Master Plan for Renewable Energy based Electricity Generation in The Gambia

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Frankfurt am Main, March 2010 Enrique Rodriguez Flores

To my parents Livia and Ramon and
to my wife Paula Ximena and my daughter Antonella Illari

Abstract

The principal objective of this paper is to develop a methodology for the formulation of a master plan for renewable energy based electricity generation in The Gambia, Africa. Such a master plan aims to develop and promote renewable sources of energy as an alternative to conventional forms of energy for generating electricity in the country.

A tailor-made methodology for the preparation of a 20-year renewable energy master plan focussed on electricity generation is proposed in order to be followed and verified throughout the present dissertation, as it is applied for The Gambia. The main input data for the proposed master plan are (i) energy demand analysis and forecast over 20 years and (ii) resource assessment for different renewable energy alternatives including their related power supply options. The energy demand forecast is based on a mix between Top-Down and Bottom-Up methodologies. The results are important data for future requirements of (primary) energy sources. The electricity forecast is separated in projections at sent-out level and at end-user level. On the supply side, Solar, Wind and Biomass, as sources of energy, are investigated in terms of technical potential and economic benefits for The Gambia. Other criteria i.e. environmental and social are not considered in the evaluation. Diverse supply options are proposed and technically designed based on the assessed renewable energy potential. This process includes the evaluation of the different available conversion technologies and finalizes with the dimensioning of power supply solutions, taking into consideration technologies which are applicable and appropriate under the special conditions of The Gambia.

The balance of these two input data (demand and supply) gives a quantitative indication of the substitution potential of renewable energy generation alternatives in primarily fossil-fuel-based electricity generation systems, as well as fuel savings due to the deployment of renewable resources. Afterwards, the identified renewable energy supply options are ranked according to the outcomes of an economic analysis. Based on this ranking, and other considerations, a 20-year investment plan, broken down into five-year investment periods, is prepared and consists of individual renewable energy projects for electricity generation. These projects included basically on-grid renewable energy applications.

Finally, a priority project from the master plan portfolio is selected for further deeper analysis. Since solar PV is the most relevant proposed technology, a PV power plant integrated to the fossil-fuel powered main electrical system in The Gambia is considered as priority project. This project is analysed by economic competitiveness under the current conditions in addition to sensitivity analysis with regard to oil and new-technology market conditions in the future.

Zusammenfassung

Hauptbestandteil dieser Arbeit ist es eine Methode zur Erarbeitung eines Masterplans für auf erneuerbaren Energien basierende Stromerzeugung in Gambia zu entwickeln. Ziel dieses Masterplans ist es erneuerbare Energien als Alternative zu konventionellen Formen der Stromerzeugung zu entwickeln und voranzutreiben.

Die Entwicklung einer maßgeschneiderten Methode für die Erstellung eines über 20 Jahre dauernden Masterplans für erneuerbare Energien, welcher auf die Stromproduktion in Gambia fokussiert sein sollte, wird angestrebt. Diese Methode soll im Zuge dieser Dissertation analysiert und verifiziert werden. Die für den Masterplan benötigten Informationen setzen sich aus (i) einer Analyse des Energiebedarfs und dessen Voraussage für die kommenden 20 Jahre, und (ii) der Bewertung der Ressourcen für verschiedene erneuerbare Energien einschließlich deren entsprechenden Stromversorgungsoptionen zusammen. Die Prognose des Energiebedarfs basiert auf einer Mischung aus Top-Down- und Bottom-Up-Methoden. Die Ergebnisse bieten zudem eine wichtige Grundlage für künftige Anforderungen von (Primär-) Energienressourcen. Die Strom-Prognose wird in zwei Prognosen aufgespaltet: in eine basierend auf der Erzeugungsseite und eine auf Seite der Endverbraucher. Auf der Erzeugerseite werden Solar, Wind und Biomasse als Energieträger im Hinblick auf die technischen Potentiale und wirtschaftlichen Vorteile für Gambia untersucht. Weitere Kriterien, z.B. Umwelt- und soziale Aspekte werden nicht in die Bewertung einbezogen. Verschiedenste Versorgungsmöglichkeiten werden, basierend auf dem untersuchten Potenzial erneuerbarer Energien, vorgeschlagen und technisch ausgearbeitet. Diese Vorgehensweise beinhaltet die Bewertung von verschiedenen erhältlichen Konversionstechnologien und die finale Dimensionierung der Lösung zur Stromerzeugung. Hierbei werden Technologien in Betracht gezogen, die unter den spezifischen Gegebenheiten in Gambia anwendbar und sinnvoll erscheinen.

