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Feasibility Study of Developing Large Scale Solar PV Project in Ghana: An Economical Analysis

Master's Thesis in Sustainable Energy Systems

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

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ABSTRACT

Solar photovoltaic industry growth in recent years has surpassed any other renewable energy sources worldwide and the need for carbon neutral electricity will continue to increase. In developed countries solar PV is a proven and feasible technology, however in African countries it is almost inexistent. So the fact that most PV systems are installed in rich countries with low solar radiation instead of sunny Africa does not add up. For this reason, the aim of this report is to assess the feasibility of developing a large scale solar PV plant in Africa, more specifically Ghana.

The installation of 100 MW of solar PV is assumed in a pre-determined location in Ghana, where solar irradiation is the highest. The computation of total plant generation uses solar maps, PV modules specification and average benchmark figures for system losses. Furthermore a review of policy framework a Feed-in-Tariff (FiT) for solar PV development in Ghana is carried out to assert the viability of the project.

Ultimately, an economic analysis is carried out via using cash flow models in Excel work sheets. The key financial indicators used for evaluation of the project include net present value (NPV), internal rate of return (IRR), benefit-to-cost ratio (B/C) and Payback period (PBP). A comprehensive risk assessment is used to identify and create risk mitigating strategies. The sensitivity analysis creates a strategy to deal with the risk of inflation and currency depreciation. The sensitivity analysis shows that the project profitability ranges from -20 to 140 million US dollars under tight inflation and currency boundary conditions. It was possible to conclude that the project is feasible indeed, but consideration must be taken in regards to contract terms and inflation data.

Keywords: solar PV, Ghana, economic analysis, Feed-in-Tariff.

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Leandro Alves Aguilar

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LIST OF TERMS AND ABBREVIATIONS

AC	Alternating Current
APAC	Asia & Pacific
B/C	Benefit-to-Cost ratio
BOS	Balancing of System
CAPEX	Capital Expenditure
CPV	Concentrating Photovoltaic
CSP	Concentrating Solar Plant
CUF	Capacity Utilization Factor
DC	Direct Current
DNI	Direct Normal Irradiation
EC	Engineering and Commissioning
EPC	Engineering, Procurement and Construction
EU	European Union
FiT	Feed-in-Tariff
GENCO	Generation Company
GHI	Global Horizontal Irradiation
ha	Hectare (10,000 m^2)
IRR	Internal Rate of Return
kWh	Kilowatt Hour
LCOE	Levelized Cost of Energy
MARR	Minimum Accepted Return Rate
MEA	Middle East & Africa
MWh	Megawatt Hour
NCF	Net Cash Flow
NPV	Net Present Value
OPEX	Operational Expenditure
O&M	Operation and Maintenance
PBP	Pay Back Period
PPA	Power Purchase Agreement
PR	Performance Ratio
PURC	Public Utilities Responsible Committee
PV	Photovoltaic
RES	Renewable Energy Source
USD	US Dollars
WACC	Weighted Average Cost of Capital

LIST OF SYMBOLS

A	Temperature loss coefficient
T_c	Operating Temperature
$T_{c,STC}$	T_c at Standard Test Condition
Y_{pv}	PV rated power output
P_{pv}	PV panel power output
P_{sys}	PV plant power output
L_{sys}	System losses
I_{GHI}	Solar irradiation
A	Area of PV panel
d_m	Number of days in a month
η_{pv}	PV conversion efficiency
R	Revenue from sales
S	Selling price of electricity
D_p	Depreciation of assets
r	Discount rate
n	Operation years
C_{op}	OPEX
C_i	CAPEX
C_T	Cost of total project life-cycle
P_T	Generation of project life-cycle
P_i	Plant ideal generation
P_W	Total installed capacity
PVn	Total number of PV modules
D	PV module degradation factor
T	Tax Liability

1

INTRODUCTION

This chapter begins by describing the current status of solar photovoltaic (PV) development worldwide and highlighting the opportunity for business in Africa and Ghana. Then the power market of Ghana is described along with motivations and problem analysis. The methodology and work scope are given with the basic knowledge in Solar PV. Finally the location of the project is reasoned and accompanied by an explanation of a solar resource map, ending with the thesis' disposition.

1.1 Solar PV Development Worldwide

In the recent decade the world has seen consistent growth in solar power, a renewable and environmentally friendly energy resource, due to its versatility and advances in solar cell development allowing for the technology to become more readily available in different contexts and applications worldwide. Specifically, the success stories of solar power are mainly due to the efforts of developed European nations (Germany, Spain, Italy, etc.) and the USA, which ironically have less solar intake than many emerging countries in South America and Africa, for example.

Africa (for instance) is a continent historically plagued by civil wars and unstable governments, which is the main contributor for the region's poor economic performance in the past. The increasing number of oil discoveries in the African continent has had a debatably positive impact on the economies of some countries so far; although much has been exposed in the media regarding the environmental impact of operations of major oil and gas suppliers in places such as the Niger delta. Regardless, the profits from oil exports mean that some governments are able to invest in domestic businesses and infrastructure, consequently promoting economic growth and attracting foreign investments.

Within this context it is not difficult to understand the lack of willingness and/or reluctance from foreign corporations and private individuals to invest in these regions. Most investors perhaps narrow mindedly, come to the perceived conclusion that investing in places such as West Africa is simply 'not worth the risk'. The term risk is vaguely associated with the financial risk of incurring a loss on investment. There are, however, ways of evaluating and controlling risks with appropriate industry and local knowledge, to be covered, in detail, in *Chapter 4*.

The disparity between solar developments in developed and emerging countries is a fact and this is highlighted in *Figure 1.1*. Below it is evident that BRICS and EU-27 countries account for over 70% of the world's total installed capacity of renewable power (excluding hydro). Perhaps surprisingly, this figure does not include the number from the USA, Japan, Canada and Australia, which leaves most of the emerging countries with a meager share of barely 7.5% of world total renewable capacity. Amongst these numbers the focus point of this report, Solar PV (Photovoltaic), appears as the second largest electricity source losing only to wind generation (both onshore and offshore).

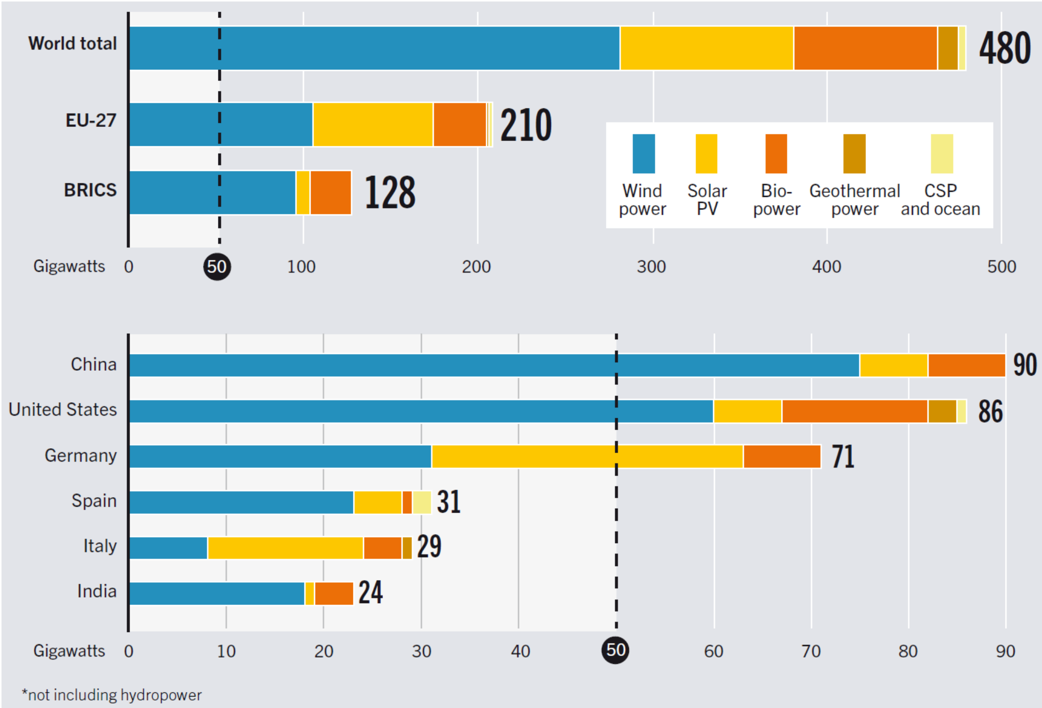


Figure 1.1: Total global installed capacity of renewable power in 2013. [1]

Another fact that follows is the recent recession being experienced mainly by OECD countries which, without notice, wiped out millions of dollars in RES investment plans worldwide. The 2008 economic downturn however did not have such severe effects on some emerging markets as it had on other, more developed countries. In effect, this meant that growth in developing countries was still possible and on-going. In addition, it also gave rise of a new middle class hungry for progress and, consequently, greater energy demand. As shown below, the flow of new solar PV investments in emerging countries can be confirmed by the scenarios shown in *Figure 1.2*.

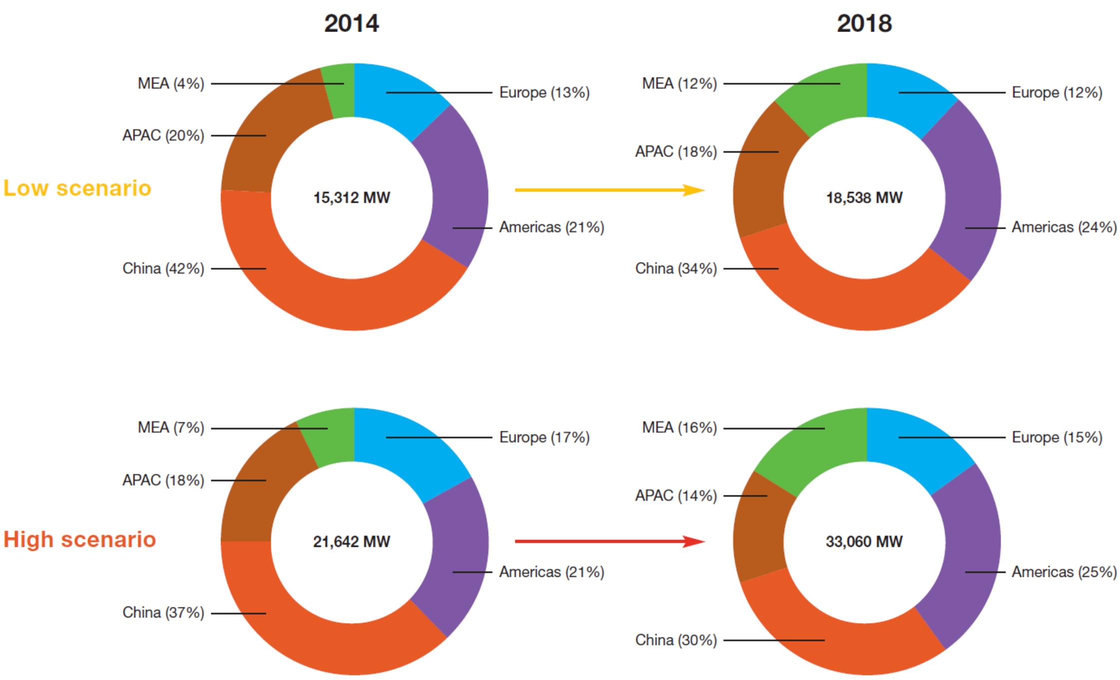


Figure 1.2: Global Solar PV growth scenarios MEA (Middle East & Africa). [2]

Figure 1.2 explicitly shows the inverse relationship between growth in developed countries and emerging ones, regarded as 'MEA' (Middle East & Africa). Even China, the rest of Asia and Pacific countries are expected to decrease investments in the solar PV sector. The highlight of *Figure 1.2* is that even in the 'low growth scenario' the level of investment is expected to triple, by the year 2018. This means that a large scale project in Ghana would be sensible and compliant with industry trends.

The increase in Solar PV developments is not by chance but rather it is due to a combination of proven technology (thus lowering PV prices) and government's FiT's ensuring fixed sustainable incomes for longer periods.

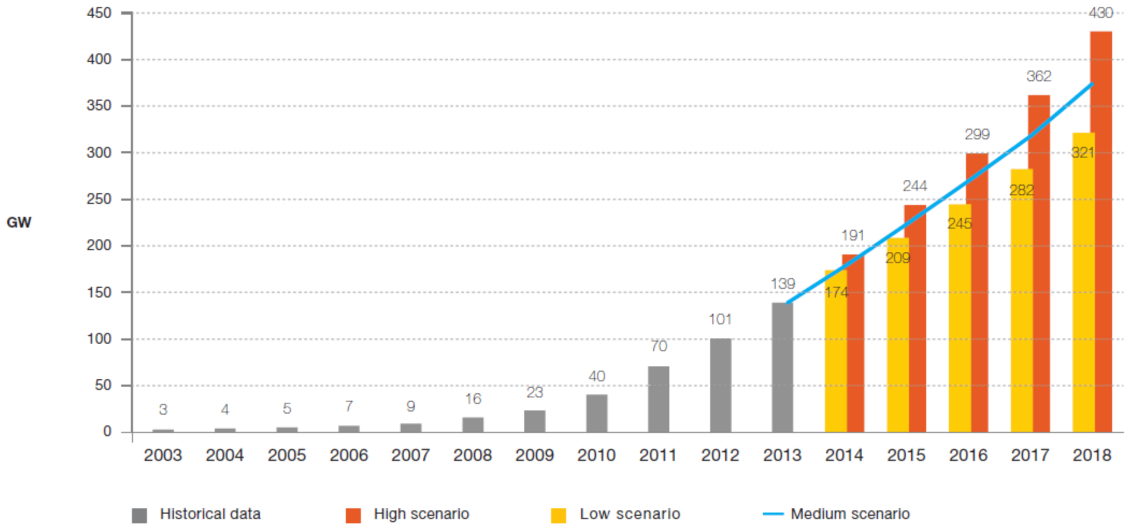


Figure 1.3: The global solar PV cumulative installed capacity. [2]

The trend, show in *Figure 1.3*, emphasizes the dramatic expected growth of Solar PV in the years to come. The cumulative installed capacity, mainly made up by solar PV in developed countries plus China, has increased a nine fold since 2006 from approximately 15 to 150 GW. Most importantly, it is projected to increase from current installed capacity to almost 350 GW (average) by the end of 2018.

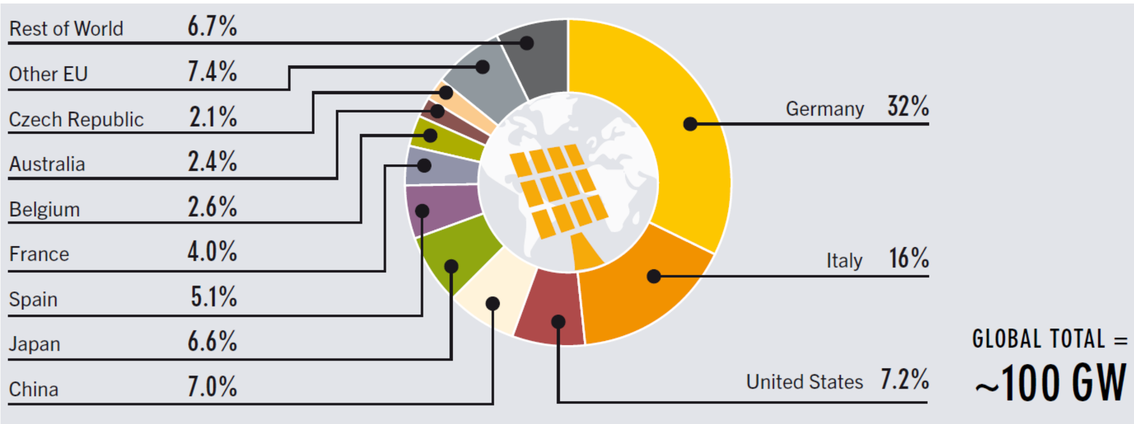


Figure 1.4: Top 10 Countries share of total global PV installed capacity. [1]

From the current 100 GW of Solar PV installed Germany, Italy and the USA alone account for 55.2 GW, as shown in *Figure 1.4*. The 'Rest of Word' share, only 6.7 GW, clearly shows the underdevelopment of Solar PV in these countries. This is not all darkness; rather it confirms the previous figures and statement regarding the growth trend of Solar PV in emerging countries. From a different perspective, this can be seen as an indication that there is an abundance of opportunity for Solar PV developments in emerging markets.

