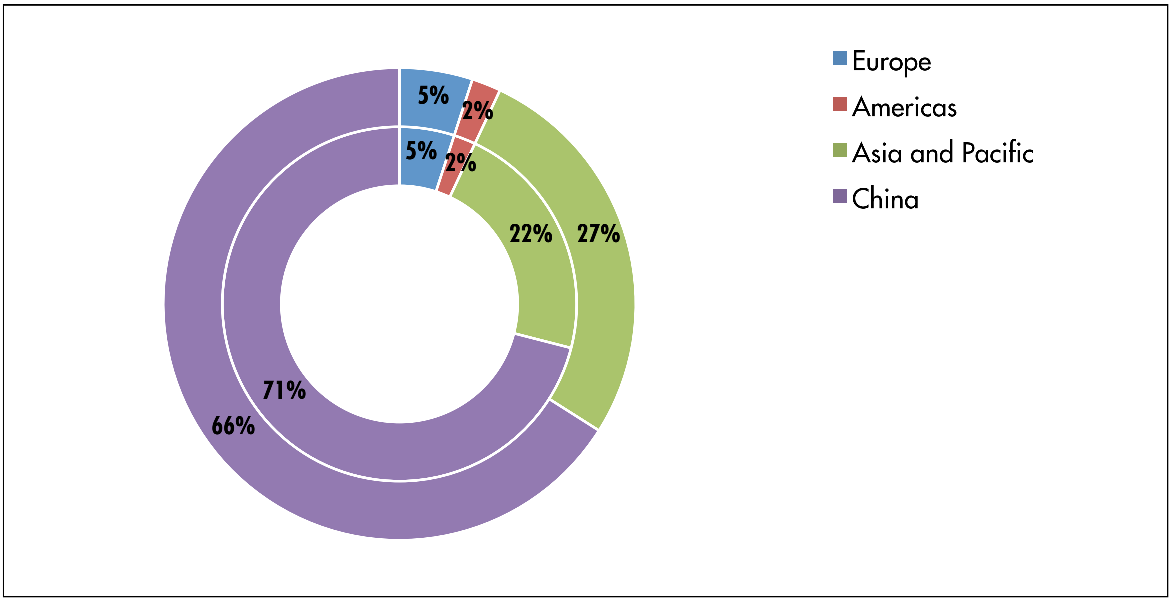


Figure 30. Regional production vs. actual production capacity of C-Si modules

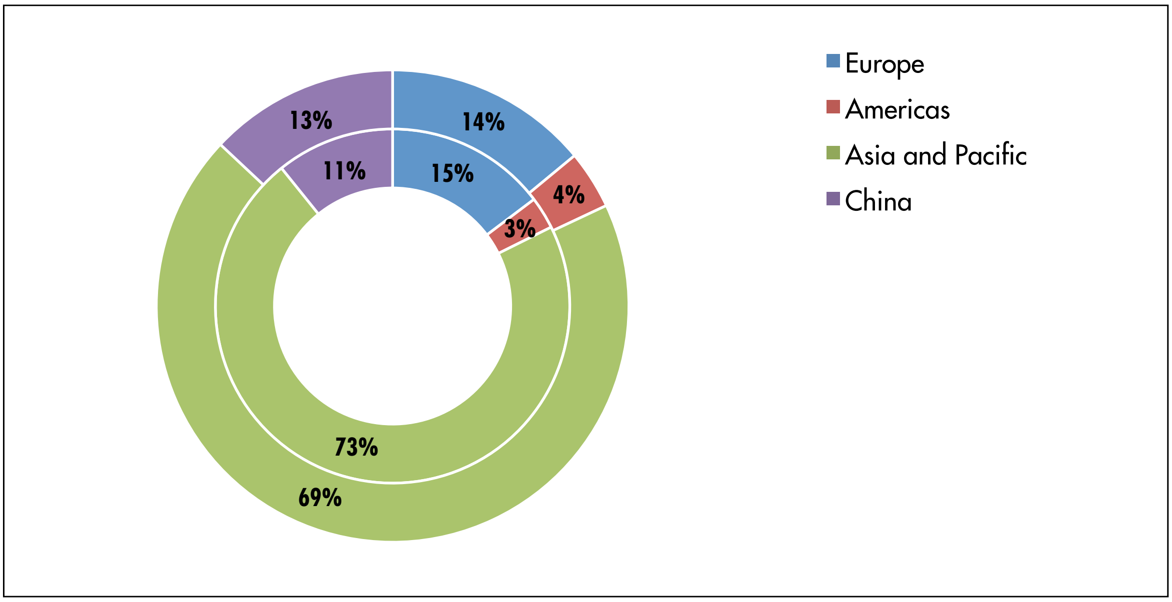
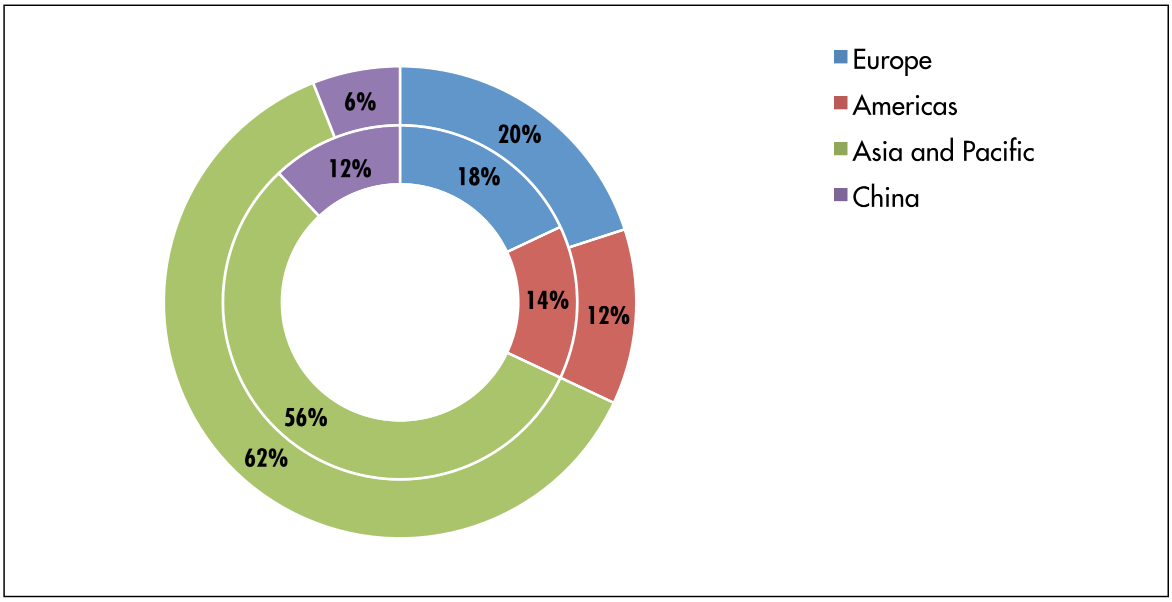


Figure 31. Regional production vs. actual production capacity of thin film modules



Source of figures 27-31: (EPIA, 2013).

5.4 Analysis of Solar PV Tariff Structure for Manufacturing in Ghana

The access and participation of countries and their enterprises in value chains are based on, among other things, their compliance with global, regional and national requirements (see section 5.1). These requirements take the shape of tariff (e.g. import taxes or custom duties) and non-tariff (e.g. environmental, quality standards, and rules of origin) measures, which are used by countries to control the amount of trade they conduct with other countries. The established view is that these requirements can impede trade among countries. Although there are global as well as regional measures to ensure that tariffs are not used to restrict access and participation in particular value chains, the concerns of major stakeholders are focused on the potential use of non-tariff measures to restrict access and participation.