Das Verhältnis dieser zwei Komponenten (Nachfrage und Angebot) zueinander stellt einen quantitativen Indikator für das Potenzial zur Substitution von primär mit fossilen Brennstoffen erzeugter Energie durch erneuerbare Stromproduktion, sowie zur Einsparung von Brennstoffen aufgrund der Entwicklung erneuerbarer Ressourcen dar. Anschließend sollen die aufgezeigten Optionen für erneuerbare Energien hinsichtlich der Analyse ihres ökonomischen Ergebnisses in eine Rangliste gebracht werden. Basierend auf dieser Rangliste und anderen Betrachtungen soll ein Investmentplan für 20 Jahre, welcher in Perioden von jeweils fünf Jahren unterteilt sein wird und aus individuellen Stromerzeugungsprojekten erneuerbarer Energien bestehen soll, erarbeitet werden. Diese Projekte bestehen hauptsächlich aus am Stromnetz angeschlossenen erneuerbaren Energien.

Schließlich wird ein Prioritätsprojekt aus dem Portfolio des Masterplans für eine tiefere Analyse ausgewählt. Da solar PV die maßgebliche vorgeschlagene Technologie darstellt, wird eine PV-Anlage, die in das fossile Brennstoffe betriebene Hauptnetz Gambias integriert werden soll, als Prioritätsprojekt ausgewählt. Dieses Projekt wird unter den Gesichtspunkten der derzeitigen ökonomischen Wettbewerbsfähigkeit in Verknüpfung mit einer Sensitivitätsanalyse in Bezug auf den Ölmarkt und den Markt der neuen Technologien in der Zukunft untersucht.

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Abbreviations

AfDB	African Development Bank
BEIS	Biomass Energy Information System
BOD	Biological Oxygen Demand
BRK	Brikama Power Station
CAPEX	Capital Expenditures
COD	Chemical Oxygen Demand
CSD	Central Statistics Department
CSP	Concentrated Solar Power
DUC	Dynamic Unit Cost
EIRR	Economic Internal Rate of Return
EC	European Commission
ENPV	Economic Net Present Value
EU	European Union
EUR	Euro
GBA	Greater Banjul Area
GBD	Ground Base Data
GDP	Gross Domestic Product
GMD (or D)	Gambian Dalasi
GNP	Gross National Product
GREC	Gambia Renewable Energy Centre
HFO	Heavy Fuel Oil
HH	Household
INEP	Integrated National Energy Planning
IPP	Independent Power Producer
IRP	Integrated Resource Planning
KPS	Kotu Power Station
LCP	Least Cost Planning
LFO	Light Fuel Oil
LGA	Local Government Area
LI	Lahmeyer International GmbH
LRD	Lower River Division
LPG	Liquefied Petroleum Gas
LUC	Levelised Unit Cost
LV	Low Voltage
MPP	Maximum Power Point
MV	Medium Voltage
NAWEC	National Water and Electricity Corporation
NBD	North Bank Division
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
OPEX	Operational Expenditures
PV	Photovoltaic