The sharp increase of PV installations worldwide, shown in *Figure 1.3* would be meaningless without comparing the historical growth of other RES, which is why it must be used in combination with *Figure 1.5*. From this, one can state, with certainty, that Solar PV is the RES which grew the most in recent years based on the grey bars shown in the chart. The entire growth in Solar PV amounts to the combined increase of all other RES, apart from CSP. In the year of 2012 alone, represented by yellow bars, the growth of solar PV yielded less than CSP, but that is only in the short term for that particular year.

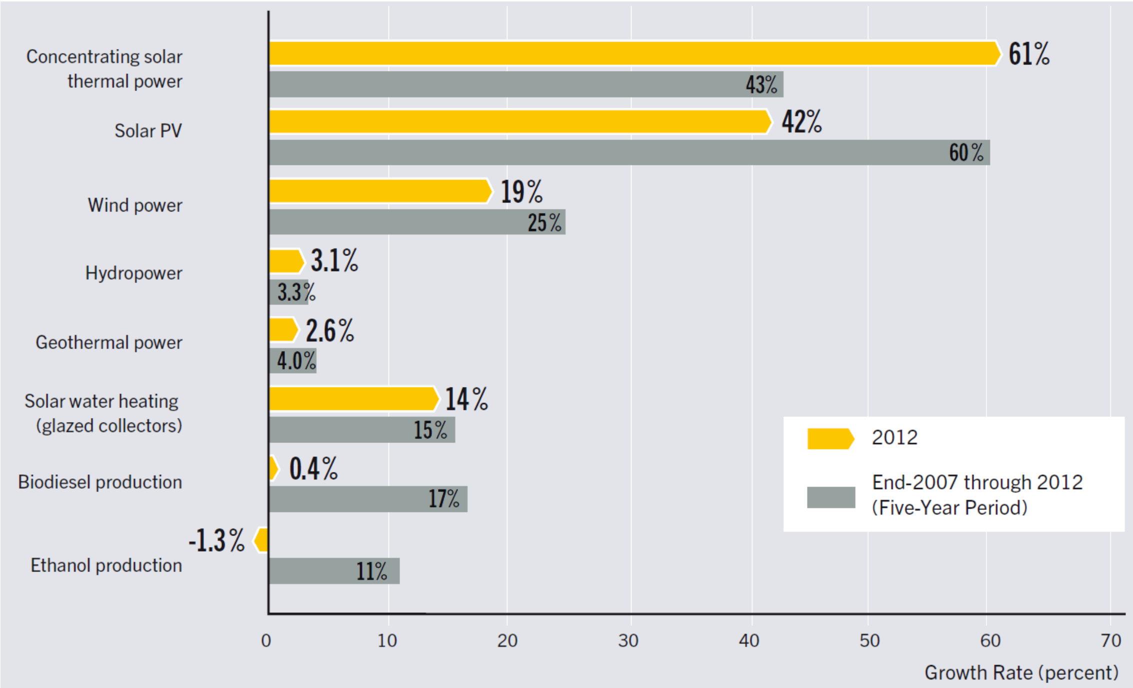


Figure 1.5: Solar PV historical growth comparison with other RES. [1]

The facts and trends presented in this section, which are based on reliable and respected business and renewable energy consultancies, will lay the pavement for the road ahead and will form the foundations for this report. These facts will create the framework from which this report shall provide both calculated findings and assessed recommendations for investment in Solar PV in a specific emerging market – Ghana. With enough regional information about future investments and growth of Solar PV, the first argument which must be addressed is where to locate a large scale Solar PV project.
The answer lies in region which fulfills the requirements outlined by financial and technical literature and research; all the while providing a solid and consistent opportunity for corporate return on investment targets.

Without disclosing personal information of any parties involved, it is sufficient to say the author has access to significant area of land (in the order of 100-200ha) for Solar PV development in Ghana. The three sites, situated in the northern half of the country, are within close reach from the transmission grid. What makes Ghana even more attractive is its recent Electricity Act, imposed in 2011 in order to boost the growth of RES (Renewable Energy Resource), offers both a Feed-in-Tariff (FiT) and Power Purchase

Agreement (PPA) at a fixed rate in US Dollar currency (Local currency which is pegged to exchange rate of USD fixed at a certain date).

In order to prove the feasibility of developing Solar PV in this country this report will create a realistic business case, taking into consideration detailed policy framework for power generation in Ghana and the current costs of solar PV systems.

1.2 Power Market in Ghana

The Ghanaian power mix, shown in *Figure 1.6*, includes both Hydro & Thermal plants, as well as Imports producing a total of 3441.9 MW of installed capacity. Thermal processes, which include Coal, Biomass and Gas Turbine, correspond to 46.8% of the country's generation capacity. Hydro power has a share similar to Thermal plants at 45.9%.According to the Ministry of Energy, Ghana, the share of Solar and Wind are incredibly low, hence being neglected from this data [3].

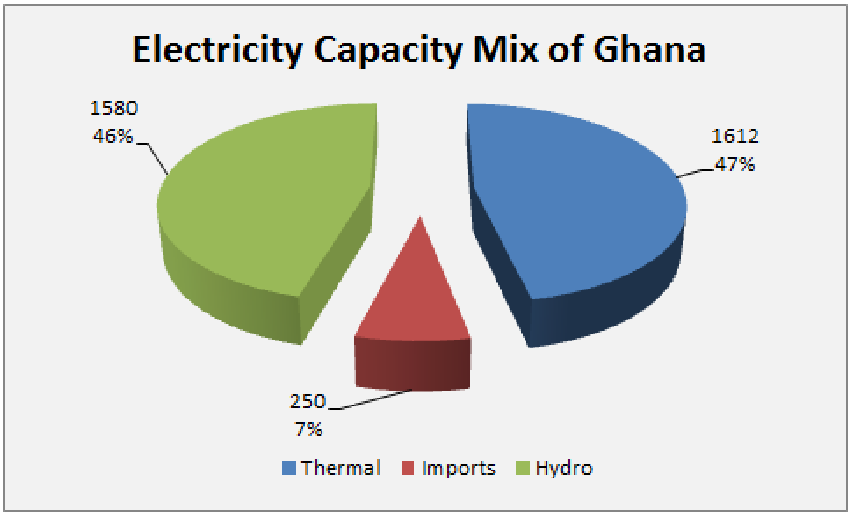


Figure 1.6: Electricity capacity mix in Ghana (Installed MW). (Data from [3])

A recently debuted power market [4] features similar players to the one in Nordpool (the Nordic Power Market), for example. Different GENCOS submit sale bids based on their variable generating costs and power distributors (bulk buyers) make buy bids. In summary this power market, assuming perfect behavior and disregarding other economic influences, means the price setting where demand and supply curve meet. This, unfortunately, is not the case for Ghana. The power market is inefficient, due to government interference, and failure to revert the real generation cost to end buyers [5].

1.3 Motivations

The main purpose of this report is to present a realistic approach for producing a pre-feasibility study of a large scale solar PV development in Ghana. This report is initially aimed at serving as a meticulous guide for solar PV developers in Ghana via highlighting the local policies and risk assessment. Secondly, this report is meant for seeking investment through displaying of economic analysis for the unilateral fulfilment of financial return.

The land acquisition of which is usually considered one of the most important and difficult tasks, has already been secured with a high degree of both certainty and flexibility in regards to specific location. This is an extra incentive for this report in the sense that the author may focus on other critically important issues, such as risk and return.

In *Section 1.2* we have assessed the degree of electricity generation diversity in Ghana, which currently is poorly diversified and highly dependent on fossil fuels. The secondary and indirect purpose of this report is to act as a bridging mechanism; effectively addressing the gap between fossil and renewable energy usage. If proved feasible, this project may serve as template for other sustainable and environmentally oriented disciplines within the power generation sector.

The prospect of making use of FiT and PPA offered in Ghana is another motivation for this business case, as there is a real possibility for constant revenue inflow guaranteed for long periods (at least 10 years). In this case the FiT offered for Solar PV has the highest price than any other RES in Ghana. Both FiT and PPA will be explained in detail in *Chapter 2*.

Finally, another main driver of this project is to create a system in which both local community and business partners can benefit from the positive externalities which result from the implementation of a sustainable energy project. It is expected that this system creates jobs for the community and provides the citizens with reliable, clean and easy accessible electricity. At the same time, the consortium (if the case) should self-sufficiently create revenues to pay for investment and partners' profit share whilst contributing for local tax revenues.

1.4 Problem Analysis

1.4.1 Technical analysis

a. the level of resource in chosen location;
b. the specification of PV modules and system losses;
c. the plant size and generation profile;
d. minimum requirements specified by grid operator.

1.4.2 Laws and regulations analysis

a. the current laws and incentives for solar PV development;
b. the identification of regulating bodies relevant to solar development;
c. the requirements for business establishment in Ghana and tax law.

1.4.3 Economic analysis

a. the evaluation of fixed and variable cost of a solar PV plant:
b. risk assessment and mitigating strategies;
c. calculation of NPV, IRR via NCF operations;
d. sensitivity analysis of NPV and IRR in respect to LCOE and WACC.

1.5 Methods

A feasibility report of developing a large scale solar PV plant is a task that depends on several types of resources. The literature review covers most government websites (in Ghana) for policies and latest up to date cost information on PV systems. The use of books and scientific journals will be used for economic analysis guidelines and comparison of results.

In order to evaluate the feasibility of this project, one first needs to describe the significance of the key economic criteria for financial decisions, such as Net present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP) and Benefit-to-Cost (B/C) ratio. The NPV puts the "time value money" into perspective and reveals the projects present profit for a given depreciation rate. The IRR determines the rate of depreciation of money. The PBP help investors predict how long it would take to recover the full investment. And the B/C ratio is a nice tool to use to determine the profit margin of an investment in present value terms. These economic indicators will be taken into consideration for the comparison and conclusion of the report. [6]

This business case will be evaluated via cash flow statements throughout the project life cycle (installation & operation). Economic calculations shall provide key financial indicators, such as NPV, PBP, and total costs. The statement charts will be produced via MS Excel formulae and the comparison shall be presented in graphical form.

One key parameter, the WACC (Weighted Average Cost of Capital), shall be used as benchmark figure for the Minimum Acceptable Rate of Return (MARR). This value should represent (a real), best practice, and acceptable return on investment to be matched against after running a sensitivity analysis. The comparison of different IRR (Internal Rate of Return) values will be used to define whether the project is feasible or not. The chosen values of IRR to be used in the sensitivity analysis will be given from a range of values of the WACC (Low risk/High risk)

Ultimately, a large scale PV plant will be considered to be 100 MW, for sake of easier manipulation of results (e.g. 100 is a round number). After costs are estimated and implemented to the size of the plant, the final costs will be provided in units of USD (US Dollars) per MW (Megawatt) of Solar PV capacity installed. This implementation will consequently provide a friendlier way to translate results into various sizes of power plants.

1.6 Work Scope

In a real company project, engineers use advanced computer programs for modeling solar plants (e.g. Homer, SAM). Most of these software contain embedded solar data and solar module conversion formulae, allowing users to predict plant generation every hour throughout plant life cycle. This project however is limited to using only the solar data (from Solar GIS) given in monthly average. The power generation and financial formulae shall be given explicitly and computed via spreadsheet software.

This report's purpose does not concern solar PV technology; however different suppliers with similar solar PV products will be compared in regards to costs. Therefore a specification sheet of the solar module manufacturer will be taken as main data input (e.g. conversion efficiency, capacity, etc). The work scope entails only the economic analysis of a large scale solar power plant in Ghana. The solar plants will be considered only as grid-connected to main transmission lines. The idea behind this is that no transmission lines must be built, only the connection between the solar plant and the nearest transmission hub.

In the financial context, no market models will be required for optimizing generation levels of electricity. Both FiT and PPA in place guarantee that all power produced will be sold with priority over all other generation technologies. Main financial parameters will be evaluated and discussed as investment options.

The literature review shall contain detailed information on energy policies and regulations concerning Solar PV, as well as technical requirements in terms of equipment installed in the solar park. Most importantly, the literature research will cover the most relevant financial requirements for assessing economic feasibility of a renewable energy project.

1.7 Basic Understanding of Solar Energy

Solar energy is the most abundant energy resource on Earth. The solar energy that hits the earth's surface in one hour is about the same as the amount consumed by all human activities in a year [7]. The energy absorbed can be either used directly for heating or transformed into electricity via PV Panels. In the latter case Solar PV units can be employed in either small scale (e.g. rooftops) or large scale (e.g. Solar PV Park) to produce electricity via absorption and transformation of sun light.

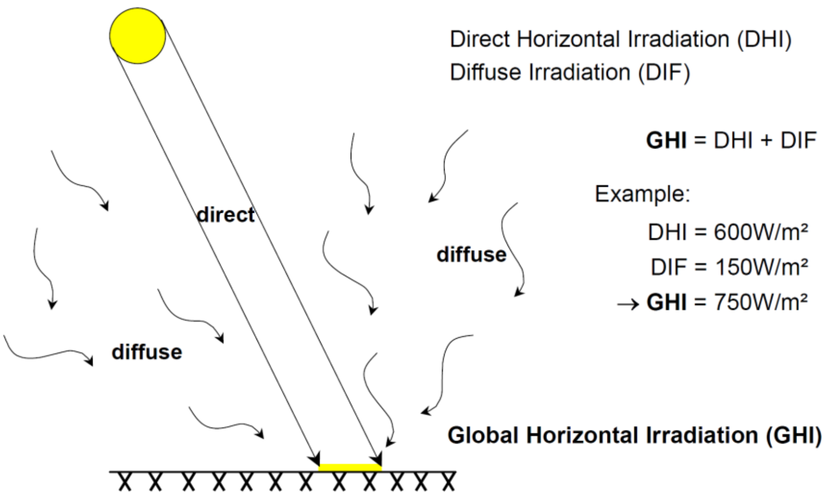


Figure 1.7: Schematic of composition of GHI parameter. [8]

So far only financial parameters were taken into consideration, but this section will touch upon key technical constrains of a solar development which is the amount of sun light available in a given location. This parameter is regarded as solar irradiation and it is measured in two forms: Global Horizontal Irradiation (GHI); and Direct Normal Irradiation (DNI). The parameter of value to solar PV projects, GHI given in $Wh/m^2/day$, is explained more in detail by *Figure 1.7*. In case of DNI, it is used in CSP and CPV projects [9]. The symbol used to describe GHI will be called 'I'.

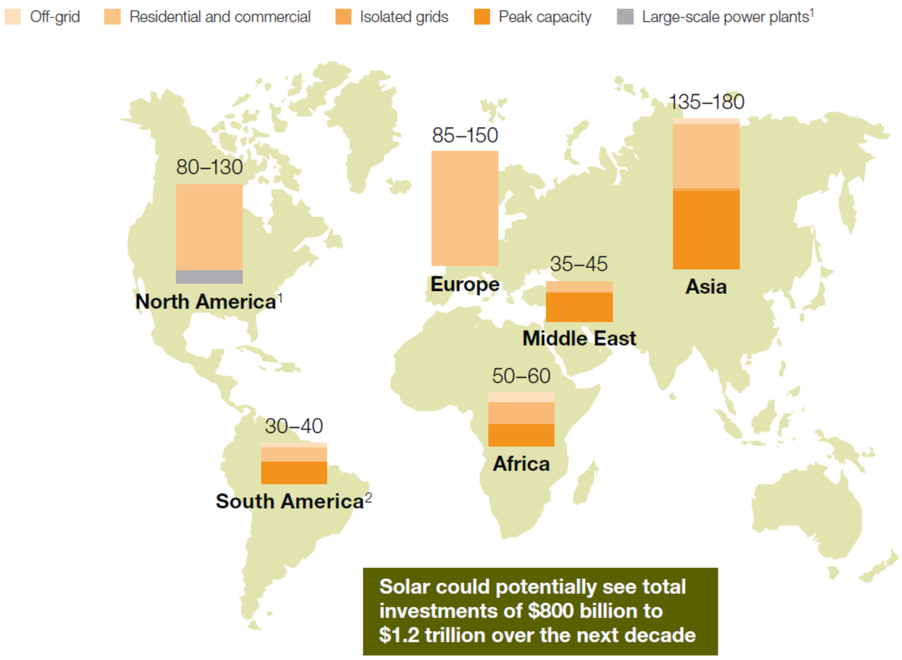
1.8 Choice of Location

The principal idea of this project was created around combining the mutual interests of the Author, the land owner and the Partner. The land is currently available for use (as described) and it was decided that a study should be carried out in order to evaluate the feasibility of developing large scale Solar PV. After further research it was then realized as a realistic opportunity, given the scope for profit potential and financial incentives offered in Ghana.