For example, local content requirements (LCR), which demand a certain percentage of local participation in industries, may have implications for domestic enterprises participating in the regional or global value chains. The same applies for domestic standards and certifications that are not aligned with international standards. Generally, anti-dumping and countervailing duties may provide a level playing field between domestic manufacturers and their international suppliers of the same product, while subsidies and other incentives may be used to create demand for trade goods.

The solar products industry in Ghana is young in comparison to other countries in Africa, such as Kenya and South Africa, and the solar PV components manufacture and assembly industry is practically non-existent. Due to the currently low domestic demand and the lack of established international markets for components and accessories from Ghana, the use of solar PV in Ghana is dependent on imports of systems or components (AGSI, 2011).

Currently, a number of both domestic and international enterprises is involved in the importation, installation, and after-sales servicing of installed systems in Ghana. An increasing number of enterprises is getting involved in this segment of the industry because of the gradually increasing consumer market. This increase in market size is attributed to the many load management programmes that have been introduced in the country over the past few years as a result of electricity supply shortages. The high cost of solar PV systems often limits uptake in Ghana, and this is cited as a fundamental constraint. Industry stakeholders also complain about the high cost of production; as of March 2014, no enterprise was found to be manufacturing or assembling solar PV components in Ghana.

Some industry stakeholders have asserted that two enterprises were engaged in the manufacture and assembly of solar panels. However, all attempts to locate and interview owners of those plants to ascertain the veracity of those claims, and understand the motivation for shutting down the plants proved futile. There is currently one enterprise that has built a solar panel plant in Accra; however, according to the enterprise's representative, no panel production has begun because of lack of domestic demand. A 50 MW constant demand on a yearly basis is said to be required to break even; this demand cannot be realistically attained in the short- to medium-term, and there is no policy that facilitates its realization.

Ghana has a policy directive that currently guides the tariff regime in operation. There is a zero rating on imports of complete solar PV systems, inverters and solar panels. However, some system components, which are duty-free, still attract a 15 per cent value added tax (VAT) (AGSI, 2011).

Table 16. Import tariff on complete solar systems and components

No.	Description	Duties	VAT
1	Solar panels	0 per cent	15 per cent
2	Batteries	25 per cent	15 per cent
3	Regulators	10 per cent	15 per cent
4	Inverters	0 per cent	0 per cent
5	Complete Solar System (panels + batteries + regulators)	0 per cent	0 per cent

Source: (AGSI, 2011)

According to AGSI (2011), the current tariff regime also contributes to the lack of cost competitiveness of solar energy relative to other power sources, consequently hindering large-scale uptake in Ghana. Some stakeholders in the industry are proposing a review of the current tariff regime, towards total waiver of tariffs on solar products (including components and accessories). According to proponents of the tariff regime review, this measure would significantly reduce the overall cost of solar application, and have a knock-on effect on uptake.

The case put forward by AGSI (2011) has the potential to affect overall costs associated with solar PV components; however, the suggested effects are only probable if the tax relief is passed on to consumers. Such a policy could also yield unintended consequences. The benefits of the waiver might accrue to both local and foreign suppliers (importers); which would adversely affect government revenue. According to proponents, the policy review toward tariff-free imports of all solar products will still benefit the government, as loss of government revenue will be compensated by, *inter alia*, a market that is oriented towards growth, competitiveness and an increased uptake/patronage of solar energy products. It is also suggested that a tariff-free regime for solar products will create opportunities for more jobs, capacity development and transfer of technology to Ghana. AGSI suggests that these benefits have the potential to spur interest into the manufacture and assembly of solar energy systems in the country. The exact way in which a tariff-free regime would spur interest in the manufacture of solar PV components is not elaborated by AGSI (2011). Furthermore, this study has not found any objective studies to support the assertions; hence, these are merely perceived benefits.

The existing inverted tariff structure in Ghana (see Table 16), applying zero tariffs to complete solar PV systems, and higher tariffs to system components, has negative implications for the prospects of a domestic manufacturing solar PV industry. According to Mehta (2006), inverted tariff measures render domestic industries uncompetitive against imported PV systems, and pose a real risk of discouraging domestic manufacture of solar PV components and systems. Although the prospect of government-supported "infant industries" remains highly debated, the importance of establishing domestic manufacturing capacity should not be neglected.

The AGSI study (2011) suggests that the existing tariff structure is stifling the uptake of solar PV and the development of a domestic manufacturing industry in Ghana. However, the study holds that with diminishing tariff barriers in both the regional and global value chain, non-tariff barriers may pose an additional challenge to the development and nurturing to maturity of a domestic solar PV manufacturing sector. Non-tariff measures play a significant role in the ways in which enterprises and their host countries get access to and participate in global value chains. Therefore, the implementation of measures that facilitate local capacity development while ensuring free but fair trade, like standards and certifications, may provide significant opportunities for Ghanaian enterprises to participate in international trade.

5.5 Opportunities for Ghana to Participate in the Solar PV Value Chain

The opportunities for Ghana to upgrade its manufacturing capacity and participate in the global solar PV value chain will depend on a variety of factors, including the governance patterns or structures prevailing in such chains, the current capability of domestic PV and related actors, and, to a large extent, the institutional and regulatory frameworks relevant in the global, regional and national context.

Enterprises can upgrade in various ways (Giuliani et al., 2005), namely:

- **functional upgrading**: realized by entering into market niches or new sub-sectors of higher unit value, or by undertaking new product (or service) functions;
- **process upgrading**: realized by making the production process more efficient, through a reorganization of production systems, or the introduction of superior technology;
- **product upgrading:** moving into more sophisticated product lines, in terms of increased unit values; and
- **intersectoral upgrading:** applying the competence acquired in a particular function to move into a new segment.

A dedicated manufacturing and assembly industry for solar PV is currently non-existent in Ghana, and this provides a wide variety of options for Ghana to consider. However, the more difficult questions to answer are (a) whether Ghana should participate in the manufacturing and assembly segments of the solar PV value chain, and (b) how Ghana could possibly enter the manufacturing market.

In response to the first question, it should be taken into account that manufacturing, in general, has the potential to yield very positive economic externalities: jobs, technology development, and foreign exchange, among others, with a knock-on effect for poverty reduction. However, the empirical as well as theoretical literature on whether developing countries should be involved in manufacturing is divided. The risk-averse school of thought considers the barriers provided by governance structures, measures and patterns in value chains (see section 5.1), and advises against developing countries venturing into manufacturing. According to this perspective, international markets exhibit market power in global value chains, and implement both tariff and non-tariff measures which can frustrate the efforts of new entrants, thus failing to yield significant economic growth and poverty reduction (Diao & Dorosh, 2007).

The less risk-averse school of thought recognizes the constraints put forward by the opposing perspective, but it argues that the significant challenges or constraints faced by developing countries in their quest for manufacturing are surmountable. Evidence exists to suggest that some developing countries have successfully upgraded and are participating in global value chains, despite the challenges facing their industries at the early stages of development (Diao & Dorosh, 2007; Humphrey & Schmitz, 2002).