PVGIS	Photovoltaic Geographical Information System
R&D	Research and Development
RE	Renewable Energy
REMP	Renewable Energy Master Plan
REIS	Renewable Energy Information System
RET	Renewable Energy Technology
SCF	Standard Conversion Factor
SD	Satellite Data
SEIS	Solar Energy Information System
SERF	Shadow Exchange Rate Factor
SHS	Solar Home Systems
STC	Standard Tests Conditions
TOE	Tons of Oil Equivalent
TOR	Terms of Reference
TPP	Thermal Power Plant
UASB	Up-flow Anaerobic Sludge Blanket
URD	Upper River Division
USD	United States Dollar
WD	Western Division
WEC	Wind Energy Converter
WEIS	Wind Energy Information System
WWA	World Wind Atlas

1 Introduction

1.1 Energy and Power System Planning in Africa

Electricity in several countries of Africa is predominantly generated by the use of heavy fuel and diesel oil. This results in high electricity costs, thus placing this form of energy beyond the reach of target groups while at the same time having an adverse impact on the environment. The necessity for development and more efficient use of renewable energy resources may therefore be the only solution to meet their energy (power) needs.

The environmental policies and guidelines of most countries in Africa are increasingly coming in line with international standards, and the majority of their governments have ratified international treaties on global warming and climate change. At the same time the policy of these African governments is to reduce the prevailing poverty of the population through the improvement of their economic and social conditions by ensuring sufficient energy for production and social services such as education, health services and water supply. The realisation of these goals calls for the development of the utilisation of available renewable energy resources as a major priority for the medium and long term planning framework [GTZ 1987, GTZ 2007, WORLDBANK 2003].

Despite the will to turn over the out-dated and dysfunctional approaches to energy provision and resource management, the preparation of national master plans specifically dedicated to the deployment of renewable energies is barely commencing to be considered in African countries. Whereas the methodology and procedures for setting up a master plan can be taken up from conventional energy and electricity master plans, particularly in the exploitation of renewable resources the approach to assess renewable energy potential, as starting point for identifying, designing, comparing and ranking projects based on renewable resources demands the development of a new tailor-made methodology. The present PhD thesis should propose and develop such methodology in order to formulate a master plan for renewable energy based electricity generation in The Gambia.

1.2 The Gambia: Country and Energy Sector Overview

The Gambia is a relatively small state with a total surface of only 11,300 km² and is located on the Western African coast. Totally surrounded by its neighbour Senegal, the Gambia is mainly dominated by the shores of the Gambia river. Population was counted at 1.3 Mio during the 2003 census, and is growing at a rate of around 3%: one of the highest in Western African countries [CSD 2005]. A lot of refugees from Sierra Leone, Liberia and Senegal are now leading to rising unemployment rates.

With a GNP per capita of USD 340, Gambia ranks among the poorest countries in the world. Nevertheless, The Gambia is very active in international programs to fight local poverty and enhance the infrastructure and the local industry. One of the major problems is – not unlike to other struggling countries – the reliable provision of energy (electricity) and electrification of rural regions.

The gross energy consumption of the Gambia in 2000 was 332,900 TOE (which represents 0.26 TOE on a per capita basis, compared to gross energy consumption per capita of 0.62 TOE for Africa and 1.68 TOE for the World). The net energy consumption of the country in 2000, estimated at 299,000 TOE, was met by firewood (230,000 TOE), petroleum products (62,300 TOE) and to a limited extent by electricity (6,700 TOE). The biggest energy consumers were households

(83%) and the transport sector (13%). To meet its commercial energy demand including electricity, The Gambia entirely relies on petroleum. Electricity consumption in The Gambia was around 80 GWh in 2002 or slightly more than 50 kWh/Capita and year. Additional energy needs were covered with fire wood (1,800 kWh/Capita) and petroleum products (480 kWh/Capita) [EIAUS 2003, IEA 2004, IEA 2005].