Ghana has a significant geographic advantage compare to other nations. The country lies just south of the Equator, which removes the requirement for complex PV mounting systems (e.g. dual tracking panels). Also the suitability for PV systems is very high in Ghana, due to generous amounts of long sunny days without significant variation in daylight hours throughout the year.

A very important issue to address is whether or not solar PV is the best use for the land in question. First of all, the owner of the lands in Ghana has these sites currently as unproductive. This is either due to lack of demand for expanding certain crops or due to high marginal cost necessary to expand crops. Secondly, other RES options have been accessed, but ruled out because of lack of incentives or resources: no FiT offered for CSP; lower FiT and wind resources for wind power.

On a different note, the use of land for urban development was inquired, however this was also ruled out since the location of these sites are in rural areas with lowest population density. This means that solar PV developments in one of these sites will not directly increase the price of land. From a sustainable view point this land use for electricity generation will not compete with food crops of any kind because the land is unproductive and far from densely populated areas. Therefore, it can be easily deduced that the implementation of a Solar PV project on this land is indeed sensible option in a business sense.



[1]Includes 10–20 gigawatts of regulated utility pipeline in the United States.
[2]Includes Mexico.

Figure 1.8: Investment potential within Solar PV to 2020. [10]

The facts about solar power have been laid out and the only remaining matter to evaluate is whether or not to develop a large scale park. One potential answer to this lies in *Figure 1.8*, which illustrates the suitability of different type of developments in regions of around the world. The investment atlas created by Mckinsey & Company [10] shows high potential investments in South America and Africa for 'Peak capacity' Solar PV. This type of development is featured by large scale developments, placing this report in line with economic trends.

1.9 Solar Resource Map

As mentioned before there is a great deal of flexibility with regards to site location in Ghana. For this reason the site chosen will be in the region shown in *Figure 1.9* by black arrows. The area in question offers the highest levels of GHI, in the range of 5.5 – 5.75 kWh/m^2/day. In another words, the maximum solar energy that can be extracted from this region is 5.75 kilowatt hour per square meter per day. The importance of this map is very high because here, assurance is given that the Solar PV project will indeed generate more electricity than most regions in the country.

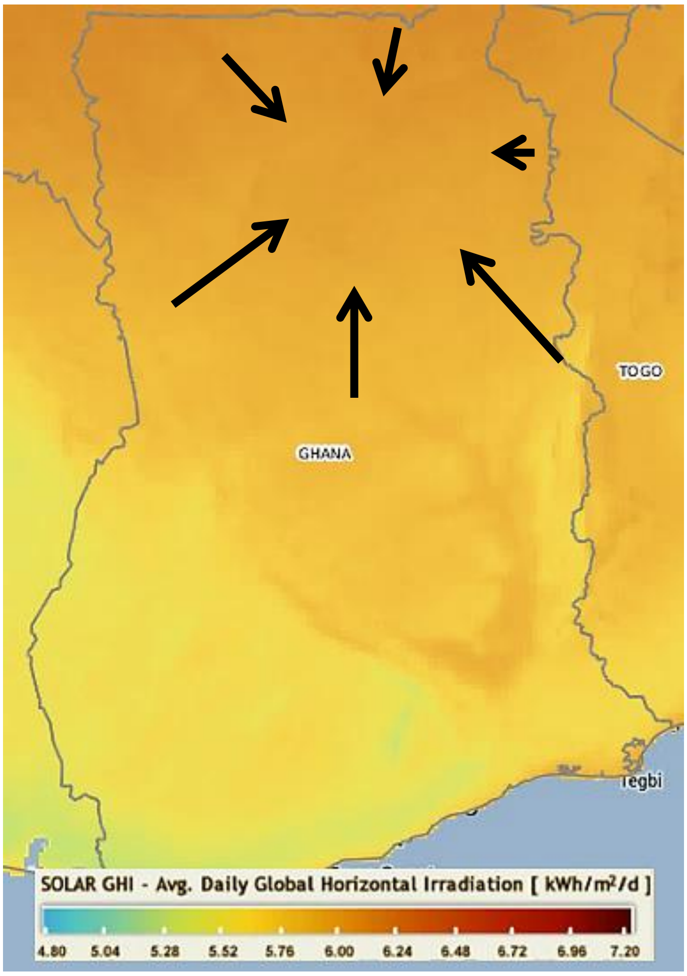


Figure 1.9: Global Horizontal Irradiation map of Ghana. [11]

It should be remembered that these potential location has high strategic value for the country: in the Upper Western region there is the possibility of electricity export to Ivory Coast and Burkina Faso; in the Upper Eastern area there is also the opportunity for exports to Togo and Benin.

1.10 Disposition

The disposition of the report is as follows:

Chapter 2: Reviews the laws, regulations and incentives for creation and operation of a renewable energy company in Ghana.

Chapter 3: Summarizes the key technical characteristics of a large scale solar plant in Northern Ghana.

Chapter 4: Describes input costs and assesses the risks involved in such project.

Chapter 5: Provides results of costs, as well as future profit associated with a large solar plant investment, as well as the sensitivity analysis.

Chapter 6: Discusses concludes the meaning of the results. Also, suggestions and recommendations for further work are given.

2

POLICY FRAMEWORK

In this chapter the main laws and regulations relevant to the solar industry are discussed. Then a set of requirements for business establishment in Ghana are presented. The chapter ends with an advice on possible problems.

2.1 Public Statements

The vision stated by the Ghanaian government is clear: *"…to develop the renewable energy sector to about 500 megawatts of power per year and also contribute 10 per cent of the country's energy mix by the year 2020", Ministry of Energy and Petroleum.* Currently, in Ghana, the total share of renewable, excluding hydro, accounts for less than 2% of the total electricity generation [12].

The government strategy is therefore to diversify the electricity mix and increase generation capacity, while at the same time boosting foreign investment in Ghana. This has been put into action via several mechanisms which include: introduction of long-term FiT for various types renewable energy to attract investors, creation of the Renewable Energy fund for facilitating domestic financing, and renewable energy fund access for GENCOS (Power Generation Companies).

2.2 The Electricity Act

"The objective of this ACT is to provide for the development, management and utilization of renewable energy sources for the production of heat and power in an efficient and environmentally sustainable manner." The Parliament of the Republic of Ghana, on Renewable Energy Act

The purpose of the Ghanaian electricity Act is to provide guidelines for new renewable energy companies [13]:

- *Feed-in-Tariff Scheme under which electricity generated from renewable energy sources will be offered a guaranteed price.*
- *Renewable Energy Purchase Obligations under which power distribution utilities and bulk electricity consumers will be obliged to purchase certain percentage of their energy requirement from electricity generated from renewable energy sources.*
- *Licensing regime for Commercial Renewable Energy Service Providers among others to ensure transparency of operations in the renewable energy industry*
- *The establishment of the Renewable Energy Fund to provide incentives for the promotion, development and utilization of renewable energy resources.*

2.3 Provision of Regulation

Here the Ministry of Energy itself creates the set of rules and regulation under the Electricity Act. In order to be granted a license for production of electricity the GENCO must provide the following [13]: *"...documents, accounts, estimates, returns, environmental impact assessment and management plans or any other information that the Board may require for the purpose of performing its functions under this Act in the manner and at the times as may be reasonably required."*

Under the electricity Act [13], only the following are legible for applying for a license:

a) *A citizen,*
b) *A body corporate registered under the Companies Act, 1963 (Act 179) or under any other law of Ghana; or*
c) *A partnership registered under the Incorporate Private Partnerships Act, 1962 (Act 152)*

2.4 Environmental Laws and Regulations

The organ responsible for environmental affairs in Ghana is the EPA (Environmental Protection Agency). Under the Environmental Act of 1994, any company that wishes to trade on Ghanaian soil has to have approval from EPA. There is no particular procedure or guidelines for solar PV projects because the environmental permits are issued on a case-by-case basis. The project study must be submitted to agency for permit request. Once the project is evaluated by the board, it will be decided whether or not to grant the permit. In the worst case scenario, the agency may require an environmental impact assessment of the project [14].

2.5 Feed-in-Tariffs

The publication of FiT in Ghana was made in 28th August 2013, and it is to be used as a complement of the 'Renewable Energy Act'. In this case, the responsible organ for the publication is PURC (Public Utilities Regulatory Commission). According to the publication the FiT took effect on 1st September 2013 [15].

"In accordance with Section 27(4) of the Act, the approved rates in existence in the year in which a Power Purchase Agreement is signed in respect of a Renewable Energy project shall be fixed and applicable for that project for a period of ten years. Subsequently the rates shall be subject to review every two years." Chairman, Public Utilities Regulatory Commission

The approved rate for Solar PV, which is the highest amongst all other RES, is fixed at 40,21 GHp/kWh or, more explicitly Ghana Pesewa per kWh. The Ghanaian Pesewa is the monetary unit to describe the subdivided Ghanaian currency, the Ghanaian Cedi. This rate, however is tied to the exchange rate of USD given on 27th August 2013 at GHS 1,9968 to USD 1.000. This means the fixed FiT applicable for a period of 10 years is US¢ 20,1732 per kWh of electricity sold to the grid. Alternatively, a GENCO may negotiate a higher FiT or duration period with PURC based on scale of the project [15]. Recently, a UK based solar company (Blue Energy) has been granted a Power Purchase

Agreement (PPA) of 20 years under the FiT rate specified for their 155 MW solar PV plant [16].

2.6 Fiscal & Legal Matters

In order to attract foreign investments, the Ghanaian government has created a customized package of incentives for private investors. The Ghana Investment Promotion Center (GIPC) Act guarantees, amongst other things, 100% profits and dividends transference, exemption of import duties and tax deduction on capital expenditures. Most importantly it guarantees investors against expropriation and full compensation on potential gains (i.e. in case an extraordinary event of expropriation, the government will fully compensate Solar PV plant owner for the potential return plus total investment) [17] . This automatically removes the risk of losing investments due to expropriation, not covered by insurance companies.

The GIPC also provides a vehicle for liaison between the company and government bodies, for example the tax office. In cases where the company will be acting in strategic markets, such as utilities for example, the government may grant tax exemption or 'holidays' [17]. The maximum corporate tax applied to all companies is 25% on income [18]. These incentives mean Solar PV project can have a higher viability and share of profit, via improving the ease of business and reducing financial risk.

International Law firm Hogan Wells suggests the company may be established under the Free Zones Act, which allows for a 10 year period of tax exemption and no more than 8% afterwards. The only requirement is that 70% of production must be exported, which is possible with current grid interconnection with neighboring countries. The Free Zone option is also comprised of import duty exemption on Solar PV panels [19]. This option however is very unlikely to suit the business model of a power generation company.

2.7 Foreseeable Problems

Amidst all possible circumstances, the Solar PV development is safe from expropriation and nationalization issues, which are considered the main threats in the eyes of investors. What then follows is an assessment of whether the local knowledge (technical and otherwise) is sufficient for constructing, maintaining and running a large scale PV project.

Regarding technical know-how, a thorough research of local grid requirements is paramount to ensure grid connection capability. There must also be guarantees from local grid operators that grid reinforcement is in place, near the connecting BUS and prior to commencing star-up operations. In the practical spectrum the project is left with relying on the will and ethics of governing bodies in granting licenses required to establish company and operate as a GENCO.

The other problem beyond the project's control lies within the nature of solar power generation, in another words intermittency. The prediction of exact daily and monthly power output is impossible; however this issue can be mitigated by employing conservative solar data based on historical solar data measurements as per *Section 1.9*. Even further beyond control is the occurrence of natural disasters. This and other issues which increase the risk of investment will be taken into account and dealt with in *Section 4.2*.

3

UTILITY SOLAR PLANT CHARACTERISTICS

This chapter reviews the technical characteristics of solar PV and power generation. An overview of solar PV plant equipment is given with a power calculation formula. The site potential generation is assessed, quantified and the generation profile is given. The grid is finally given, ending with a description of the grid minimum specifications.

3.1 Solar Panel

Most solar panels available nowadays are generally made from the same main raw material, Silicon. Whilst being one of the most abundant elements in earth, Silicon has to undergo rigorous processes in order to obtain desired semi-conductor characteristics and be used as a photovoltaic end product. In simple terms, the higher the purity of silicon, the higher is the performance of a PV cell. Amongst all the different technologies for producing PV panels there are two in particular that are worth mentioning for this report: crystalline and thin-film panels.

Both types of panels are created from the same elements, presented on *Figure 3.1*. The n-type and p-type semiconductors are simply plates made of silicon. The n-type plate is treated with Phosphorous, which create an excess of electrons. The p-type is treated with Boron, and becoming deprived (in need) of electrons. When put together, the two Silicon plates create an electromagnetic potential which allows a DC current to flow between semiconductor plates [20].

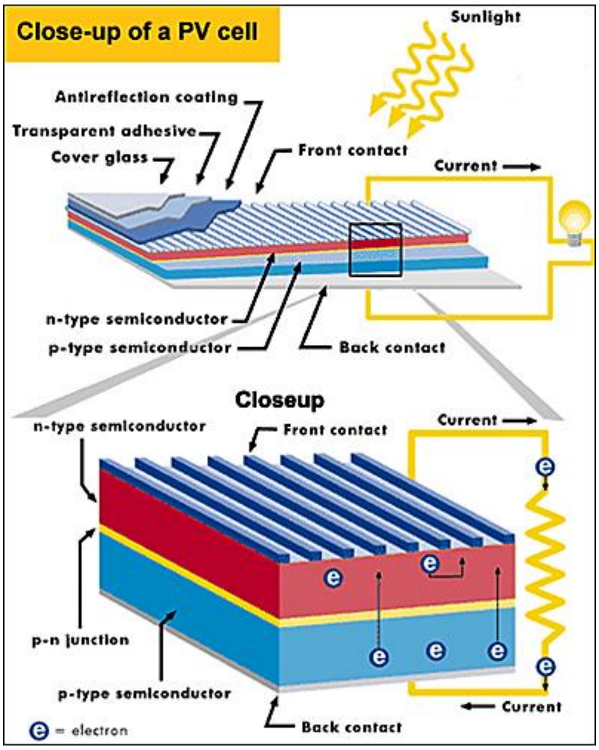


Figure 3.1: PV cell schematic. [20]

Crystalline panels are divided into mono and poly crystalline cells depending on the purity of silicon. Mono-crystalline panels or m-Si have the highest conversion efficiency amongst all commercial solar panels, in the range of 20-24%. This means that up to 24% of sun energy absorbed can be converted into electricity. Poly-crystalline panels or p-Si, whilst having similar properties to m-Si, operate in the range of 15-19% efficiency and are twice, or even three times, cheaper than c-Si [20].

Thin-film panels, on the other hand have the same construction as a crystalline panel; however they are made of a very thin layer of semiconductor material. In crystalline panels, for example, the silicon plates are made approximately 200-300µ thick. In the Thin-film modules the thickness of semiconductors plate is in the order of 1µ, which means that sunlight wave lengths larger than semiconductors' cross-section cannot be absorbed. For this reason Thin-film panels operate in the range of 8-14% efficiency [20].

3.2 Power Generation

This report shall not explain PV technology in depth because the technical information is specified by all PV manufacturers. Technical specifications, for the components within the solar plant, are made widely available via many suppliers' websites.

The manner in which solar panels transform sun light into electricity is the same for all types of modules; however they represent only one major component within a PV plant seen on *Figure 3.2*.