The authors lean towards the less risk-averse view of developing countries manufacturing and participating in global value chains using manufactured products. Enough opportunities seem to exist for Ghana to participate in the global PV value chain, using high value-added products, as long as the country develops the capability needed to respond to global, regional and national level requirements. In order to do so, Ghana may need to pursue national regulatory, fiscal and other frameworks conducive to upgrading its manufacturing and trading capacity, especially with regard to domestic growth industries, which solar PV seems likely to become.

Laws, regulations and policies are the capability tools that prescribe how manufacturing operations are to be organized in particular contexts and how products safety can be assured. To be effective, they need to be complemented by strategies, processes and resources (human and financial resources, and information).

For the second question, there is consensus among interviewed stakeholders that opportunities exist for functional, product and process upgrading. In the short-term, participating functionally[36] from the lower end of the upstream value chain will be most feasible. That is, participating in the BOS component segments, such as charge controllers, cables, mounting frames and conductors. Some of the existing local manufacturing industries already possess capabilities that enable them to provide such components for national electrification projects, and these could be integrated into the global value chain with minimal adaptation.

Segments like the cell, module and inverter manufacture[37] have become the preserve of very few enterprises and their host countries, and therefore participation of a new entrant like Ghana could only be a medium- to long-term goal. This is because the solar PV value chain is highly competitive and controlled by few lead enterprises mostly in China and Taiwan (see Figures 27-31). These have invested in high technology, capital-intensive equipment and large plants relevant to key segments of the upstream chain, creating huge barriers, particularly for new entrants from developing countries. Therefore, a desire for Ghana to participate could only be a medium- to long-term goal.

To exploit the opportunities available in the solar PV value chain, Ghanaian enterprises will have to be able to adequately comply with the order-qualifying requirements of the value chain, and compete with other enterprises on the order-winning requirements (see section 5.1). Capability may need to be developed both at the national, industry and enterprise level, and knowledge about these requirements has to be spread among industry and government. Also, methods on how to address these requirements have to be developed.

Governmental capability in the form of regulations, policies, standards and complementing institutions with relevant mandates and resources will demonstrate to the international community that Ghana is committed to the development of a solar PV industry that has the capability to manufacture high-quality, reliable and safe products. At the industry level, such capability is required to develop and implement standards and to test for compliance, using recognized conformity assessment processes (see section 1). Enterprises need the knowledge, skills competence and resources to manufacture and assemble solar PV components and systems to meet the set requirements.

Since this a relatively new sector in Ghana, a lot of government intervention is required to nurture the industry in the form of creating the opportunities for technological learning (e.g. innovations hub), to expose domestic enterprises to their international counterparts, and to create and maintain domestic and international demand for manufactured solar PV components and systems from Ghana.

The above-mentioned efforts will ensure that the Ghanaian solar PV industry can develop and nurture the capabilities to undertake functional, process and product upgrading successfully in the medium- to longer-term.

36 It must be noted that for a late entrant into the global solar PV value chain like Ghana, process upgrading will have to be pursued alongside functional upgrading, as there will be only one opportunity to win over customers.
37 The manufacture of these high-end products of the upstream value chain qualifies as product upgrading.

6. Positive externalities from solar electricity exports

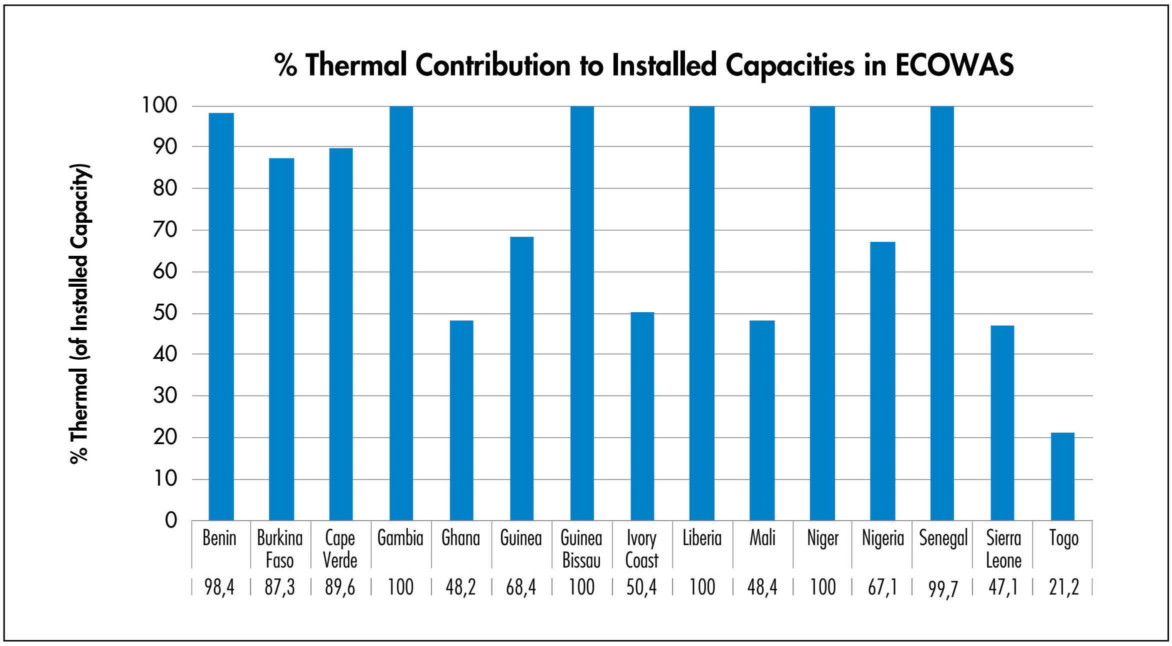
Externalities are (environmental or social) costs or benefits to society that are not included in the market price of an item or service. Pollution is the most commonly cited negative externality because the buyer or the seller of a polluting consumable does not directly bear the cost of clean-up. In the electricity sector, these are external costs arising from impacts on, for example, climate, human health, crops, structures and biodiversity (ATSE, 2009).

Various studies have shown that the external cost of fossil-based power generation is much higher than the external cost of technologies based on renewable energy. Studies by the European Commission in 2004 estimated the annual externalized cost of power generation in the EU-15 at EUR 12-21 billion for oil and gas, against EUR 2-2.7 billion for renewable energy technologies (EEA, 2004). A similar study by The Australian Academy of Technological Sciences and Engineering (ATSE) puts the external cost of power generation in Australia at A$ 40-50 per MWh for coal-based generation, A$ 19/MWh for natural gas and A$ 5/MWh for Solar PV (ATSE, 2009).

A more recent study by RCREEE (Regional Center for Renewable Energy and Energy Efficiency) for the Arab region quantifies externalities arising from power generation in 13 Middle Eastern countries. The study observed trends similar to the EU and Australian studies, and proceeded to show the savings obtained if the renewable energy targets of member countries were achieved (RCREEE, 2013).

The increasing role of power generation from fossil fuels in West Africa translates into a higher externalized cost, in addition to the rising direct cost. In 2011, more than 10 out of 15 ECOWAS member countries depended on thermal power plants for more than half of their electricity generation capacity (see Figure 32), which implies significant fossil fuel consumption and increased cost of generation, particularly for diesel-based plants.

Figure 32. Percentage thermal generation capacities in West African countries (2011)



Data Sources – ECREE (http://www.ecowrex.org), EIA (http://www.eia.gov/)

Ghana's Second National Communication to the UNFCCC (Environmental Protection Agency, 2011) acknowledges the increasing role of thermal power generation.