Presently, the responsibility of the entire energy sector lies with the Energy Ministry which comprises of two Divisions: Petroleum Commission and Energy Division. The Energy Division formulates energy policies and supervises the activities of the Gambia Renewable Energy Centre, a body responsible for research, development and utilisation of alternative energy resources. The Division collaborates with the Department of Forestry within the Department of State for Forestry, Natural Resources and the Environment on policy for fuel wood supply and demand [LAHMEYER 2005b].

The National Water and Electricity Company (NAWEC), responsible for the nation wide generation, transmission and distribution of electricity is also supervised through the Energy Ministry.

Regarding the electricity sector, the core problems and objectives of the government remain the following:

- Increase of generating capacity that is presently inadequate and unable to meet the demand. The government therefore seeks foreign and local partnership in increasing the generating capacity,
- Capital investment to improve the poor state of the transmission and distribution system which result in high technical losses and un-metered consumption estimated at 30% - 35%; and
- Improving efficiencies in order to reduce the extremely high cost of energy.

The Government continues to undertake measures to overcome these problems through institutional strengthening and other restructuring efforts. In that regard, the Government welcomes local and foreign interest in the sector so as to achieve, in the short to medium term, the following:

- Reduce the cost of electricity,
- Increase the accessibility and supply reliability of electricity nation-wide, and
- Mitigate the environmental impact of the power sector.

Strategies laid down for the electricity sector include the creation of a more conducive legal and regulatory framework, the formation of a partnership with the private sector, and the participation of independent power producers (IPP). Negotiations are being intensified with donor agencies and private companies on all these points [GOG 2005].

To further exacerbate the energy shortages, electricity boards can not guarantee stable deliveries and power failures are frequent. This is of course a major obstacle for business in The Gambia. Most serious businesses, therefore, have their own generators, irrespective that the costs are high.

The Greater Banjul Area (GBA) is supplied from diesel-run generators with a total installed capacity of 43.7 MW. Two 33 kV transmission lines convey energy from power stations to 33 kV/ 11 kV substations. Lines at a voltage of 11 kV from the substations carry electricity to 11 kV/ 400-volt substations at various locations in the GBA, feeding low voltage lines to three phase and single-phase consumers at 400 and 230 volts respectively [EDF 1992, NAWEC 1998].

Six isolated power stations; located at Mansakonko, Farafenni, Kerewan, Janjangbureh, Bansang and Basse supply electricity to rural areas of The Gambia. All these power stations are equipped with diesel-run generators, which supply electricity for 12 to 15 hours per day to six rural towns. A rural electrification project financed by AfDB and other funding entities, increased the installed generation capacity of these isolated grids to 4,260 kW, extended the MV-lines and electrified additional 40 villages i.e. in total to 46 villages. The service of power supposed to be increased to 24 hours. Notwithstanding the positive impact of the project, after completion the electrification rate of The Gambia reached only 40%, with more than half the population having no access to electricity supply at all [LAHMEYER 1998, NAWEC 2004a, DMC 2005 a].

Consequently, the main objective in the government energy policy framework is the provision of efficient, reliable and affordable energy, the exploitation of which is sustainable and environmentally sound. In this context and with the funding of AfDB, the German Consultancy company Lahmeyer International GmbH (LI) [1] performed, on behalf of the governmental Energy Division, the preparation of a Renewable Energy Study for The Gambia, which is the core reference and information source of the present dissertation.

1.3 Objective and Outline of the Dissertation

The present PhD thesis is aimed at designing and formulating a methodology of the development of a Master Plan for the deployment of renewable energies to generate electricity. This methodology is specifically developed for the case of developing countries and shall under this thesis, be applied to the example of The Gambia. The main goal of this Master Plan is to develop and promote renewable sources of energy as an alternative to conventional forms of energy for generating electricity in The Gambia.