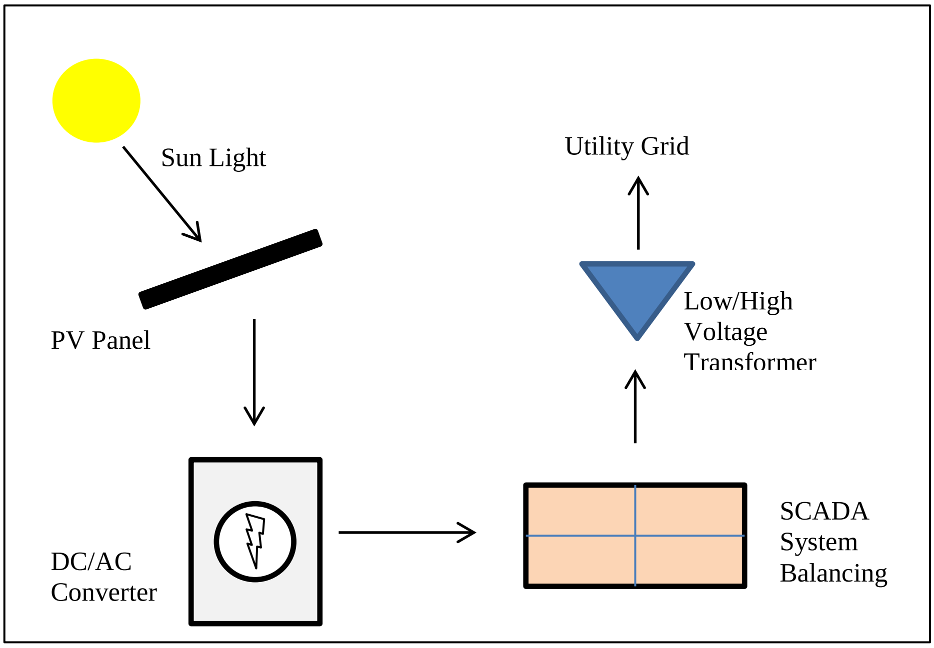


Figure 3.2: Example of solar plant infrastructure. (Data from [21])

There are several pieces of equipment and infrastructure to consider in a large scale development. For instance, the PV modules need to be mounted on racks which are fixed to the ground; inverters are needed to convert DC current (from PV modules) into AC current (utilized on transmission grid); an AC Panel is required to manage simultaneous incoming AC current from all inverters; a meter is to be connected just before the delivery point in order to account for electricity sold; a voltage step up transformer is needed to ensure the electricity leaving the plant matches the potential (or voltage) of the grid; and finally, a large quantity of cables are needed to connect the various pieces of equipment located throughout the plant.

3.3 Solar Farm Infrastructure

Before any work can be carried out on the plant site, ground works must take place. The land must be levelled in order to minimize shading in the panel array. Trenches will also need to be dug in order to provide a suitable fit for conduits and to prevent cables from exposure to the environment. Furthermore, foundation works, in form of self-screwing or pile-driven steel studs, will also be required to provide secure fixation for the mounting racks. Finally, fencing of the premises is essential for protecting the asset against theft as well as to provide safety for the individuals involved in the operation and maintenance of the plant. All these land operations will be accounted as a lump sum cost under 'Civil works'.

3.4 Solar Power Calculator

The power generation potential mainly depends on two key parameters: Global Solar Irradiation and PV panel efficiency. The first was explained in *Section 0*, and has to do with the total energy available. The second, efficiency is provided by solar module supplier. This value is given at Standard Testing Conditions (STC) at 25ºC. The power output of the PV array is given by equation 3.1 [22]:

$$P_{PV} = \sum Y_{PV}\, D\left[1 + \alpha\left(T_c - T_{c,STC}\right)\right] PV_n \qquad (3.1)$$

Where:

P_{pv} : annual PV array power output
Y_{pv} : PV panel power output
D : Degradation factor (0.5%/year)
α : Temperature loss coefficient
T_c : Operating temperature
$Tc_{,STC}$: Temperature at Standard Test Conditions
PV_n : Number of PV panels

Given in equation 3.1 the term Y_{pv}, which relates to the solar resource, can be obtained from equation 3.2 below:

$$Y_{PV} = I_{GHI} A d_m \eta_{PV} \qquad (3.2)$$

Where:

I_{GHI} : monthly average solar irradiation
A : area of PV panel
d_m : number of days in a month (30 days)
η_{pv} : PV conversion efficiency
Finally, the total power generated by the solar plant is given by equation 3.3 below:

$$P_{SYS} = P_{PV} L_{sys} \quad (3.3)$$

Where:

P_{SYS} = Power output of solar plant (kWh)
L_{SYS} = Product of all System Losses [23]

Note: A description of all losses in presented below:

PV module degradation (D): linear yearly increasing loss guaranteed by suppliers. Set at 2.5% in the year and increasing 0.5% per year afterwards [24].

PV module performance loss due to temperature (α): standard loss due to PV cell overheating. Typical values are 0.4-0.5% loss in power output per every degree Celsius above Standard Testing Conditions (25°C). The value to be used in this report will be 0.41%/°C [25].

Inverter efficiency loss: typical loss due to converting DC/AC current is 5-2.5%.

Loss due to soiling of module surface: accumulation of particles on module surface or suspended in air. Typical values range from 0.5-70%.

AC wiring: loss from cables and transformer. Typical loss varies from 1-3%.

DC wiring: loss from power cables. Typical loss varies from 1-3%.

Mismatch: loss due to incompatible electrical components - varies from 1-3%.

System Availability: loss due to grid or plant down times - varies from 1-3%

Connectors: loss from diodes and connections - varies from 1-3%.

Table 3.1: Loss accountability breakdown for the month of January.

Loss description	Accountability	Energy (kWh/m2/day)
Annual Energy available	0.00%	6.5
Soiling and reflectance	5.00%	6.175
Module conversion loss	83.77%	1.002
Temperature loss	1.60%	0.986
Degradation loss	2.50%	0.962
DC Wiring loss	2.00%	0.942
Component mismatch	2.00%	0.923
Inverter loss	4.00%	0.886
AC Wiring loss	2.00%	0.869
Power connectors	1.00%	0.860
System availability	1.00%	0.851
Total system losses	86.90%	5.649

Some input parameters from *Table 3.1* shall be based on the specification sheet from *Table 3.2*. Note that from this one can obtain main input relate to the module such as conversion efficiency, temperature coefficient and area. The module chosen from Jinko Solar has a conversion efficiency of 16.23% and suits the warranty requirements, supplier location (China), installation purpose (large scale and module type (Poly-crystalline).

The efficiency of the module however is lower than the average efficiency (17.3%) of a module within the price taken. This means the calculations in this report will benefit from an extra margin of safety because it was not possible to find a module with exactly 17.3% efficiency.

Table 3.2: Jinko 315W_p Poly-crystalline module specifications. (Data from [25])

Module Type	JKM315PP
Cell Type	Poly-crystalline
Dimensions	1956x992x40mm
Weight	26.5 kg
Maximum Power	315Wp
Module Efficiency (STC)	16.23%
Temperature coefficient	0.4%/°C

3.5 Site Potential

The assessment of the total solar energy available took into account the different available site locations and two calculation sources [9] [26] , given in *Figure 3.3*. The values below reflect the average of all sites and sources. The annual average irradiation for the profile below is 5.58kWh/m^2/day and it is optimized for solar modules mounted on an inclined angle between 12 and 14 degrees.

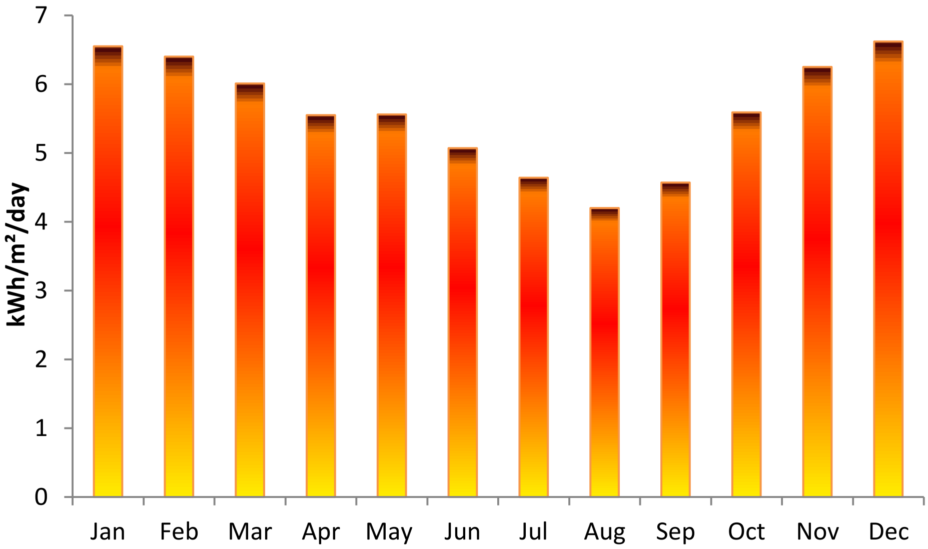


Figure 3.3: Annual average GHI profile for site in Ghana. (Data from [9] [26])

The site generation profile, in *Figure 3.4*, is produced in two steps: first, equations from *Section 3.4* are used to evaluate the entire generation for the first year of operation; from second year onwards, the generation of every year decreases by 0.5% reflecting on module degradation data.

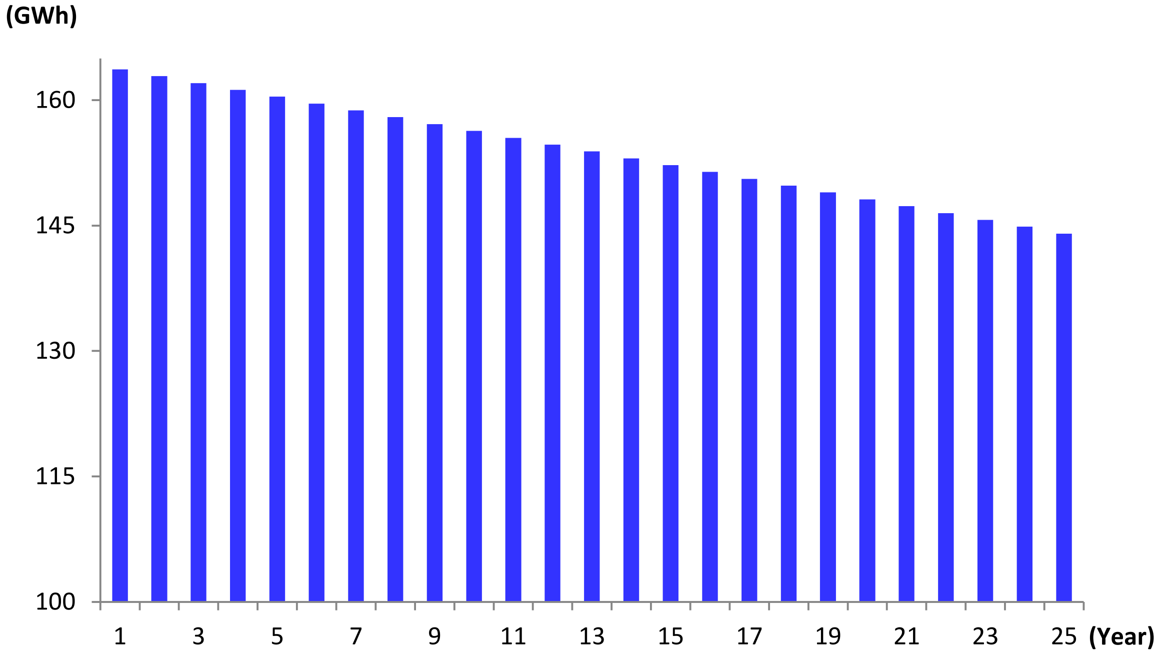


Figure 3.4: 100MW PV plant generation through entire life cycle. *Table A.2*

3.6 Power System Integration

3.6.1 Grid Connection Possibilities

There are plenty of options for grid connections. The black dashed lines, showed in *Figure 3.5*, point to the available transmission lines within close distance from potential sites. There are two choices of connection, 161kV and 34.5kV lines however it seems the first is more probable because it carries power through a longer distance (e.g. most populated areas). This information is useful because it concerns the BOS (Balancing of System) equipment specifications. Moreover it gives an idea of the size of transformer required.

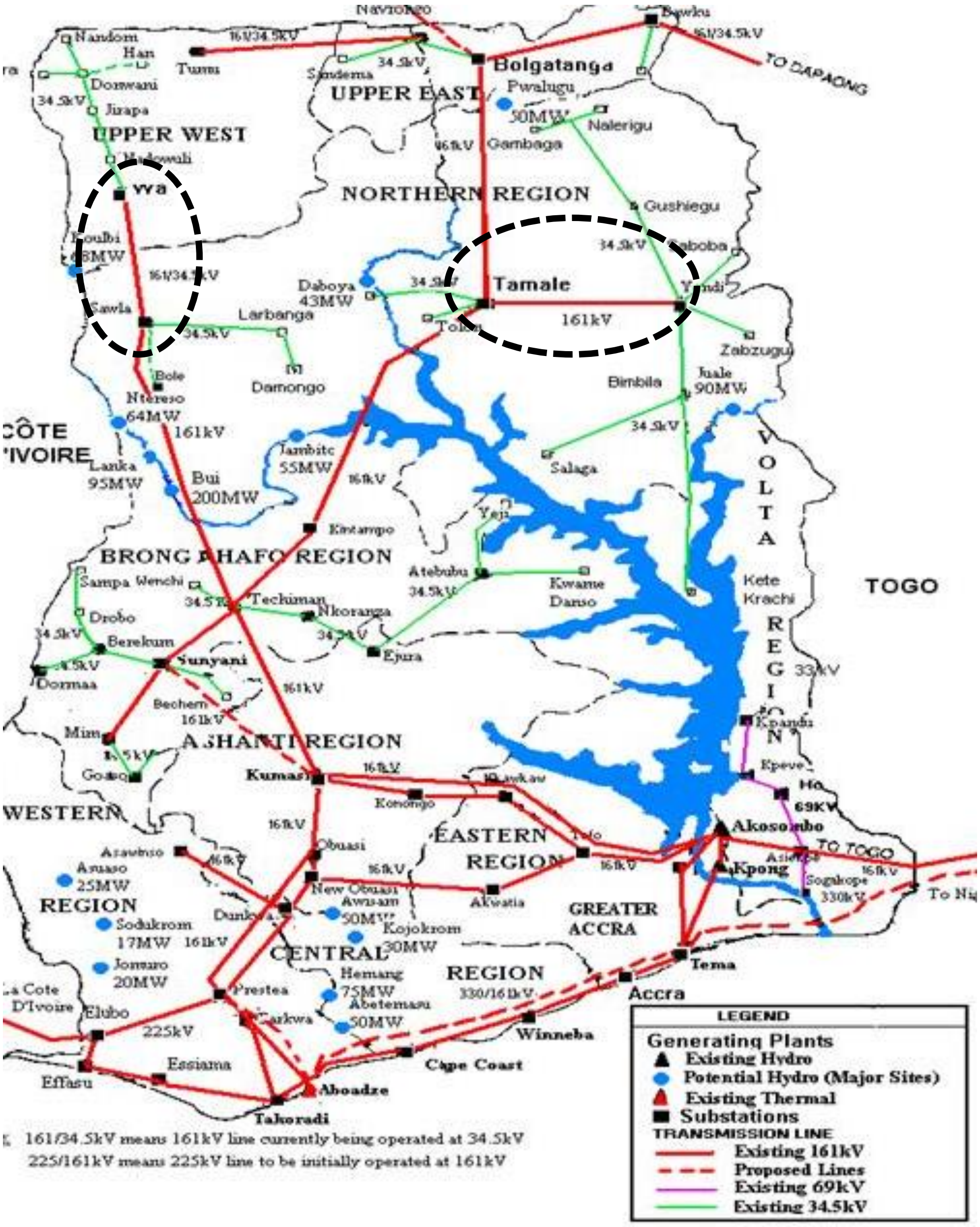


Figure 3.5: Ghana transmission grid. [27]

3.6.2 Requirements

As per Article 3.14 of the National Electricity Grid Code a Wholesale Supplier (the solar plant owner) is responsible for (quoted from [28]):

a. *Ensuring the design, installation commissioning and maintenance of equipment meet the requirements of the relevant regulations;*

b. *Compliance at all times with applicable requirements and conditions of connection for generating units in accordance with the Connection Agreement with the ETU (Electricity Transmission Unit) and in consultation with any relevant NITS (National Interconnected Transmission System) Asset Owner, where necessary;*

c. *Providing the ETU with information on available capacities and operating constraints of its generating units to facilitate dispatch under all power system operating states;*

d. *The development of maintenance plans for its equipment and the provision of necessary information to the ETU for outage planning and maintenance coordination;*

e. *The operation of its plant and equipment in accordance with the dispatch instructions of the ETU to meet system performance and reliability requirements and in a manner that is consistent with the reliable operation of the NITS;*

f. *The provision of accurate and timely data, information and reports to the ETU.*

3.6.3 Power quality

According to Article 12.07 of the National Electricity Grid Code, the quality of power supply should be considered acceptable under the following conditions: [28]

a. The system nominal frequency of 50 Hz does not deviate by more than 0.2 Hz unless otherwise specified by the technical scheduling authority ;

b. The voltage magnitudes do not exceed the allowable deviation of 5% unless otherwise specified by the technical scheduling authority ;

c. There is no imbalance in the magnitude of the phase voltages or (otherwise) outside the limits stipulated by the technical scheduling authority ;

d. The phase displacement between voltages is equal to 120 degrees unless otherwise specified by the technical scheduling authority ;

e. Voltage fluctuations are within the allowable limits stipulated by the technical scheduling authority;

f. Voltage harmonics do not exceed the limits stipulated by the technical scheduling authority.