"The general increase in emissions from the sector could be attributed to the increasing fuel consumption in the growing proportions of power generated from thermal sources, increasing fuel consumption and poor fuel efficiency in the road-transport category as well as rising biomass use in the residential sub-category." (Environmental Protection Agency, 2011)

An increased uptake of renewable energy within the sub-regional electricity supply system would, therefore, provide an important opportunity to reduce negative environmental externalities. This section analyzes the potential reduction in greenhouse gases (GHG), the job prospects and the likely impacts on the economy, resulting from increased solar PV deployment.

6.1 GHG Emission Reduction Compared with Baseline Generation, and Business as Usual

Solar Photovoltaic systems emit no GHG gases during their operational life. Also from a life-cycle perspective, these systems are important tools in the fight against climate change.

Emission factors for grid electricity in Ghana and Burkina Faso were adopted from recent emission reduction profile studies by the UNEP Risø Center. Emission factors for electricity generation consider, among others, the fuels that were used, the conversion technologies, and the transmission and distribution losses, to estimate the amount of GHG emissions per unit of electricity delivered. Using emissions factors of 0.40853 tCO_2 and 0.7 tCO_2 (UNEP Risø, 2013)[38] per MWh for Ghana and Burkina Faso respectively, emissions reductions for a typical 20 MWp Solar PV plant are estimated at 15,026.95 tCO_2eq (Ghana) and 25,748.10 tCO_2eq (Burkina Faso) annually. In the medium term, with electricity export-oriented PV installation of 100 MW (as analyzed in this study), GHG savings could rise to an annual 128,740.5 tCO_2eq.

It should be noted that the WAPP system is likely to lead to a decarbonization of the electricity sector of Burkina Faso and other West African countries that heavily rely on diesel power plants. Most of the proposed WAPP plants are based on natural gas and hydropower. Further analysis is needed to estimate the effect of changing power supply technologies on emission factors in the electricity sector. Despite the potential global environmental benefits from a relative decarbonization of the power sector, growth in demand, spurred by economic growth and increasing population, could result in an overall increase in energy-related GHG emissions. An increased uptake of renewable energy, and the efficient use of energy and materials, together with other low-carbon development strategies, are needed to sustain the benefits of green power trade.

6.2 Socio-Economic Impacts

Solar electricity exports can result in significant positive socio-economic impacts in Ghana and the sub-region at large. These include job creation, improved foreign exchange earnings (including the resulting macro-economic benefits) as well as energy security for the sub-region. The Savannah Accelerated Development Authority of Ghana (SADA)[39] has identified solar PV projects as having the potential to yield particularly significant benefits for communities in the northern part of Ghana, where solar radiation levels are highest.

38 Available at: http://www.unepdtu.org/~/media/Sites/Uneprisoe/Publications%20(Pdfs)/Emissions%20Reduction%20Potential/FINAL%20Country%20Profile%20BURKINA%20FASO.ashx.

39 SADA is a special entity established by the Government to initiate programmes to accelerate development of Ghana's most deprived regions – including the 3 northern regions of the country, where poverty is most prevalent (according to the 2010 census report by the Ghana Statistical Service).

"The Savannah Accelerated Development Authority (SADA) has decided to invest in solar energy farms to add about 40 megawatts of power to the national grid." "The Chief Executive Officer (CEO) of SADA, Alhaji Gilbert Iddi, who made this known in an interview, reiterated the authority's mandate to stop at nothing to execute projects and programmes in order to improve the livelihoods of the people in the SADA zone."[40]

6.2.1 Job Creation

Job creation and livelihood enhancement are important objectives of economic activities, which have a direct impact on all citizens. Two categories of jobs feature within the solar PV value chain, namely direct and indirect jobs. Direct jobs are provided by companies or individuals fully dedicated to the solar PV chain, such as PV production sites, inverter manufacturers, providers of on-roof or on-ground installation and maintenance services, and recycling companies. Indirect jobs support the PV industry by providing more generic components or services.

Industry estimates put job creation prospects for the solar PV industry at 10-20 Full-Time Employees (FTE)/ MW in terms of direct jobs, and 22-40 FTE/MW in terms of indirect jobs (EPIA, 2012). It further estimates that half of these direct and indirect jobs are related to the installation, maintenance and recycling of solar PV systems. Ghana, like most developing countries, currently participates at the lower end of the value chain, with activities such as installation and maintenance. Taking into account the lack of high-capital upstream jobs in manufacturing of modules and inverters, and applying these factors to a scenario of an added capacity of 100 MW (as estimated by the authors), approximately 500-1,000 FTE in direct jobs and up to 2,000 FTE in indirect jobs are created (see Table 17).

Table 17. Job Creation Prospects

ITEM	Min	Max
FTE/MW – direct	10	20
FTE/MW – indirect	22	40
Capacity, MW	100	-
Total jobs – direct	1 000	2 000
Total jobs – indirect	2 200	4 000
Subtotal	3 200	6 000
50 per cent (derating) – for non-existence of high- capital upstream jobs.	1 600	3 000
Household size (in Northern Ghana)	5.8	7.7
Livelihood impact	9 280	23 100

With average household sizes of between 5.8 and 7.7 in the northern regions of Ghana, livelihoods could be created for over 23,000 people through direct and indirect jobs. The authors consider these numbers to be optimistic estimates, as local capacity for participation is still inadequate, even at the lower ends of the PV value chain. Significant expertise is still imported for the design and installation of solar PV plants in Ghana and Sub-Saharan Africa. For example, the VRA's recent installation of solar PV plants in northern Ghana was undertaken by German and Chinese partners.[41]

Internationally, it is projected that employment in the solar power industry could reach 6.3 million by 2030, up from 170,000 in 2006 (ILO, 2008). In order to maximize the job-creation benefits from the burgeoning solar PV market in Ghana, there is a need to have a targeted capacity development agenda, which includes *inter alia* training and creative procurement processes.

Considering that the potential locations for these projects in northern Ghana also happen to be the parts of the country with the highest poverty rates (GSS, 2013), the socio-economic impact of such projects could be even more pronounced.

40 See URL: http://graphic.com.gh/archive/General-News/sada-to-invest-in-solar-energy.html.
41 Available at: www.vraghana.com/our_mandate/solar_energy.php.

6.2.2 Estimated Foreign Exchange Inflow

The estimated annual income from a 100 MW plant with a capacity factor of 20 per cent would be around US$ 38 million using the feed-in tariff of US$ 210/MWh for solar PV systems, as published by the Public Utilities Regulatory Commission on 1 September 2013.[42] It is worth noting that the Government of Ghana views energy exports as an important source of foreign exchange (NDPC, 2010). It is estimated that the country currently earns over US$ 80 million annually from electricity exports, having exported 667 GWh in 2012.

7. Conclusions and policy recommendations

The main objective of the SEPS, which is part of the GE-TOP Ghana project, was to assess the potential for solar electricity trade, by considering related opportunities and challenges. The study also assessed the current and future opportunities for Ghana to increase its participation in the solar PV value chain in the medium- to long-term. The electricity export potential was estimated by analyzing the solar resource and land availability, transmission infrastructure issues, the financial viability and the policy environment.