The present PhD thesis consists of twelve Chapters. Chapter 1 is introductory, provides a regional and country overview related to energy aspects, and a description of the thesis objective as well as an outline of the dissertation. Chapter 2 analyses the concept behind master plans and proposes a methodology for a Renewable Energy Master Plan (REMP) focussed on electricity generation.

The REMP is then based on the inputs: (a) demand analysis and forecast as described in Chapter 3 and (b) resource assessment and renewable energy supply options, as described in Chapter 4 and 5, respectively.

These two inputs are brought together and consolidated into a supply-demand-balance (see Chapter 6) indicating present and future demand conditions (20 year forecast) as well as fuel savings through use of renewable resources and its substitution potential or proportion of electricity generated by RET.

The various renewable energy supply options are ranked in Chapter 7 according to the outcomes of an economic analysis. Based on this ranking, and other considerations, a 20-year investment plan (Chapter 8) is derived. The investment plan is broken down into five-year investment periods and consists of individual renewable energy projects.

A priority renewable energy project is identified and selected for further deeper analysis in Chapter 9. This project is presented and discussed, where its economic competitiveness under the current conditions is assessed. Furthermore, a sensitivity analysis for the project with regard to oil and new-technology market conditions in the medium and long term is performed.

Chapter 10 presents Summary of Results and Conclusions. References and Annexes are given in Chapter 11 and Chapter 12, respectively.

[1] Mr. Enrique Rodriguez Flores is a Staff-member of the LI´s Department of Renewable Energy and was appointed as Project Manager for this particular project.

2 Methodology for a Renewable Energy Master Plan

Several definitions for “master plan” can be found in the literature. Some of them are:

- a comprehensive document that sets out an overall strategy
- long-term outline of a project or government function for new developments
- a comprehensive plan to guide the long-term physical development of a particular area – zoning
- planning tool that provides detailed guidance for the comprehensive development of a specific area
- a comprehensive plan emphasizing areas of future growth and setting goals
- overall development concept
- a plan giving comprehensive guidance or instruction – overall guidance
- is designed to provide a comprehensive overview of the future development

There are many common words in these definitions. A master plan is, in the simplest of the terms, a comprehensive strategy paper to guide future developments.

Master plans are outlined and used for different activities and sectors such infrastructure: energy, transportation; tourism; urbanism, architecture, land use, etc. One of the most prominent areas of master planning is energy master planning. Increases in energy prices have drawn attention to the importance of developing an integrated approach to energy sector planning in developing countries, in contrast to the prevailing practice of uncoordinated planning in different energy sub-sectors. Integrated national energy planning (INEP), at country level, requires a clear definition of national objectives, in relation to which links between the energy sector, and activities in each individual sub-sector, may be analysed. Policy tools for achieving national goals include physical controls, technical methods, education and propaganda, and pricing. Use of these tools must be coordinated. The INEP procedure, which leads to an energy master plan, consists of several steps: determining the socio-economic background, demand and supply analysis, energy balance, and policy formulation. Initially INEP may be carried out at a relatively simple level, and later as data and analytical capabilities improve more sophisticated computerized modelling techniques could be implemented. The institutional structure should be rationalized by setting up a central energy authority or ministry of energy, with its principal focus on energy planning and policy formulation [APDC 1985].

Due to the global climate change problematic, the non-renewable character of fossil fuels and their price volatility, energy master plans became lately a macro-scale assessment that prepares the governing body for responsible and sustainable energy development. However, the bottleneck in many developing countries is the lack of detailed information about available renewable resources, which could offer the opportunity to develop and implement renewable energy projects. This deficit also impedes or hinders the effective integration of this kind of sustainable energy projects in the national conventional energy master plan or rural electrification plans. Another key aspect for the successful introduction of renewable energies in the national energy planning is the political willingness to efficiently support such sustainable energies providing them with the necessary legal and regulatory framework.