3.6.4 Ancillary Services & Transmission

Provision of ancillary services is made by State owned GRIDCo, which is the body responsible for frequency balance of the system and control of reactive power. On an issue related to this project, GRIDCo is responsible for providing transmission reinforcement at the point of connection with solar plant. This means that the technical issues regarding the compatibility between the solar plants to the grid must be addressed directly to GRIDCo [29].

The billing for transmission and ancillary service charges is also responsibility of GRIDCo. This means all charges issued in regards to transmission and services are to be paid monthly, directly to GRIDCo [29].

4

FINANCIAL APPRAISAL

This chapter presents the economics of solar PV and an in-depth discussion in risk assessment. The main cost inputs are explained and given in benchmark figures. The chapter ends with an introduction of financial formulas and parameters' definition.

4.1 Solar Power Economics

Following the proposed scope, this report will only consider cost and benefits from segments of the value chain shown in *Figure 4.1*. These reflect on the actual stages through which the project will be executed: development, execution and operation.

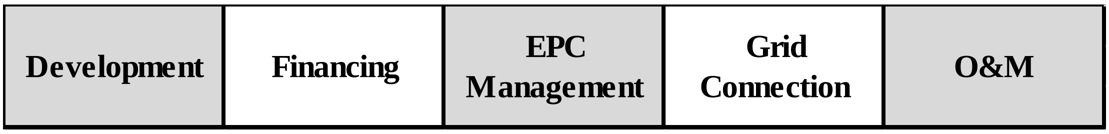


Figure 4.1: Utility scale solar PV value chain. [30]

Throughout the value chain of Solar PV systems, in some cases, indirect factors may be considered. Factors regarding CO_2 avoiding credits or any other CO_2 emission scheme will be disregarded from this development for the simple reason that it does not add any value to the project. The CO_2 market, similar to the one featured in EU for example, is not present in Ghana.

One of the most bankable ways of assessing the feasibility of a generation project (in a perfectly deregulated market) is via LCOE (Levelized Cost of Electricity). This is the main parameter when comparing various types of sources of generation by their life time costs. In simple terms LCOE represents the ratio between the project's total cost and total generation throughout its life cycle. This equation takes into account energy production (P_T) and the total cost throughout the entire life cycle of the project (C_T) [31].

$$LCOE = \frac{C_T}{P_T} \left(\frac{US\$}{kWh}\right) \tag{4.1}$$

The utilization of LCOE is very important for; solar plant developers to assess the suitability of Feed-in-Tariffs; and policy makers to design subsidies and tariffs.
Note: It is assumed that decommissioning and scrapping values cancel each other out. This is because of the lack of such information, but in reality scrapping value would exceed decommissioning, thus decreasing LCOE.

A second indicator, called Performance Factor (PR) serves as an operating feedback of the plant. This output parameter focus on the losses due to different equipment, instead of location and site potential. The PR value can be influenced by the quality of components in the solar plant, for example higher efficiency Inverters will improve the plant's PR [32]. In equation 4.2 below, the term P_i stands for ideal plant generation (without system losses).

$$PR = \frac{P_T}{P_i} \quad (4.2)$$

The third parameter (equation 4.3) measures the level resource usage, in this case the solar energy, via a ratio called Capacity of Utilization Factor. The CUF helps to compare plants with same equipment but in different locations. This factor has focus on location and site available energy, rather than operating efficiencies [32]. In the equation below P_W means the total installed capacity (100 MW).

$$CUF = \frac{P_T}{P_W * 8760\left(\frac{h}{yr}\right)} \quad (4.3)$$

The performance parameters shown below in *Table 4.1* relate to a 100 MW PV plant in Ghana (see data in ***Error! Reference source not found.***). In order to these figures into erspective one must compare to solar power CUF from different regions. In Germany for example, the common CUF values for solar PV plants barely reach 9% [33]. This goes out to show that in terms of resource use, this project is sensible indeed.

Table 4.1: Performance parameters for a 100 MW solar PV plant.

Ideal generation (GWh/yr)	204
Real generation (GWh/yr)	154
PR	75.60%
CUF	18.69%

4.2 Risk Assessment

Alongside every business opportunity there is always a margin of uncertainty that increases the chance of a project inheriting risk. This solar development is no different than any other project, but what distinguishes one project from another is the chance of success. The rate of success per se cannot be measured; however one can thoroughly identify and analyze potential threats to the project. This is risk management and its best practice requires one to identify, analyze and mitigate potential risks.

4.2.1 License Approval

The official 'go ahead' for this project depends on the approval of several government bodies and organizations. It is therefore of paramount importance that all requirements are fulfilled prior to submitting an application. The chances of the license being denied must be treated as substantial, regardless the site location. The risk of having the license denied means a financial loss associated with capital invested in legal firms and pre-engineering and feasibility studies. This may also taint the reputation of companies involved.

Also pending approval is the change in land use, even if the land in question is listed as unproductive. This means that site preparation cannot commence until the appropriate land use is granted. The land owner or leaser must have the consent of a competent body stating the land is registered for electricity generation purposes. The risk of the land change application being rejected is less probable; however the consequence will be similar for all rejected license approvals.

The most appropriate mitigating action is to make use of local law firms for legal advice. For the technical aspects, special attention must be paid to industry standards and local requirements. In case of unclear specifications, a third party local firm must be consulted. Should an application be submitted, one must ensure integral compliance with local laws and standards. A lump sum value, as a percentage of total CAPEX, has been allocated for legal & engineering fees.

4.2.2 Electricity Generation

Solar power generation has an intermittent characteristic, due to random cloud patterns. It is simply impossible to predict exactly when the sun will shine on a solar plant, however weather data collected for over 20 years can be used as a reliable source for predicting the site generation potential.

With more focus on the plant, instead of the resource, higher risk is often associated with plant underperformance due to faulty equipment. The consequence of this is often a substantial decrease in revenue, if not a loss. As a rule of thumb, every piece of equipment must have acceptable warranty terms and comply with industry standards. Guarantee and refund claims must be agreed by both developers and suppliers prior entering any formal contract.

It is possible to attenuate this risk by choosing only suppliers offering comprehensive warranty terms on performance and faults. The author has found three companies offering the best warranty terms: Jinko and Trina (China) and Sunpower (USA). [24] Most importantly, the efficiencies from entire plant must be accounted under best practice examples. Therefore the power generation model contains an embedded formula that accounts for solar panel degradation all other typical system losses.

4.2.3 Energy prices

In most deregulated power markets, the electricity selling price is volatile. This is not the case for Ghana. The PPA in place is an assurance that all electricity generated will be sold at a given price and for a given period. This however only helps predicting revenues until the PPA is over. It is therefore necessary to address to unpredictable electricity prices in the next 15 to 25 years. It is not possible to predict these with 100% accuracy, so current data on electricity prices combined with inflation rates will be used instead to extrapolate future price projections. By doing so, future revenues can be projected more accurately thus decreasing the risk of overestimating future cash flow.

4.2.4 Inflation & Currency depreciation

The inflation outlook of Ghana pointed out that the main driver for inflation was the increase in domestic oil and utility prices as a consequence of depreciation of local currency. In broad terms this means the government strategically targets price increase in the energy sector because most costs are taken in USD, such as crude oil and the FiT for solar PV for example [34]. This offers a potential risk for this project, though it regards only the grid fees applicable in Cedis, meaning that high inflation will drive operation costs up.

A potential threat to shrinking future revenues will only exist if transmission fees increase at a higher rate than the one for the depreciation of the Cedi, against the USD. As long as these rates remain equal or lower than currency depreciation, the net cash flow shall remain uncompromised.

The way forward on mitigation steps, for this issue, is to have a clear agreement between all parties involved in signing a long term PPA. There must be written guarantees that; either GRIDCo must not apply uneven increased charges; or the PPA off taker must adjust the selling price of electricity.

4.2.5 Political Risk

Previously mentioned in *Section 1.1*, African countries have had their image stained by political turmoil. It is standard, for a European investor, to assess the possibility of reoccurrence of such events and how to prevent their investments from suffering losses. The interpretation of political and financial climate varies from one investor to another; therefore the current status of Ghana (set as stable) does not diminish the risk level.

One of the mitigation strategies is to ensure the investment is not vulnerable to nationalization or expropriation. This was covered in *Section 2.6*, and is verified that the investments, in Ghana, is protected by local legislation. The other strategy is to secure a comprehensive insurance policy which, if possible, protects the investment fully. An insurance cost as a percentage of total CAPEX shall be taken into account, for costing purposes.

4.2.6 Interference with Crops

This topic has been subject of recent debate worldwide, often associated with socio-environmental concerns. The issue of contention is the competition for land, which makes prices of land increase and become inaccessible to lower income population. As mentioned in *Chapter 1*, there is no further acquisition of land required for developing either project. So this means the developer will not influence in land price fluctuations.

Another concern frequently cited is the shortage of cropping land influenced by changing the land use. Within this context it has been assessed by the landowner that, further expansion of his current crops is not required for future crop demand projections. This means energy generation meets a more sustainable use of land. In summary this projects do not impose any direct or indirect threat to current local land usage.

4.2.7 Natural Hazards

Perhaps the most unforeseeable risk, acts of nature can incur in the complete loss of an investment. Most common events are hurricanes, earthquakes, hail storms, wild fires and mudslides. In Ghana there was no extreme weather conditions or natural disasters found in the research. In this case the insurance policy will not have a clause covering the investment from these events. This clause is usually addressed to as 'Force Majeure'. Should any investment be damaged or destroyed, the insurance will not reimburse the investor for the total amount of losses.

4.3 Costs

4.3.1 Capital Expenditure (CAPEX)

I. *Poly-crystalline modules*

The cost of Polycrystalline module, as per contract price 2014-09-01, range from 52-80 USD/W_p [35] for p-Si modules with average efficiency of 17.3% [36]. The price applicable for the modules only will be 0.70 USD/W_p (shipping excluded). This price is very conservative and compliant with anti-dumping laws, which prevents Chinese manufactures from lowering costs further. In this report, it will be assumed that Ghana does not have such policies in place, meaning that there is a high probability to strike a deal with a supplier, in China, at a price lower than the spot market.

II. *Inverters*

The price of Inverters, also given in the spot market, varies from 0.15-0.25 USD/W_p, however the applicable average value will be 0.202 USD/W_p (volume based average) in order to be more conservative [35]. Typical efficiency of inverters is 97%. Note that spot prices exclude sales, shipping and fees.

A recent benchmarking study, carried out by the Central electricity Regulatory Commission (CERC) in India involving the biggest solar PV manufacturers and developers revealed a number of capital costs for investment purpose. Costs relevant to this report (BOS, civil works, etc.) were taken into account due to economical similarities between India and Ghana (both emerging economies). From that report it was also able to extract costs for shipping & handling (freight, taxes and insurance) of modules and inverters, which must be increased by an additional 8% of their given spot prices [37].

III. *BOS*

The abbreviation BOS stands for Balancing of System, which includes meters, cabling, switch gear, SCADA monitoring system and transformers. Unlike the price of modules and inverters, BOS equipment is not exclusive to solar PV systems and its price was not available in the same spot market. The prices for BOS equipment found range from 0.064 to 0.1 USD/W_p. The value chosen, of 0.1 USD/W_p, goes in tandem with maintaining a conservative safety margin. [37, 38]

IV. *Mounting racks*

The resting support for the PV modules must be structurally sound and able to resist corrosion for, at least 25 years. More over the structure must have a certain degree of adjustment for optimal incline positioning. Typical racks are either made of corrosion resistant galvanized steel or low grade aluminum. The mounts are traditionally fixed to the ground via oversized ground screws. The value gathered in the research is 0.083 USD/W_p. [37, 38]

V. <u>Civil works</u>

The costs for equipment and labor vary from 0.06 to 0.067 USD/W_p. The chosen value is 0.06 USD/W_p [37] because the labor cost in Ghana is expected to be cheaper than India.

The remaining costs will be allocated as a lump sum equivalent to 10% of the total capital costs. This category shall be broken down into five costs: 2.5% allocated to engineering and commissioning contractor; 5% contingency capital for unforeseeable events such as project deviations, equipment replacement and extra fees; 1% pre-operative cost which includes labor and maintenance; 1.5% insurance premium.

4.3.2 Operational Expenditure (OPEX)

The total cost for operating the solar plant (OPEX) is given by the sum of Operation & Maintenance (O&M) cost and grid costs. OPEX is a variable, which is determined by the level of generation of electricity. For this reason OPEX is given in the unit of US Dollar per Megawatt hour (USD/MWh)

The availability of empirical data concerning O&M costs for large scale PV plants was very scarce and, for this reason conservative approach was employed. In the researched articles the O&M cost found varied from 10-25 USD/MWh [39]. These prices were collected from utility solar plats in the US only, therefore it sensible to assume that O&M costs in Ghana would be equivalent to the cheapest one in the USA. This is mainly due to lower labor costs.

An O&M cost estimate of 10 USD/MWh is indeed reasonable for a plant in Ghana, which will include general maintenance, cleaning of the panel and replacement of spares. The final figure will amount to approximately 1.3% of total investment being spent every year throughout the plant life cycle. This highlights the importance of conservative estimate, meaning that underestimation of O&M costs may lead to lower profit or even negative cash flow.

As per Table 4.2, the grid charges proposed by GRIDCo are valid from the beginning of 2014. The exchange rates are based on the market values issued on 2014-09-01 [40].

Table 4.2: Grid fees description. Data [29]

Service Description	GHS/MWh	USD/MWh
Transmission Service Charge	31.9	**8.5**
Reserve Capacity Charge	5.132	**1.367**
Reactive Power Charge	0.419	**0.111**

4.4 Sales Revenue

The accounting for cash in-flow due to selling of electricity shall be executed in the most simplistic way, multiplying the total monthly generation (P_{SYS}) (equation 3.3) by the selling price of electricity (S):

$$R = P_{SYS} \times S \tag{4.4}$$

4.5 Cash Flow Statements

A cash flow Excel sheet (see *APPENDIX B*) shall be used for the entire duration of the project, 25 years, plus year zero. In year zero the net cash flow is negative and equal to the total CAPEX, which means the plant will be under construction and non-operational. The cash flow shall contain the following cash streams: sales revenue on the positive side; CAPEX, OPEX and tax liability on the negative side.