The authors conclude as follows:

- Ghana, by virtue of its geographical location, receives significant amounts of sunshine, especially in its northern regions, measuring up to 6 kWh/m^2/day. 1 per cent of Ghana's land area has the potential to generate up to 167,200 GWh (106.2 GW) of electricity annually, which is 13 times the national electricity generation in 2012 (12,024 GWh) and 140 times the energy consumed in neighbouring Burkina Faso in 2012 (1,200 GWh). This indicates the significant potential that exists for greening the power sector.
- In the short term, Ghana's government plans to expand its power generation capacity to 5000 MW, with a 10 per cent share of renewable energy (excluding large hydropower). In September 2014, the Ministry of Energy and Petroleum announced an overall cap on intermittent renewable energy of 550 MW by 2020; solar PV comprises 150 MW of this overall RE capacity cap. As more base load (the minimum amount of electric power delivered at a constant rate) and dispatchable (having the possibility to be turned on or off according to the demand) capacity becomes available, this number is likely to increase. It is also expected to be revised as grid operators gain more experience with the management of increased levels of intermittent RE within the national grid.
- Although Ghana's solar radiation is not superior to that of its neighbours, it has a comparative advantage in attracting investment, as a result of a number of factors and measures:
  - the passage of a renewable energy law that creates the fundamental legal and regulatory framework for RE projects;
  - an open power sector with separate and different players in generation, transmission (open access) and distribution, and with various IPPs involved;
  - a politically stable and democratic system with a thriving private sector; and
  - a transmission network that runs across the entire country, reducing the cost of power evacuation for potential investors.
- Over 30 companies, with a proposed total generation of over 2,000 MW from solar PV, have already been granted provisional licenses by the country's Energy Commission. It must be noted, however, that only the Volta River Authority has gone ahead with the construction and commissioning of a 2.5 MWp Solar PV plant in northern Ghana. It is unclear how much of this will actually proceed to building and commissioning.
- Using job creation factors from the EPIA, 3,000 jobs are expected to be created for 100 MW solar PV installations. Data from the GSS shows that the regions of high solar resource (the three northern regions of Ghana) also happen to be the regions with the highest levels of poverty, and with household sizes between 5.8 and 7.7. Livelihoods could be created for up to 23,000 people in Ghana's poorest regions.

42 The tariffs used in this analysis are subject to exchange fees, and other standard transaction charges apply.

- Over 40,000 tCO_2 will be avoided annually with the deployment of 100 MW of installations. Emission reductions more than double – to around 120,000 tCO_2 annually – if the solar electricity is used in a neighbouring country such as Burkina Faso, where the power generation is dominated by diesel-powered systems with an emission factor of 0.7 tCO_2/MWh.
- In line with the Government of Ghana's vision of increasing its foreign exchange earnings from energy trade, it is estimated that the country could earn up to US$ 38 million annually from cross-border electricity exports, using an export rate of US$ 210/MWh (Ghana's feed-in-tariff rate for solar PV). This will be in addition to the estimated US$ 80 million that is currently earned annually from cross-border power supply arrangements. In 2012, Ghana's electricity exports to neighbouring countries amounted to 667 GWh.
- Ghana has an extensive network of 161 kV transmission lines, which connects to that of its neighbours. Ghana's MoEP indicates the grid is operating near full capacity. This implies a need to continue expanding the grid network, in order to match up with the anticipated generation capacities. Fortunately, upgrades have been planned, both at the national and the WAPP level. For instance, planned 330 kV networks would quadruple the carrying capacity of the current 161 kV lines.
- Although the base scenario analyzed in Section 4.0 (with installed cost of US$ 3000/kWp and FIT of US$ 210/MWh) shows unimpressive financial viability indicators, with equity payback of 13.8 years, exceeding the period of guaranteed FiT rate (i.e. 10 years), prospects for cost reduction remain, and at a cost of US$ 2,000/kWp, the indicators are strongly positive, with IRR (equity) around 35 per cent, a benefit-cost ratio of 5.79 and a debt service coverage of 1.26.
- On increasing participation in the solar PV value chain, there is consensus that opportunities exist in the balance of system segment, such as charge controllers, cables and mounting frames. Some of the existing local manufacturing industries already possess capabilities that enable them to participate in the solar PV value chain. For example, local companies that provide cables and conductors for national electrification projects could be integrated into the local chain with minimal adaptation.
- At the sub-regional level, the creation of WAPP, ERERA and ECREEE is helping to establish a conducive and facilitative environment for the exploitation of the important potential of the sub-regional power market. While the WAPP has been working towards the strengthening of generation capacity and grid infrastructure in the sub-region, ERERA has been working towards the restructuring of the power sector in ECOWAS member countries to conform to open market rules. These efforts, together with ECREEE initiatives, are helping to remove barriers to regional power trade, and enhance the development of renewable and greener energy technologies.

Policy Recommendations

Based on the information and analysis contained in this report, the following recommendations aim to help to realize the objective of harnessing trade opportunities in the transition towards a Green Economy in Ghana:

1. Financial and institutional support mechanisms available to investors in the renewable energy sector (particularly solar PV) should be documented and promoted. These could range from PPP opportunities (as guided by the PPP Law of 2011) to concessionary financing arrangements provided by the Government of Ghana as well as its bilateral and multilateral partners. Investment financing opportunities within the context of the WAPP and the developing regional power market, as well as the ECOWAS Solar Energy Initiative (ESEI), should be captured in such an investor reference catalogue.

2. The cost of electricity generation from solar PV still remains relatively high in comparison to the current cross-border bulk supply tariff of around US$ 0.15/kWh. Solar PV technology can be enabled to cater for regional power trade, with the help of international funds that support low-carbon and climate-friendly technologies. It is recommended that WAPP and ECREEE engage international stakeholders to determine support mechanisms that can make cross-border trade in solar electricity an attractive investment – within the current technical limits of the regional interconnected grid.

3. PV projects above 1 MW often require significant tracts of land. Considering the significant challenges resulting from the land tenure system in Ghana (which constitute a draw-back on investment), it is recommended that the Government of Ghana initiates steps to ease the process of land acquisition for ground-mounted solar PV projects. In implementing this recommendation, proximity to existing or proposed transmission and power evacuation infrastructure should be taken into account. The government may acquire parcels of land in areas with high insolation close to the electricity grid, or facilitate some form of arrangement with landowners (or custodians) to make it easier to acquire land for solar PV power plants. It must also be ensured that there is adequate protection for the rights of settlers, and that appropriate compensation packages are paid to persons affected. Alternative livelihood support mechanisms should be provided to those whose means of livelihoods might be affected by large-scale solar PV projects.

4. A case study should be undertaken in conjunction with GRIDCo and WAPP to analyze the effects of PV injection above 1 MW into the power grid at various potential locations and under various scenarios. The case study should take into account the existing power infrastructure, as well as the grid / transmission infrastructure planned under the WAPP initiative.

5. It is recommended that pilot projects for the export of solar power are undertaken in partnership with the VRA – Ghana's state power generation utility. The VRA has decades of experience in cross-border electricity trade in the sub-region, predating the WAPP initiative. Such experience will be a strong asset in introducing new technologies to regional power trade – particularly considering the challenge of intermittency. The VRA also has a number of dispatchable power technologies in its portfolio, such as hydro and different thermal power technologies. Such diversity of technologies is necessary for flexibility in power grids. These factors, together with the VRA's experience in partnering with private entities for power generation should make a joint venture, export-oriented solar PV project a worthwhile effort.

6. It is finally recommended that studies be conducted in the context of current and future grid infrastructure to consider the relationship between increased base load and dispatchable generation capacities and the amount of intermittent renewable electricity that can be accommodated in the grid. This study should also consider the role of current and emerging technologies for power conditioning and smoothening. This activity could in the near term be institutionalized as part of the responsibilities of the national grid operator, the Ghana Grid Company, in cooperation with relevant sub-regional agencies.

References

Adenikinju, A., 2008. *WEST AFRICA Energy Security Report.* [Online]
Available at: www.beg.utexas.edu/energyecon/IDA/Smart_Development/WAESR_Fall_08.pdf.

ADF, 2006. *West Africa Power Pool: Ghana-Togo-Benin Interconnection Project.* [Online] Available at: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/ADF-BD-IF-2006-245-EN-MULTINATIONAL-GHANA-TOGO-BENIN-POWER-INTERCONNECTION-PROJECT-VRA-CEB-SUMMARY-REPORT.PDF.

ADF, 2009. *Electricity Infrastructure Strengthening and Rural Electrification Project.* [Online] Available at: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Burkina_Faso_-_Electricity_Infrastructure_Strengthening_and_Rural_Electrification_Project_-_Appraisal_Report.pdf.

ADF, 2014. *Republic of Ghana : Electricity Distribution System Reinforcement and Extension.* [Online] Available at: www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Ghana_-_Electricity_Distribution_System_Reinforcement_and_Extension_-_Appraisal_Report.pdf.

AfDB, 2013. *AfDB enhances access to reliable and affordable electricity supply in Côte d'Ivoire.* [Online]
Available at: www.afdb.org/en/news-and-events/article/afdb-enhances-access-to-reliable-and-affordable-electricity-supply-in-cote-divoire-12150/.

African Energy Journal, 2012. Côte d'Ivoire's transmission infrastructure. *African Energy Journal.*

Ahiataku-Togobo, W., 2014. *Universal access to modern energy services in Ghana: Issues, progress and next steps for electrification.* Webinar, 9th July 2014. Accra: Ministry of Energy and Petroleum. Available at: cleanenergysolutions.org/webfm_send/1369.

AICD, 2011. *Burkina Faso's Infrastructure: A Continental Perspective.* [Online]
Available at: http://www.ppiaf.org/sites/ppiaf.org/files/publication/AICD-Burkina-Faso-Country-Report.pdf.

Arku, F. S., 2011 . The modelled solar radiation pattern of Ghana. *Journal of African Studies and Development,* pp. 45-64.

AGSI, 2011. *Information Memorandum to Parliament on Promoting Solar Energy Applications as a Viable Alternative Power Source in Ghana.* [Online]
Available at: ghanasolarindustries.com/PDFarticles/AGSI_Background_Research_Report_2011.pdf.

ATSE, 2009. *The Hidden Costs of Electricity: Externalities of Power Generation in Australia.* Australian Academy of Technological Sciences and Engineering (ASTE).

Bahar, J. & Sauvage, J., 2013. *Cross-Border Trade in Electricity and the Development of Renewables-Based Electric Power: Lessons from Europe.* OECD Publishing.

Bloomberg , 2010. *Ivory Coast Faces Three Months of Power Outages (Update1).* [Online] Available at: www.bloomberg.com/apps/news?pid=newsarchive&sid=aW7Ie7yuxJDg.

Bloomberg, 2013. *Solargiga of China forms Venture to develop Solar Farms in Ghana.* [Online]. Available at: www.bloomberg.com/news/articles/2013-12-10/solargiga-of-china-forms-venture-to-develop-solar-farms-in-ghana.

Cleland, T. & Leverton, J. R., 2010. *Accurately Predicting and Optimizing Yield Factors Which Impact Financial Efficacy of Solar Arrays.* Ontario: Hybridyne Power Electronics.

Denholm, P. & Margolis, R. M., 2008. Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States. *Energy Policy 36,* pp. 3531 – 3543.

Diao, D. & Dorosh, P., 2007. Demand Constraints on Agricultural Growth in East and Southern Africa; A General Equilibrium Analysis. *Development Policy Review* 25(3), pp. 275-292.

ECOWAS, 2003. ECOWAS Energy Protocol. [Online] Available at: http://www.comm.ecowas.int/sec/en/protocoles/WA_EC_Protocol_English-_DEFINITIF.pdf.

ECOWAS, 2007. ECOWAS in Brief. [Online] Available at: www.comm.ecowas.int/sec/index.php?id=about_a&lang=en

ECREEE, 2012a. *ECOWAS Renewable Energy Policy (EREP)*, Cape Verde: ECREEE.

ECREEE, 2012b. *Country Profile - Cote d Ivoire*. [Online] Available at: www.ecowrex.org/country_profile/378/2011.

ECREEE, 2013. *Country Profile – Burkina Faso*. [Online] Available at: www.ecowrex.org/country_profile/372/2010.

EIA, 2013. *Overview data for Burkina Faso*. [Online] Available at: www.eia.gov/countries/country-data.cfm?fips=UV&trk=m.

Energy Commission, 2006. *Strategic National Energy Policy*. Accra: Energy Commission.

Energy Commission, 2009. *Renewable Energy Policy Framework for Climate Change Mitigation in Ghana. Accra*: Energy Commission.

Energy Commission, 2012. *2012 Energy (Supply and Demand) Outlook for Ghana*. Accra: Energy Commission.

Energy Commission, 2013. *National Energy Statistics, 2000 – 2012*. Accra: Energy Commission.

Environmental Protection Agency, 2011. *National Greenhouse Gas Inventory Report for 1990 - 2006, Volume 1: Synthesis Report*. Accra: EPA.

EScience Associates; Urban-Econ Development Economists; C. Ahlfeldt, 2013. *The Localization Potential of Photovoltaics (PV) and a Strategy to Support Large-Scale Roll-Out in South Africa*. [Online] Available at: www.sapvia.co.za/wp-content/uploads/2013/04/PV-Localisation_Draft-Final-Report-v1.2.pdf.

European Environment Agency, 2004. *Energy subsidies in the European Union: A brief overview.* Technical report No 1/2004. [Online] Available at: www.eea.europa.eu/publications/technical_report_2004_1.

EPIA, 2012. Sustainability of Photovoltaic Systems: Job Creation. *EPIA Fact Sheet*.

GTZ, 2012. *Regional Report on Potentials and Markets – 17 Country Analyses*. [Online] Available at: https://giz.de/expertise/downloads/gtz2009-en-regionalreport-westafrica-introduction.pdf.

Ghana Business News, 2010. *Ghana to generate revenue from energy project*. [Online] Available at: www.ghanabusinessnews.com/2010/07/24/ghana-to-generate-revenue-from-energy-project/.

Ghana Lands Commission. 2012. *Guidelines for Considering Large-Scale Land Transactions for Agricultural and other Purposes*. Accra: Woelli Publications.

Ghana News Agency, 2010. *Ghana To Generate Revenue From Energy Export*. [Online] Available at: http://ghananewsagency.org/economics/ghana-to-generate-revenue-from-energy-export–18408.

GRIDCo, n.d. *The National Grid*. [Online] Available at: www.gridcogh.com/site/ng.php.

GSS, 2013. *2010 Population and Housing Census - National Analytical Report*. Accra: Ghana Statistical Service.

Gibbon, P., Bair, J. & Ponte, S., 2008. Governing Global Value Chains: An Introduction. *Economy and Society* 37(3), pp. 315-338.

Giuliani, E., Pietrobelli, C. & Pietrobelli, R., 2005. Upgrading in Global Value Chains: Lessons from Latin America Clusters. *World Development* 33(4), pp. 549-573.