Within the value of Tax Liability (τ)there will be a new equation on its own, given by Asset Depreciation (D_p), Revenue (R) and O&M (C_{op}) Tax Rate = 25%:

$$\tau = \left(R - C_{op} - D_P\right) \times 25\% \tag{4.5}$$

The equation above explains that OPEX and Asset Depreciation (over 10 years) can be deducted from total revenues. This mean the 25% taxation will only be applicable to a fraction of the total revenues. This relates to existing tax law in Ghana, explained in *Section 2.6.*
NOTE: In year 16 an extra deduction can be made, corresponding to the purchase of new inverters, which can also be depreciated over a period of 10 years.

The Net Cash Flow (NCF), from which the NPV shall be extracted, is evaluated from the equation below where: NCF is the net cash flow, R is the total revenue; C_{op} is the annual operating cost; and τ is the corporate tax. Eventually, the net cash flow of the entire project will be equal to the sum of all yearly cash flows.

$$NCF = R - C_{op} - \tau \tag{4.6}$$

4.6 Net Present Value (NPV)

The NPV value, obtained from an embedded formula from Excel, will tell how much profit the project will generate in present value. The function simply requires cash flow input (NCF) from all years of operation of the solar plant, including CAPEX (Ci) as a negative amount. The discount rate (r) will increase exponentially from year 1 to 25 (n). This also requires the input of an acceptable discount rate, which will be discussed in the next section.

$$NPV = \sum_1^n \left(\frac{NCF}{(1+r)^n}\right) - C_i \tag{4.7}$$

4.7 IRR (Internal Rate of Return)

By definition IRR is the discount rate that brings the NPV to zero, meaning a break even. In order to be viable, a project requires (in theory) an IRR at least equal to the Minimum Acceptable Rate of Return (MARR). Alternatively the MARR is based on the industry and country specific discount rate, the WACC. The calculation of the IRR is done iteratively via Excel, where the IRR is the rate that brings the project's NPV to zero.

4.8 WACC (Weighed Average Cost of Capital)

The WACC is a discount rate employed by real companies in business investments, usually country and industry dependent (e.g. solar PV in Ghana). In a sense the WACC is a tailor made discount rate that covers financial risk and specific market climate. In fact an entire dissertation could be made around this subject; however this report shall explain only relevant theory.For the derivation of the WACC, a method called CAPM regards the WACC in two important pieces, cost of equity and cost of debt. In a nut shell, this method calculates the risk based on country specific interest rates or long term bond returns. More specifically, the derivation of the WACC also takes into account the maturity of similar investments (in this case solar PV).

In the paper "WACC THE DOG: THE EFFECT OF FINANCING COSTS ON THE LEVELIZED COST OF SOLAR PV POWER", the author explains the significant influence of the WACC in the viability of Solar PV projects. Also the author calculates the WACC of every country in globe along with minimum FiT levels required to make a project feasible. As previously mentioned, this project is assumed to be financed via 100% equity, and then the debt share of the WACC will be regarded as a safety margin in the sensitivity analysis. [41]

For the purpose of this report only, the CAPEX will be assumed to be of 100% equity. This means that no loans will be taken during the project's life cycle. At this stage (feasibility study), the purpose of cash flow analysis is to ensure project is profitable. Therefore the WACC value taken for this project (13.3%) will be purely based on equity. If this was done with an equal ratio of equity and debt (e.g. 50:50) the WACC values would be considerably higher (19.4%), since rates are driven by market risk and cost of borrowing. [41] This means a project IRR much greater than the highest possible WACC will reduce the financial risk.

4.9 Payback and B/C ratio

The calculation of PBP describes (in present value terms) how long it takes the project to recover its initial investment. This is possible by solving the equation below by the variable *n.* Lastly, the B/C ratio is simply the ration between NPV and CAPEX. These parameters give investors an idea of profit margin of an investment in present terms.

$$\frac{NCF}{(1+r)^n} = C_i \tag{4.8}$$

5

RESULTS AND DISCUSSION

This chapter shows the results of the financial calculation. First a general discussion on the base case results is followed by a brief analysis on NPV, IRR, B/C ratio and payback time. The dynamic model is presented and lastly a sensitivity analysis regarding price, discount rate, inflation and exchange rate is discussed.

5.1 Total Costs

First, the results are shown for the total capital and operating costs for a solar plant size equivalent to 100 MW of installed capacity. The total values, given in millions of USD (MUSD), will not be affected by the sensitivity analysis; therefore they shall be used in all scenarios. As per *Table 5.1*, the specific installed price of 1.34 USD/W_{dc} translates into a total investment 134.5 MUSD for 100 MW of installed capacity.

Table 5.1: Capital investment cost sheet.

	Capital Expenditure Breakdown		
Category	**Description**	**USD/Wdc**	**Total Capacity Installed (10^6 W)**
			100
Hard Costs	**PV Panel**		
	Module	0.75	75000000
	Power Electronics		
	Inverters	0.218	21800000
	BOS	0.1	10000000
Soft Costs	**Pre-Installation**		
	Mounting racks	0.083	8300000
	Civil works	0.06	6000000
	EC contract 2.5%	0.0336	3363889
	Contingency 5%	0.0673	6727778
	Pre-operative cost 1.5%	0.0202	2018333
	Financial cost 1%	0.0135	1345556
	TOTAL CAPEX	1.3456	$134,555,556

In the same context, it is interesting to analyze the contribution of each component towards the total investment cost. The module alone (as expected) represents over 55.74% of CAPEX, whilst the 'Soft Costs' amounted to roughly 20% of total investment. A clear view of cost distribution is shown in *Figure 5.1*.

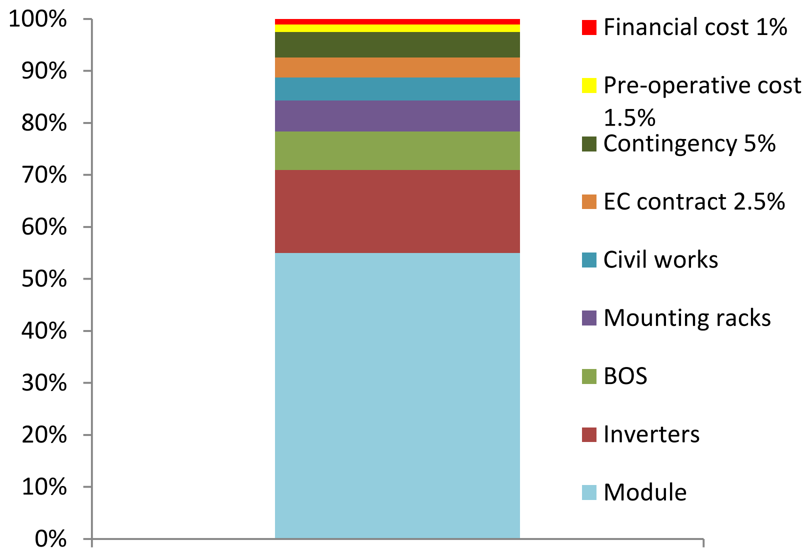


Figure 5.1: CAPEX contribution per type of expense.

The next data set is for the operating costs, which include maintenance, insurance and transmission costs. Unlike CAPEX, OPEX is a recurring cost for each year of operation of the solar plant; therefore all total values shall be expressed in MUSD/yr. It is sensible to point out that the total operating cost in *Table 5.2*, similarly to the CAPEX, increases linearly with the size of installed capacity. The total OPEX for the first year of operation of the solar plant is 45,935 USD/MW.

Table 5.2: Operation & Maintenance cost sheet.

Operation Cost Breakdown			
	Description	**USD/ MWh**	**100 MW**
O&M Costs	*Un/scheduled maintenance (1.3% CAPEX)*	10	1,614,667
	Insurance premium (1% CAPEX)	N/A	1,345,556
Grid Costs	*Transmission charge*	8.50	1,391,363
	Reserve power charge	1.367	223,764
	Reactive power charge	0.111	18,170
TOTAL OpEx		**USD/yr**	$4,593,518

The grid charges altogether correspond to approximately to 70% of total OPEX. This requires extra attention because grid charges are given in GHS and therefore are subject to inflation adjustments. This means that either plant owner or GRIDCo will require compensation to ensure net change in revenues will remain zero.

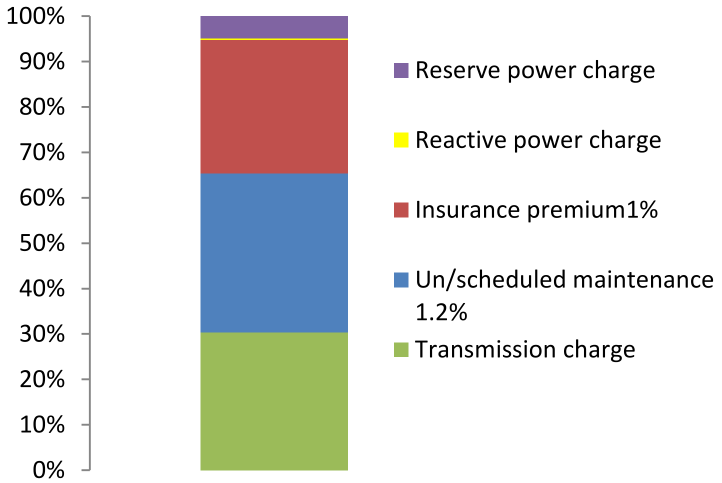


Figure 5.2: OPEX contribution per type of expense.

5.2 Cash Flow

The cash flow series requires graphical representation into two different ways in order to become fully understood. First the year snapshot graph year to describe different cash streams in detail. Second the life cycle net cash flow will serve as a tool for predicting fluctuations in future income, showing only the NFC for every year of operation. In order to maintain the report clear and concise, the size of solar PV plant used will be 100 MW, as previously established. The tables used for constructing the graphs will be accessible in the APPENDIX A. As shown in *Figure 5.3* the 'Tax' stream does not represent 25% of Revenue. That is because of OPEX and depreciation allowances.
NOTE: the cash flow streams will begin from start of operations, which means the year zero has a negative flow.

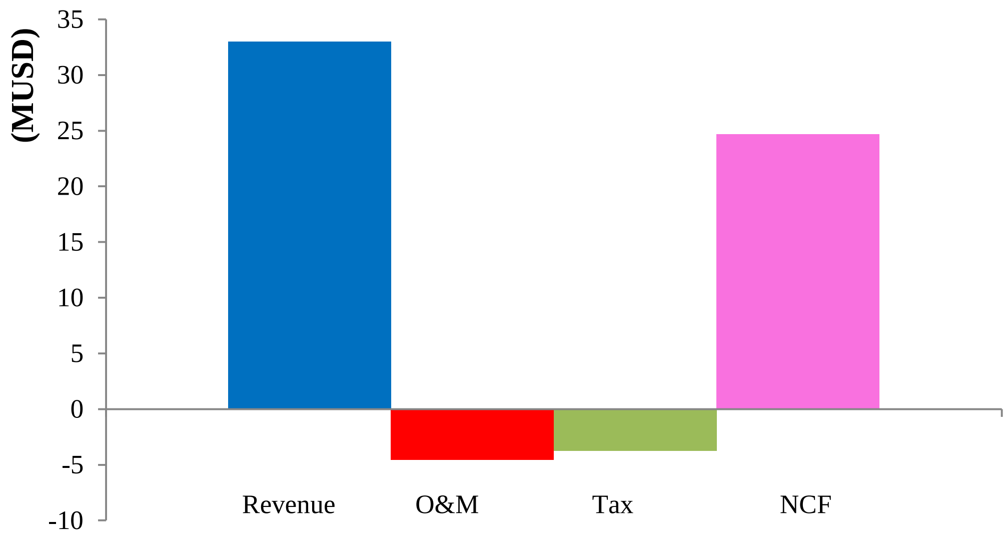


Figure 5.3: Cash flow snapshot of 100 MW plant during first year of operation.

The plant complete NFC outlook, shown in *Figure 5.4*, projects a smooth decline due to decreasing performance. The explanation for the generation decrease is the linear cell degradation described in *Section 3.4*. The sudden drop in year 15 has to do with the replacement of inverters. And the sudden drop in year 11 represents the end of Asset Depreciation (10 years).

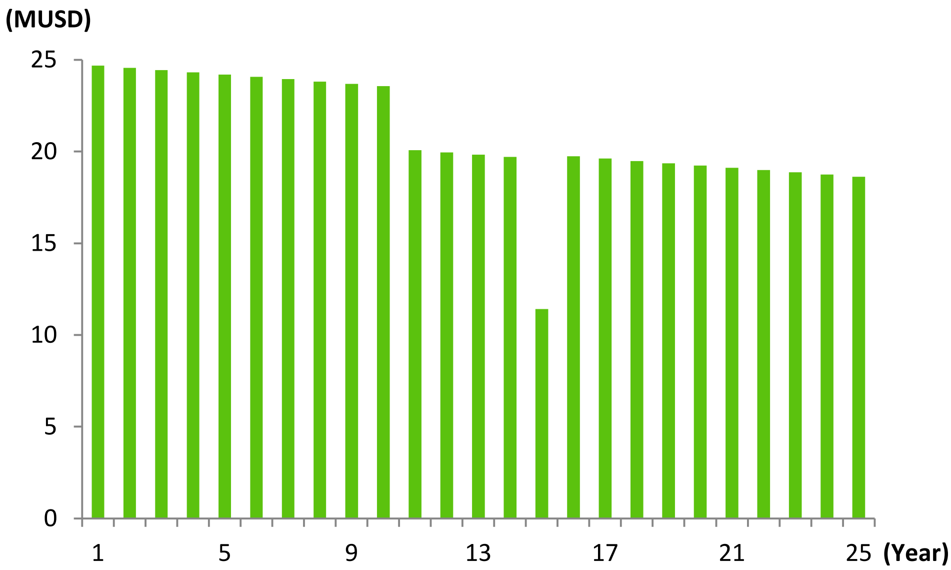


Figure 5.4: Cash flow from beginning of operation.

Finally the key feasibility indicators for the base scenario, shown in *Table 5.3* reveals the long term Levelized Cost of Energy of 0.135USD/kWh. In the meantime the plant will be selling the energy for 0.202USD/kWh. Even though the specific values seem promising, the project must fulfil the MARR requirement. Most importantly the IRR calculated for the base scenario is 16.94%.

Table 5.3: Presentation of key feasibility indicators using base scenario.

	Base Scenario 100 (MW)
LCOE (USD/kWh)	0.135
CAPEX (USD)	134,555,556
IRR	16.94%

5.3 Sensitivity Analysis

5.3.1 Base Case Discount Rate Analysis

The base scenario has to satisfy a minimum return rate of 13.3%, as per WACC description in *Section 4.8*. In order to explore risk scenarios, where higher interest rates carry a potential threat to NPV, a rate of 19.4% will be considered, as per highest expect WACC. Also, a medium risk scenario will be implemented at a WACC of 16.4% (approximated mean value between highest and lowest rates). The range provided between 13.3%-19.4% shall be sufficient to cover the viewpoints of different stakeholders.

The analysis shown in *Table 5.4* tells us the NPV decreases exponentially as the discount rate is increased to 16.4% and 19.4% respectively. As a confirmation, B/C ratio decreases as well. In case of 13.3% discount rate, project will pay back only after 15 years, whereas in the other cases the project will not achieve a payback. In summary the sensitivity analysis of the base case in respect to IRR tells us the project is only feasible at the lowest expected WACC, therefore vulnerable to higher rates.

Table 5.4: Variable discount rate effect on NPV, B/C and PBP.

WACC	Plant Size 100 (MW)		
	13.3%	16.4%	19.4%
LCOE (USD/kWh)	0.135		
CAPEX	134,555,556		
ERR	16.94%		
B/C ratio	1.22	1.03	0.89
PBP (years)	15.4	Project will not payback!	
NPV (USD)	30,024,890	3,769,268	-15,116,314

5.3.2 PV Module Cost

According to most experts in Solar PV, the price of modules could drop between 10-20% from 2014-2015 based on efficiency improvement [42]. For this reason a range of scenarios, where PV module supply contract is only achieved in 2015, will assume the panel prices will be 10-20% cheaper than current prices.

The effect of lower PV cost can be seen on *Table 5.5* shown below. It is important to observe that the project's IRR shifts considerably and the LCOE decreases. Only in case of a hypothetical scenario, where PV cost is 20%, the project will be able to clear the risk zone (*Section 4.8*). Even if this is the case, the project NPV should be considered as a break-even because the margin of profit will be insignificant over a 25 year period (only 1.1 MUSD). A similar recent study carried out in Nigeria shows the LCOE prices range from 0.103 – 0.159 $/kWh [22].