Government of Ghana, 2010. *The Coordinated Programme of Economic and Social Development Policies 2010-2016*. Accra: Government of Ghana.

Humphrey, J. & Schmitz, H., 2002. How Does Insertion in Global Value Chains Affect Upgrading in Industrial Clusters. *Regional Studies* 36(9), pp. 1017-1027.

IEA-ETSAP and IRENA, 2013. *Solar Photovoltaics Technology Brief*. Abu Dhabi: IRENA.

Informa Exhibitions, 2013. *Cote d'Ivoire to export 17 MW to Togo, Benin*. [Online] Available at: www.power-nigeria.com/en/IndustryNews/Cote-dIvoire-to-export-17-MW-to-Togo-Benin-/.

Infrastructure Consortium for Africa, 2011. *Regional Power Status in African Power Pools*. Tunis: ICAfrica.

ISSER, 2005. *Guide to Electric Power in Ghana*. Texas: Bureau of Economic Geology.

IEA, 2010. *Technology Roadmap: Solar Photovoltaic Energy*. [Online] Available at: http://www.iea.org/publications/freepublications/publication/pv_roadmap.pdf.

IEA, 2012. *Medium-Term Renewable Energy Market Report*.[Online] Available at: http://www.iea.org/publications/freepublications/publication/MTrenew2012_web.pdf.

ILO, 2008. *Green Jobs Facts and Figures*. [Online] Available at: http://www.ilo.org/wcmsp5/groups/public/@dgreports/@dcomm/documents/publication/wcms_098484.pdf.

IRENA, 2014. *Estimating the Renewable Energy Potential in Africa: A GIS-based approach*. [Online] Available at: http://www.irena.org/DocumentDownloads/Publications/IRENA_Africa_Resource_Potential_Aug2014.pdf

ISRIC, n.d. Major Soils of the World. [Online] Available at: www.isric.org/isric/webdocs/docs/major_soils_of_the_world/start.pdf.

Jacobson, M. Z., 2009. Review of Solutions to Global Warming, Air Pollution and Energy Security. *Energy and Environmental Science*, pp. 148-173.

Kappiah, M., 2013. *Sustainable Energy Solutions for All – Made in Austria GFSE Side Event Vienna Energy Forum 2013: Opportunities for SE4All actions in West Africa*. Vienna: ECREE.

Mechanical Engineering Department, KNUST, 2003. *Solar and Wind Energy Resource Assessment*. Accra: Energy Commission, Ghana.

Mehta, P. S., 2006. *Address Policy-Related Distortions to Realise Full Potential of Economic Reforms, CUTS International's Memorandum to the Finance Minister*. [Online] Available at: cuts-international.org/pdf/pre-budget_memo2006-07.pdf.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. Washington, DC: World Resources Institute.

MoEP, 2010. *Energy Sector Strategy and Development Plan*. Accra: Ministry of Energy.

MoEP, 2012. *Meet the Press "Energy for a Better Ghana"*. Accra: Ministry of Energy.

MoEP, 2014. *225 kV Bolga-Ouagadougou project is priority – Energy Minister*. [Online] Available at: www.energymin.gov.gh/?p=2220.

MoFEP, 2012. *Ghana Infrastructure Plans*. Accra: Ministry of Finance and Economic Planning.

Ministry of Food and Agriculture, 2010. *Agriculture in Ghana: Facts and Figures*. Accra: Ministry of Food and Agriculture.

NDPC, 2005. *Ghana Poverty Reduction Strategy (GPRS II) (2006-2009)*. [Online] Available at: http://planipolis.iiep.unesco.org/upload/Ghana/PRSP/Ghana%20PRSP%20June%202006.pdf

NDPC, 2010. *Medium Term National Development Policy Framework: Ghana Shared Growth and Development Agenda (GSGDA), 2010-2013*. Accra: NDPC.

National Population Council, 2004. *Population of Ghana: National Trends*. Accra: National Population Council.

NREL, 2005. Global Horizontal Solar Radiation Map for Ghana: *Solar and Wind Energy Resource Assessment Ghana*. [Online] Available at: http://en.openei.org/wiki/File:NREL-gha-glo-sep.jpg.

NREL, 2013. *Derate*. [Online] Available at: rredc.nrel.gov/solar/calculators/pvwatts/version1/derate.cgi.

Normann, R. & Ramirez, R., 1994. *Designing interactive strategy: from value chains to value constellation*. New York: Wiley.

OECD, 2012. Regional Trade and Employment in ECOWAS. In: D. Lippoldt, ed. *Policy Priorities for International Trade and Jobs*. pp. 415-446.

OECD and IEA, 2011. *Harnessing Variable Renewables - A Guide to the Balancing Challenge*. Paris: IEA.

OECD and SWAC, 2013. *NewsBrief, 4-10 March 2013*. [Online] Available at: www.westafricagateway.org/rss-news/newsbrief-4-10-march-2013#ghana.

Ong, S. et al., 2013. *Land-use requirements for solar power plants in the United States*. Washington, DC: NREL.

Pearce, D.W. & E. Barbier, 1989. *Blueprint for a green economy*. London: Earthscan Publication Ltd.

Platzer, M. D., 2012. *U.S. Solar Photovoltaic Manufacturing: Industry Trends, Global Competition, Federal Support*. Washington, DC: Congressional Research Service.

PSEC, 2010. *Ghana Wholesale Power Reliability Assessment*, Tema: Gridco.

PURC, 2014. Publication of Feed-In-Tariffs and Capacity Caps for Electricity Generated from Renewable Energy Sources. [Online] Available at: http://www.purc.com.gh/purc/sites/default/files/fit_2014.pdf.

RCREEE, 2013. *Environmental Externalities from Electric Power Generation - The Case of RCREEE Member States*. Cairo: RCREEE.

REEGLE, 2013. *Ivory Coast (2012)*. [Online] Available at: www.reegle.info/policy-and-regulatory-overviews/CI.

REN21, 2013. *Renewables: Global Futures Report*. Paris: REN21.

Sealite, 2014. *Solar Tables*. [Online] Available at: www.sealite.com.au/solar_tables/g.txt.

Simmonds, G. (2002), "Consumer representation in Europe policy and practice for utilities and network industries", *Centre for the Study of Regulated Industries Research Report 11*. Bath: , University of Bath School of Management.

Sittie, R., 2006. *Land Title Registration. The Ghanaian Experience*. Munich.

Tansey, G. & Worsley, T., 1995. *The food system: a guide*. London: Earthscan Publication Ltd.

TEC, 2009. *GIS-Based Energy Access Project: A Review of Trends, Policies and Plans for Increasing Energy Access in Ghana*. Germany: European Union Energy Initiative.

UNCSD, 2012. *The Future We Want*. Rio de Janeiro: UNCSD.

UNCED, 1992. *The Earth Summit*. Rio de Janeiro: United Nations.

UNIDO, 2009. *Scaling up Renewable Energy in Africa*. [Online] Available at: www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Renewable_Energy/Publications/Scaling%20Up%20web.pdf.

UNEMG, 2011. *Working towards a Balanced and Inclusive Green Economy: A United Nations System-wide Perspective*. [Online] Available at: http://www.zaragoza.es/contenidos/medioambiente/onu/1209-eng.pdf.

UNEP, 2011a. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. Nairobi: UNEP.

UNEP, 2011b. *Keeping Track of our Changing Environment - From Rio to Rio+20 (1992-2012).* Nairobi: UNEP.