Table 5.5: Effect of the PV cost on LCOE and IRR.

	Price (USD/kw)	LCOE (USD/kWh)	IRR
PV Panel normal price	750	0.135	16.94%
PV Panel 10% cheaper	675	0.131	18.20%
PV Panel 20% cheaper	600	0.126	19.60%

The base case is limited only to fixed incomes and no allowances for cost and revenue fluctuations in relation to inflation or currency depreciation. A dynamic model, in which cost and revenues shift in relation to inflation, ensures a robustness set of results for addressing to strategic pricing agreements. Therefore a dynamic model shall be used for the next steps in the sensitivity analysis.

5.3.3 Feed-in-Tariff

The duration of the PPA has a fixed period of 10 years, however this report has shown that negotiation of PPA period is possible depending on the scale/scope of developments. Therefore a sensitivity analysis will include PPA with the basic 10 years and other 3 cases with 15, 20, and 25 years. These are all based on real and recent cases taken place in Ghana, where large scale PV plant owner were given 'custom made' PPA's different the 10 years [16, 43].

5.3.4 Inflation & feasibility conditions

This section is most likely to influence on the price of electricity because the PPA is assured to expire after a pre-established period. The goal of this analysis is to observe how the profitability of the project will be affected in function of future electricity sales to the grid. The strategy used, for predicting future electricity prices, will be based on extrapolation of historical and projected inflation.

It seems, in Ghana, the main driver for inflation is currency depreciation and increased energy prices. The current inflation stands just shy of 14%, at 5 notches above the predicted 9%. This is mainly due to an increase in domestic oil retail price (22-25%) and increase in utility charges (water 54% and electricity 74%). The projection for 2016 is 8%, but no further outlook is given [34]. Another report also assumes inflation shall drop to 4.21% within the next 15 years. Most importantly, this outlook also includes currency exchange value against the dollar within the same time horizon (15 years) [44].

Table 5.6 shown below was created via introducing random numbers between predicted inflation and currency values for the next 26 years (plant lifecycle including year zero). This table will be used to predict future values of OPEX and FiT. (The complete table is shown in *APPENDIX C*).

Table 5.6: Inflation series example.

Year	Currency	Currency change	Inflation	FiT	Fees
2014	3.75	1	14.5	0.2	9.98
2015	3.3	1.136	13.11	0.2	9.98
:	:	:	:	:	:
:	:	:	:	:	:
2024	2.8	1.339	4.06	0.2	9.98
2025	2.76	1.359	4.09	0.2	9.98
2026	2.72	1.379	4.02	0.211	10.406
2027	2.74	1.369	4.17	0.219	10.841
:	:	:	:	:	:
:	:	:	:	:	:

The interaction of inflation and currency exchange will play an important role in the Opex levels, as shown in *Figure 5.5*. Prices for grid fees are set in Cedis, which means it will be volatile due to currency fluctuations. With the currency and inflation series, prices for both O&M will be allowed to escalate from the year after termination of PPA. For this sensitivity analysis, the following feasibility conditions apply:

a. PPA-10 – The FiT isfixed for the first 10 year of generation. The OPEX will adjust to inflation and currency exchange every year, starting from accumulated inflation in year 10. The FiT will be readjusted by current inflation and currency depreciation, starting from year 10 values only.

b. PPA-10 (Enhanced) – Similar to regular PPA-10 with one difference; FiT values are readjust in the same manner as OPEX values.

The same methodology shall be employed for creating scenarios with horizons of 15, 20 and 25 years. Different terms of PPA will have its own cash flow series. They will be called PPA-10, PPA-15, PPA-20 and PPA-25.

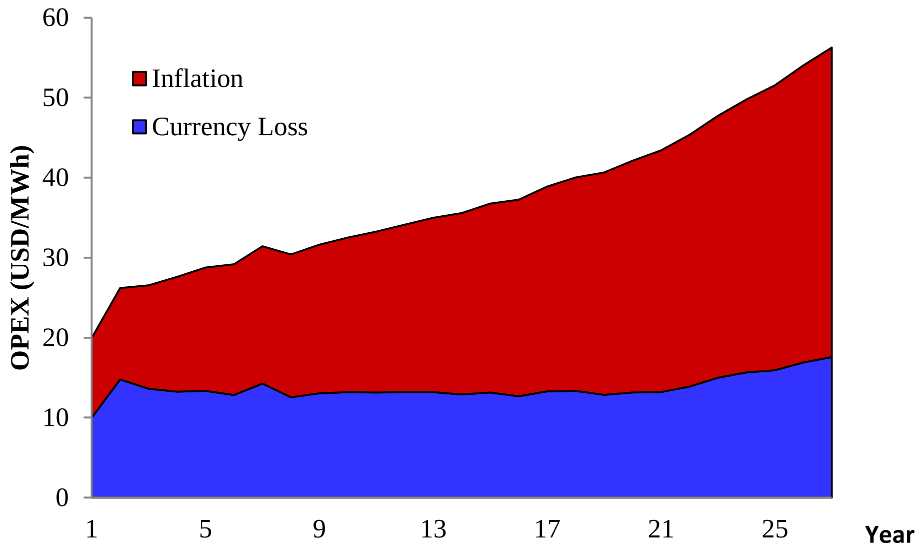


Figure 5.5: OPEX escalation due to inflation and currency depreciation.

5.3.5 Discussion of the Sensitivity Analysis

In the discussion of the sensitivity analysis, the effects of inflation and currency will be analyzed, first in respect to the WACC. Then it will be followed by a discussion about the influence of cost fluctuation on LCOE and comparison between different project's IRR. Lastly, a final discussion on modeling and data limitations shall set up for a smooth transition for the conclusions.

First shown in *Figure 5.6* , the WACC of 13.3% was taken in comparison with the project's IRR from all scenarios. The colored bars represent the same base case values and are used mainly to illustrate the order of appearance of each scenario in the graph. The main features of the graphs are the deviation bars, which show how much the NPV from projects vary in respect to accumulated inflation (upper values) to current inflation (lowest values).

Still in *Figure 5.6* shown below it is interesting to observe that a shorter, but renegotiable, PPA such as 10 years is more beneficial to longer agreements. The upper values (accumulated) of all cases satisfy the WACC. On the lower values, PPA-25 (accumulated) fails to achieve base case limit but still make a discreet positive NPV.

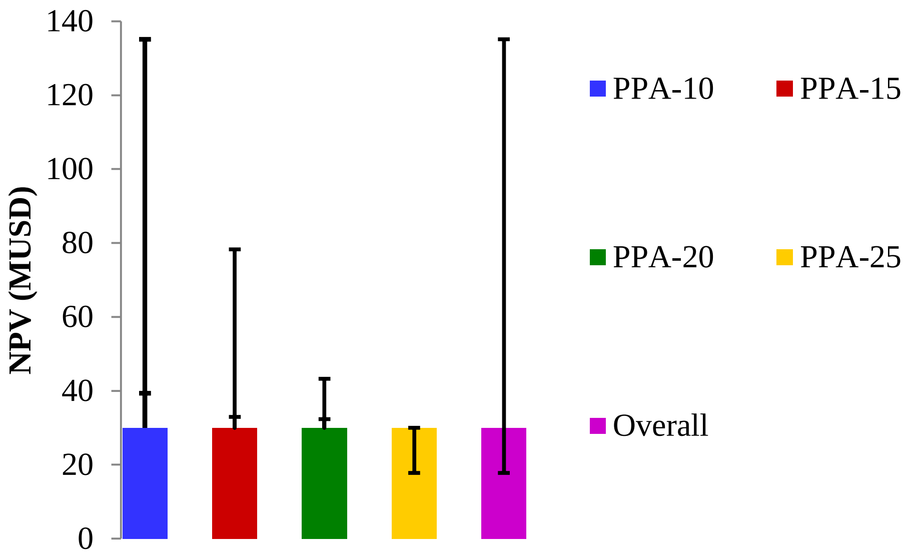


Figure 5.6: NPV deviation from base case, WACC at 13.3%.

With the discount rate at 16.4%, as shown in *Figure 5.7*, all 'accumulated' scenarios' NPV levels are halved in comparison to previous rate. The sharp decline serves also the lower values and delivers the first failing scenario (PPA-25 Accumulated). Also the NPV of all lower values are very discreet or close to a break-even. This is a sign the project starts showing its vulnerabilities.

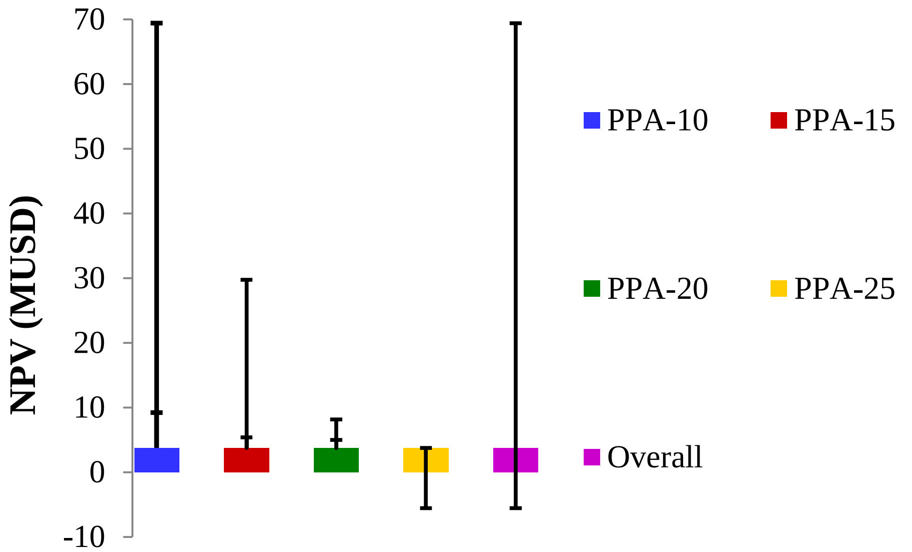


Figure 5.7: NPV deviation from base case, WACC at 16.4%.

*Figure 5.8*is the ultimate test for evaluating the feasibility of all scenarios under the constraints imposed in this report. All cases, but PPA-10 (Accumulated), failed to deliver a positive NPV under a WACC of 19.4%. Even though this WACC value represents a 50:50 capital strategy, it shows that only one case is feasible.

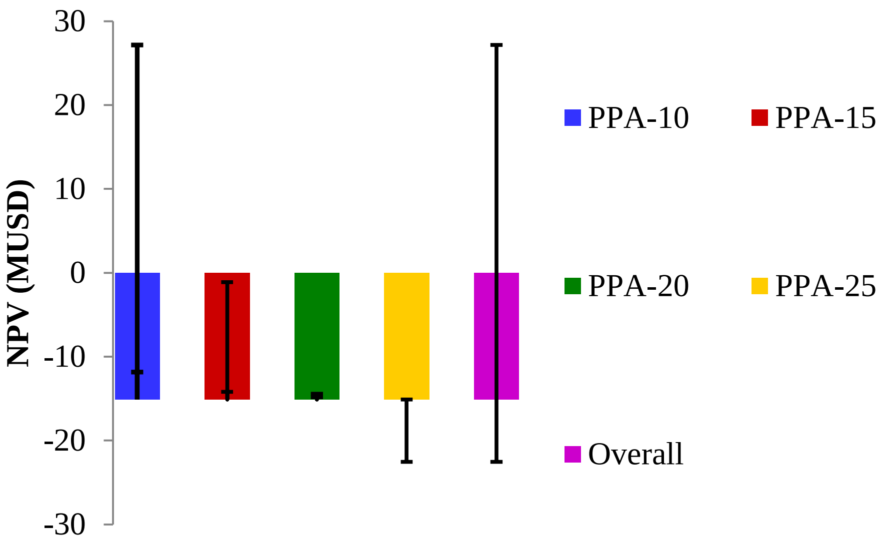


Figure 5.8: NPV deviation from base case, WACC at 19.4%.

In *Figure 5.9* the LCOE analysis shows the highest generation costs relate to accumulated inflation and currency series. This is very reasonable since cost increase will lead to higher LCOE. Note the change is considerable (approximately 100% change overall).

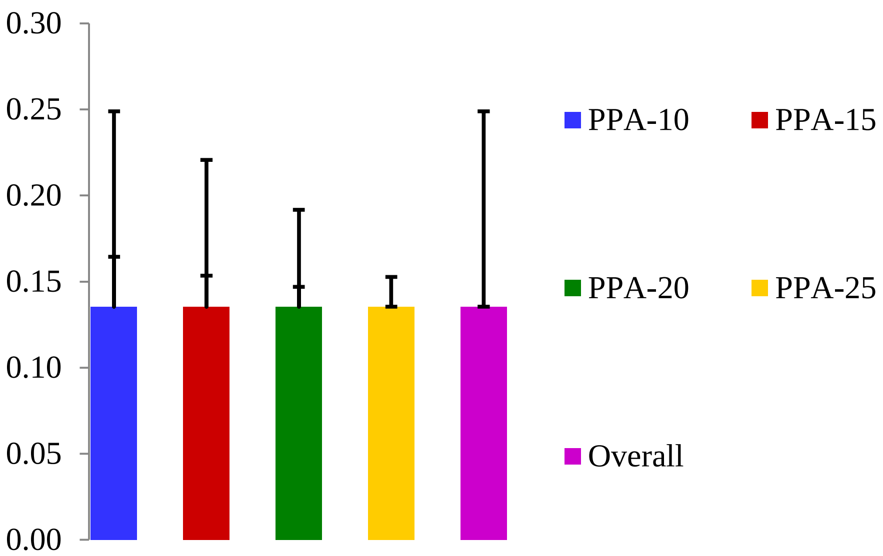


Figure 5.9: LCOE deviation from base case.

In essence there is a trade-off between low LCOE and NPV which must be addressed to carefully, without leaving room for misinterpretation. In this model the highest LCOE scenario is the one providing the highest returns. This is due to the fact that inflation rates only drive a fraction of variable costs (grid fees) and the full value of revenue. Normally the GENCO's aim at reducing the LCOE as low as possible in order to compete against other generation types, but this is not the case here since it is assumed that all electricity produced is sold regardless the price and type of generation.

The ultimate goal of this sensitivity analysis is to establish a fail/success criterion for scenarios modelled. This is clearly shown in *Figure 5.10*, which portraits the IRR for all scenarios analyzed.

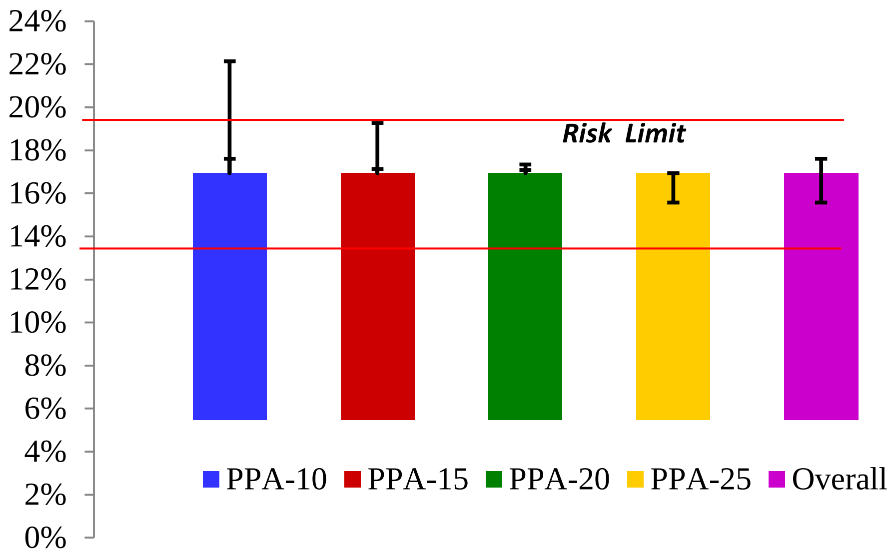


Figure 5.10: Project's IRR deviation from base case.