UNEP, 2013. *Green Economy and Trade – Trends, Challenges and Opportunities*. Geneva: UNEP.

UNEP Risø Centre, 2013. *Emissions Reduction Profile: Ghana.* [Online] Available at: www.uneprisoe.org/~/media/Sites/Uneprisoe/Publications per cent 20(Pdfs)/Emissions per cent 20Reduction per cent 20Potential/FINAL per cent 20Country per cent 20Profile per cent 20GHANA.ashx.

Vignola, F., Mavromatakis, F. & Krumsick, J., n.d. *Performance of PV Inverters.* Oregon: University of Oregon.

WAPP, 2010. *West Africa Power Pool: Priority Projects and Implementation Strategy.* Cotonou: Energy Charter.

WAPP, 2011. *Update of the ECOWAS Revised Master Plan for the generation and transmission of electrical energy: Final Report, Volume 4.* [Online] Available at: file:///C:/Users/Home/Downloads/MP_WAPP_VOLUME_4_Summary.pdf.

World Bank, 2013a. *Doing Business 2013 - Smarter Regulations for Small and Medium-Size Enterprises.* Washington, DC: World Bank.

World Bank, 2013b. *Energizing Economic Growth in Ghana: Making the Power and Petroleum sectors rise to the challenge.* Accra: World Bank.

World Bank, 2013c. Burkina Faso – Country at a Glance. [Online] Available at: www.worldbank.org/en/country/burkinafaso.

World Bank, 2013d. *Republic of Togo – Togo Energy Sector Policy Review, Review of the Electricity Sub-Sector,* Washington, DC: World Bank.

WTO, 2008. *Understanding the WTO.* Geneva: World Trade Organisation Publications.

APPENDIX A. ATTENDEES TO THE 1st NATIONAL STAKEHOLDER WORKSHOP, 12 SEPTEMBER 2013 – KNUST, KUMASI, GHANA

	NAME	ORGANIZATION
1	Ahmad Addo	Agric Engineering Department/ The Energy Center
2	Fred Akuffo	Aekosolar Enterprise
3	Gifty Tettey	Ministry of Energy
4	Ishmael Ejekumhene	Kumasi Institute of Technology and Environment
5	Osei Oteng Asante	Ministry of Finance and Economic Planning
6	Papa Bartels	Ministry of Trade and Industry
7	Peter Dery	Ministry of Environment, Science and Technology
8	Elvis Demuyakor	Northern Electricity Distributions Company (NEDco)
9	Norbert Anku	Ghana Grid Company (GRIDCo)
10	Ekow Sam	Volta River Authority
11	Godfred Mensah	Electricity Company of Ghana
12	Julius C. Ahiekpor	Centre for Energy, and Sustainable Development
13	Samuel Adu Asare	Association of Ghana Solar Industries
14	Richard M. Addo	ARB APEX Bank
15	Emmanuel Ackom	UNEP Risø Center/Global Network on Sustainable Energy Development
16	Amadu Mahama	New Energy
17	Ekow Coleman	Ministry of Finance and Economic Planning
18	Lennart Kuntze	United Nations Environment Programme
19	George Amegashie	Takoradi Thermal Plant
20	Simon Bawakyillenuo	Institute of Statistical, Social and Economic Research, University of Ghana
21	Kwaku Anto	Department of Electrical Engineering/ The Energy Center
22	Lena Dzifa Mensah	Department of Mechanical Engineering/ The Energy Center
23	David Ato Quansah	Department of Mechanical Engineering/The Energy Centre
24	Ebenezer Nyarko Kumi	The Energy Centre
25	Emmanuel Narh	The Energy Centre
26	Triumph Tetteh	The Energy Centre
27	Anthony Osei-fosu	Department of Economics/The Energy Center
28	Samuel Danquah Yeboah	The Energy Centre
29	Edward Awafo	The Energy Centre
30	Linus Abenney-Mickson	Volta River Authority
31	E Mensah	The Energy Centre
32	Oscar Amonoo-Neizer	Public Utilities and Regulatory Commission
33	Eric Osei Esandoh	The Energy Centre
34	Edward Quarm	The Energy Centre

APPENDIX B. ATTENDEES TO THE 2ND NATIONAL STAKEHOLDER WORKSHOP,
16 JANUARY 2014 – KNUST, KUMASI, GHANA

S.N	NAME	ORGANIZATION
1	Agyenim Boateng	Wilkins Engineering
2	Fred Akuffo	Aekosolar Enterprise
3	Ishmael Ejekumhene	Kumasi Institute of Technology and Environment
4	Seth Agbeve	Ministry of Energy
5	Gladys Ghartey	Ministry of Finance and Economic Planning
6	Papa Bartels	Ministry of Trade and Industry
7	Elvis A. Demuyakor	Northern Electricity Distributions Company (NEDCo)
8	Ekow Sam	Volta River Authority
9	Godfred Mensah	Electricity Company of Ghana
10	Julius C. Ahiekpor	Centre for Energy, and Sustainable Development
11	Samuel Adu Asare	Association of Ghana Solar Industries
12	Ekow Coleman	Ministry of Finance and Economic Planning
13	Oumar Bangoura	ECOWAS Regional Electricity Regulatory Authority
14	Lennart Kuntze	United Nations Environment Programme
15	Rhoda Wachira	United Nations Environment Programme
16	Kwaku Anto	Department of Electrical Engineering/ The Energy Center
17	David Ato Quansah	Department of Mechanical Engineering/The Energy Centre
18	Ebenezer Nyarko Kumi	The Energy Centre
19	Emmanuel Narh	The Energy Centre
20	Triumph Tetteh	The Energy Centre
21	Anthony Osei-fosu	Department of Economics/ The Energy Center
22	Samuel Danquah Yeboah	The Energy Centre
23	Edward Awafo	The Energy Centre
24	Edward Quarm	The Energy Centre
25	Eric Osei Esandoh	The Energy Centre
26	Robert Kyere	The Solar Energy Lab
27	Rose Mensah-Kutin	ABANTU for Development
28	Norbert Anku	GRIDCo
29	Ahmad Addo	The Energy Centre

www.unep.org
United Nations Environment Programme
P.O. Box 30552 Nairobi, 00100 Kenya
Tel: (254 20) 7621234
Fax: (254 20) 7623927
E-mail: uneppub@unep.org
web: www.unep.org

UNEP

Economics and Trade Branch
Division of Technology,
Industry and Economics
United Nations Environment Programme
International Environment House
11 - 13 Chemin des Anémones
CH-1219 Geneva, Switzerland
Email: gei@unep.org

The Green Economy and Trade Opportunities Project in Ghana (GE-TOP Ghana) identifies and assesses opportunities for solar energy exports to the ECOWAS sub-region. Under the umbrella of GE-TOP Ghana, the Ghana Solar Export Potential Study (SEPS) scopes out the national & regional energy policy landscape, the technical and financial potential for solar energy in Ghana, and assesses the contribution of solar exports to Ghana's economic growth, employment creation, and climate change mitigation. Based on robust assessment, the SEPS offers policy recommendations for harnessing Ghana`s solar export potential. The GE-TOP Ghana is part of the global Green Economy and Trade Opportunities Project (GE-TOP), which addresses the critical nexus between a green economy and international trade through research and country-level advisory services on how the green economy transition can create sustainable trade opportunities for developing countries. The global GE-TOP is financially supported by the European Commission.

Job Number: DTI/1944/GE