The figure above tells us that, if inflation and electricity prices are accurately predicted, this project should seek contract terms allowing inflation readjustments 10 years. Within this context, the economic model is not fail proof so extra attention to its limitations must be paid; the inflation series contains only predictions based on short-term economic data, however the compensation mechanism shall remain unchanged for different data; the capital investment is assumed as 100% equity and does not include loan repayment allowance.

If PPA-10 (accumulated) is the best performing scenario, then a potential agreement should allow for both GRIDCo and GENCO to increase charges by the inflation accumulated through initial 10 years. Therefore both parties would benefit from increased returns.

6

CONCLUSION AND RECCOMENDATION

In this chapter the conclusions are drawn as well as suggestions and recommendation for further work.

6.1 Conclusions

The sole purpose of this report is to evaluate the prospect of developing a large scale solar PV plant in Ghana. It is evident that the project is viable under the boundary conditions created in the financial model; however this may not completely translate into an appealing business opportunity for investors. This is because different project stakeholders have distinct goals, and all of them must be fulfilled.

The large scarcity of solar PV developments in Ghana is attributed to a number of factors, such as economic instability, high financing costs lack of local knowledge from foreigner investors. This proved to be changing dramatically, since the government created a legal platform for developing solar PV plants. The proof of this is the current reports of 2 GW of solar developments that are pending approval by the Ghanaian government, information that came to light towards the end of this report [45]. This sudden rush for solar PV in Ghana would not have been possible without the implementation of a FiT and the political will to bring the new Electricity Act forward.

In relation to the problem analysis in *Section 1.4*, this report addresses to the following:

- Technical analysis of solar resource and solar PV generation.
- Review of policy framework and regulations for solar development in Ghana.
- Economic analysis of the solar PV plant.

In the technical scope the level of resource encountered in the chosen location was deemed satisfactory, given that levels of solar radiation are higher than any other location in Ghana. This was however a mere coincidence with the fact that the land available for this project happened to be in the same region. Also, the total generation profile was calculated from average values within best practice benchmark figures for PV system losses. Finally the grid operator requirements were specified solely for information purposes, but it still remains unclear how far or close the grid connection options are from the chosen location.

From reviewing the laws and regulations in Ghana it was possible the describe exactly how the FiT mechanism works, however it was unclear how the agreement would be amended after the PPA period is over. The business establishment incentives seem to benefit the model of this project because the law provides extra guarantees for foreign investments. Lastly, the tax law in Ghana was very clear and simple in regards to income taxes and corporate allowances.

The economic analysis targeted risk assessment and cost estimation and profitability indicators, such as NPV, IRR, B/C ratio and some discussion in payback periods. First the calculations were carried out on the base-case and then on other scenarios in the sensitivity analysis.

In the risk assessment it was possible conclude that risks would be inherited within the project. Also every risk can be mitigated, as long as it properly identified and addressed to in the model. This was the case of inflation and currency risk which lead to the creation of a dynamic model.

Unlike others, this report covers a significant portion of risk associated with inflation and currency uncertainties. All reports and articles encountered in the literature research described a one-dimensional approach to economic analysis and failed to include this uncertainty. The security of investment is paramount to this project, which is why a dynamic model was created with conservative inflation and currency projections. This added not only value to the project, but another dimension in the economic analysis.

During the execution of this report it was deemed, by Statkraft ASA, that the most important measure of fail and success of a project is the WACC. The WACC was found to be 13.3% for 100% capital investments and 19,4% for 50:50 investments. With the addition of a 16.4% average WACC, the project was measured for three different discount rates. For the base-case, it was found that the project would only clear the 19.4% IRR via a drop in PV module price by 20%. Yet the project would technically break-even, since the profit margin was insignificant.

In the sensitivity analysis the only scenario that achieved an acceptable IRR was PPA-10 (accumulated), at 22.15%. The NPV was 135.1 MUSD, with a B/C ration of 2 and an estimated payback of 7 years. From this, the following conclusions were drawn:

- The dynamic model helps to understand how pricing strategies and/or agreement can mitigate on the uncertainty of cost projection due to inflation and currency depreciation.
- The sensitivity analysis proves that, if inflation and electricity prices are accurately predicted, this project should seek contract terms allowing inflation readjustments.
- Due to limitations of the model and inflation data, the project still carries considerable risk of incurring financial loss.

6.2 Recommendations

The work scope has evolved substantially during the course of execution of this thesis, which is why the following recommendations apply:

- A complete derivation of the WACC shall decrease the IRR requirements, since the values used in this report date to 2011 (the only report of its kind available).
- The use of a computer modeling software for improved generation profile may improve the revenue data, but not the entire economic analysis.
- The inclusion of different equity and debit shares in order to make full use of WACC range.

This report has proven to be very challenging from the beginning. The amount of local (Ghana) and industry specific information I have gathered is invaluable, and I hope it will come to the aid of those interested in this discipline.

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APPENDIX A

Table A.1: Complete table of plant generation in 1st year of operation.

B22 | =SUM(B21:M21)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**100 MW Plant - Electricity Generation - Year 1**												
2	**Site Potential**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
3	*GHI (kWh/m2/day)*	6.5	6.4	6.01	5.55	5.56	5.07	4.64	4.2	4.57	5.59	6.25	6.62
4	*Air temperature (℃)*	29	30	32	34	32	29	28	27	27	29	30	30
5	*Total available days*	31	28	31	30	31	30	31	31	30	31	30	31
6	**PV Panel**												
7	*Module area*	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085	1.94085
8	*Module efficiency*	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%	16.23%
9	*No. Modules*	317500	317500	317500	317500	317500	317500	317500	317500	317500	317500	317500	317500
10	*Cell degradation loss*	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%	97.50%
11	*Cell temperature loss*	98.40%	98.00%	97.20%	96.40%	97.20%	98.40%	98.80%	99.20%	99.20%	98.40%	98.00%	98.00%
12	**Losses**												
13	*Inverter efficiency*	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%	96.00%
14	*Soiling*	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%	95.00%
15	*AC wiring*	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%
16	*DC wiring*	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%
17	*Mismatch*	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%	98.00%
18	*System availability*	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%
19	*Connectors*	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%	99.00%
20	*Total losses*	80.71%	80.38%	79.73%	79.07%	79.73%	80.71%	81.04%	81.37%	81.37%	80.71%	80.38%	80.38%
21	*Monthly Output AC (GWh)*	16.266	14.407	14.856	13.167	13.744	12.278	11.658	10.596	11.157	13.988	15.074	16.499
22	**Total Output AC (GWh)**	163.690											

Table A.2: Total lifecycle operation of the 100 MW plant.

G32 | =SUM(D25:D34,F25:F34,H25:H29)

	B	C	D	E	F	G	H
24							
25		**Year 1**	163.690	**Year 11**	155.505	**Year 21**	147.321
26		**Year 2**	162.871	**Year 12**	154.687	**Year 22**	146.502
27		**Year 3**	162.053	**Year 13**	153.868	**Year 23**	145.684
28		**Year 4**	161.234	**Year 14**	153.050	**Year 24**	144.865
29		**Year 5**	160.416	**Year 15**	152.231	**Year 25**	144.047
30		**Year 6**	159.597	**Year 16**	151.413	**Total Life Cycle Generation (GWh)**	
31		**Year 7**	158.779	**Year 17**	150.595		
32		**Year 8**	157.961	**Year 18**	149.776	3846.708	
33		**Year 9**	157.142	**Year 19**	148.958		
34		**Year 10**	156.324	**Year 20**	148.139		

APPENDIX B

Table B.1: Complete NFC table for the 'base case'.

I5 | f_x =-B5+E5-F5-G5

	A	B	C	D	E	F	G	H	I
2–3	Year	Capital Investment (USD)	Power generation	Price of electricity	Total revenue (USD/yr)	Operating cost (USD/yr)	Tax Liability (USD/yr)	Depreciation (USD/yr)	Cash Flow (USD/yr)
4	0	134,555,556	0	0	0	0	0	0	-134,555,556
5	1	0	163.690	0.202	33,021,454	4,593,518	3,743,095	13,455,556	24,684,841
6	2	0	162.871	0.202	32,856,347	4,593,518	3,701,818	13,455,556	24,561,011
7	3	0	162.053	0.202	32,691,240	4,593,518	3,660,542	13,455,556	24,437,180
8	4	0	161.234	0.202	32,526,133	4,593,518	3,619,265	13,455,556	24,313,350
9	5	0	160.416	0.202	32,361,025	4,593,518	3,577,988	13,455,556	24,189,519
10	6	0	159.597	0.202	32,195,918	4,593,518	3,536,711	13,455,556	24,065,689
11	7	0	158.779	0.202	32,030,811	4,593,518	3,495,434	13,455,556	23,941,858
12	8	0	157.961	0.202	31,865,703	4,593,518	3,454,157	13,455,556	23,818,028
13	9	0	157.142	0.202	31,700,596	4,593,518	3,412,881	13,455,556	23,694,197
14	10	0	156.324	0.202	31,535,489	4,593,518	3,371,604	13,455,556	23,570,367
15	11	0	155.505	0.202	31,370,382	4,593,518	6,694,216	0	20,082,648
16	12	0	154.687	0.202	31,205,274	4,593,518	6,652,939	0	19,958,817
17	13	0	153.868	0.202	31,040,167	4,593,518	6,611,662	0	19,834,987
18	14	0	153.050	0.202	30,875,060	4,593,518	6,570,385	0	19,711,156
19	15	10,900,000	152.231	0.202	30,709,953	4,593,518	3,804,109	0	11,412,326
20	16	0	151.413	0.202	30,544,845	4,593,518	6,215,332	1,090,000	19,735,995
21	17	0	150.595	0.202	30,379,738	4,593,518	6,174,055	1,090,000	19,612,165
22	18	0	149.776	0.202	30,214,631	4,593,518	6,132,778	1,090,000	19,488,334
23	19	0	148.958	0.202	30,049,523	4,593,518	6,091,501	1,090,000	19,364,504
24	20	0	148.139	0.202	29,884,416	4,593,518	6,050,224	1,090,000	19,240,673
25	21	0	147.321	0.202	29,719,309	4,593,518	6,008,948	1,090,000	19,116,843
26	22	0	146.502	0.202	29,554,202	4,593,518	5,967,671	1,090,000	18,993,013
27	23	0	145.684	0.202	29,389,094	4,593,518	5,926,394	1,090,000	18,869,182
28	24	0	144.865	0.202	29,223,987	4,593,518	5,885,117	1,090,000	18,745,352
29	25	0	144.047	0.202	29,058,880	4,593,518	5,843,840	1,090,000	18,621,521

Table B.2: Key financial indicators calculation sheet for the ‘base case’.

O10 | =NPV(O5, I4:I29)*(1+O5)

	M	N	O	P	Q	R	S	T
4	Tax		Interest		Interest		Interest	
5	25.00%		13.3%		16.4%		19.4%	
6	IRR		Loan interest					
7	16.94%		1.50%					
8		PBP	15.4		#NUM!		#NUM!	
9		IRR			16.94%			
10		NPV	30,024,890		3,769,268		-15,116,314	
11		BC	1.22		1.03		0.89	
12		Tot cost	521,051,734					
13		LCOE	0.135					

APPENDIX C

Table C.1: Inflation and currency vs. FiT and grid fees for scenario PPA-10.

Year	Currency (GHS/USD)	Currency change	Inflation (%)	FiT (USD/kWh)	Grid fees (USD/MWh)	FiT Accum. (USD/kWh)	Fees Accum. (USD/kWh)
2014	3.75	1	14.5	0.202	9.98		9.98
2015	3.3	1.136	13.11	0.202	9.98		11.42
2016	3.15	1.048	11	0.202	9.98		14.68
2017	3.09	1.019	7.5	0.202	9.98		17.08
2018	3.01	1.027	6	0.202	9.98		18.71
2019	3.05	0.987	5	0.202	9.98		20.36
2020	2.78	1.097	4.01	0.202	9.98		21.10
2021	2.88	0.965	4.06	0.202	9.98		24.08
2022	2.87	1.003	4.04	0.202	9.98		24.19
2023	2.83	1.014	4.11	0.202	9.98		25.25
2024	2.8	1.011	4.06	0.202	9.98		26.66
2025	2.76	1.014	4.09	0.202	9.98		28.04
2026	2.72	1.015	4.02	0.214	10.556	0.599	29.61
2027	2.74	0.993	4.17	0.226	11.160	0.634	31.25
2028	2.71	1.011	4.05	0.234	11.561	0.656	32.32
2029	2.78	0.975	4.18	0.247	12.182	0.692	34.00
2030	2.72	1.022	4.21	0.251	12.394	0.704	34.53
2031	2.65	1.026	4.18	0.268	13.224	0.751	36.78
2032	2.68	0.989	4.22	0.287	14.165	0.804	39.33
2033	2.65	1.011	4.3	0.296	14.624	0.830	40.53
2034	2.61	1.015	4.16	0.313	15.454	0.878	42.75
2035	2.58	1.012	4.05	0.331	16.372	0.930	45.21
2036	2.52	1.024	4.2	0.349	17.261	0.980	47.59
2037	2.49	1.012	4.4	0.373	18.447	1.048	50.77
2038	2.51	0.992	4.25	0.395	19.528	1.109	53.64
2039	2.5	1.004	4.21	0.410	20.233	1.149	55.47

Table C.2: Cash streams for scenario PPA-10.

Year	Capital Investment (USD)	Power generation (GWh/yr)	Price of electricity (USD/kWh)	Total revenue (USD/yr)	Operating cost (USD/yr)	Tax Liability (USD/yr)	Depreciation (USD/yr)	Cash Flow (USD/yr)
0	134,555,556	0	0	0	0	0	0	-134,555,556
1	0	163.690	0.202	33,021,454	5,363,969	3,550,482	13,455,556	24,107,003
2	0	162.871	0.202	32,856,347	5,741,460	3,414,833	13,455,556	23,700,054
3	0	162.053	0.202	32,691,240	5,992,792	3,310,723	13,455,556	23,387,725
4	0	161.234	0.202	32,526,133	6,243,516	3,206,765	13,455,556	23,075,852
5	0	160.416	0.202	32,361,025	6,345,198	3,140,068	13,455,556	22,875,760
6	0	159.597	0.202	32,195,918	6,803,167	2,984,299	13,455,556	22,408,452
7	0	158.779	0.202	32,030,811	6,800,542	2,943,678	13,455,556	22,286,590
8	0	157.961	0.202	31,865,703	6,948,946	2,865,301	13,455,556	22,051,457
9	0	157.142	0.202	31,700,596	7,149,757	2,773,821	13,455,556	21,777,019
10	0	156.324	0.202	31,535,489	7,343,612	2,684,080	13,455,556	21,507,796
11	0	155.505	0.599	93,217,231	7,564,784	21,413,112	0	64,239,335
12	0	154.687	0.634	98,031,090	7,794,744	22,559,087	0	67,677,260
13	0	153.868	0.656	101,012,875	7,933,132	23,269,936	0	69,809,807
14	0	153.050	0.692	105,875,819	8,163,988	24,427,958	0	73,283,873
15	10,900,000	152.231	0.704	107,136,252	8,216,737	22,004,879	0	66,014,636
16	0	151.413	0.751	113,697,509	8,528,770	26,019,685	1,090,000	79,149,054
17	0	150.595	0.804	121,133,401	8,882,591	27,790,202	1,090,000	84,460,607
18	0	149.776	0.830	124,375,094	9,030,253	28,563,710	1,090,000	86,781,131
19	0	148.958	0.878	130,716,588	9,327,949	30,074,660	1,090,000	91,313,980
20	0	148.139	0.930	137,719,822	9,657,494	31,743,082	1,090,000	96,319,246
21	0	147.321	0.980	144,399,671	9,970,815	33,334,714	1,090,000	101,094,142
22	0	146.502	1.048	153,461,835	10,397,640	35,493,549	1,090,000	107,570,646
23	0	145.684	1.109	161,551,375	10,774,535	37,421,710	1,090,000	113,355,130
24	0	144.865	1.149	166,437,340	10,996,330	38,587,752	1,090,000	116,853,257
25	0	144.047	1.204	173,461,744	11,320,646	40,262,774	1,090,000	121,878,323