According to the existing literature [IAEA 1984, APDC 1985, GTZ 1988, WIESE 1994], the scope of Master Plan studies for electricity supply comprises often the same following major steps:

i) making energy (electricity) demand projections
ii) assessing energy resources
iii) evaluating supply options (technologies)
iv) supply-demand balancing
v) analysing economy and comparing/ranking alternatives
vi) drafting action/investment plan
vii) identifying project (project catalogue)

A methodology for a Renewable Energy Master Plan (REMP) in developing countries should however emphasize resource assessments and include specific tailor-made steps and sub-steps considering as well the specific conditions of the analysed country. The REMP should be prepared on long-term basis, i.e. 20 years, and guided, as much as possible, by the concepts of Least Cost Planning (LCP) and Integrated Resource Planning (IRP) in order to be online with the usual energy planning policies in developing countries.

The following Figure 2-1 presents an overview on the proposed methodology for the preparation of the REMP focussed on electricity generation for the specific case of The Gambia. This methodology is followed and verified during this dissertation. The methodology can be easily adapted to specific characteristics of other developing country, especially with regard to the available renewable energy resources.

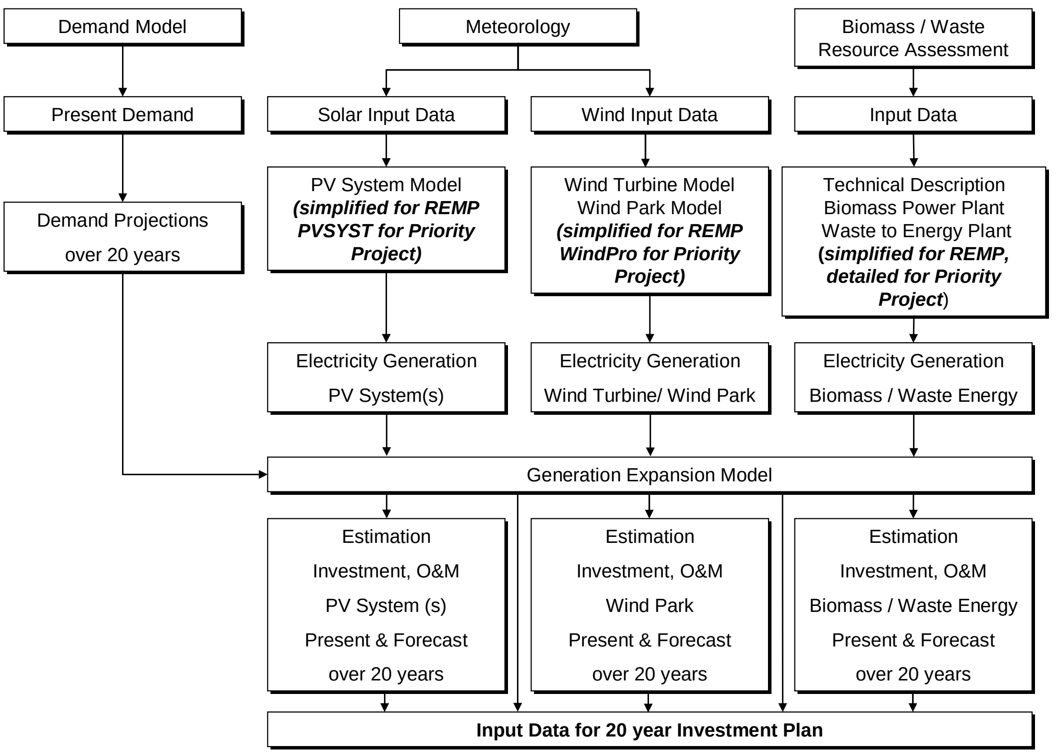


Figure 2-1: Proposed Methodology for a REMP focussed on Electricity Generation

3 Energy Demand Assessment and Projection

No energy balance of The Gambia is available. For this reason, the energy demand assessment begins with the evaluation of primary resources followed by secondary energy sources. The energy demand in The Gambia is exhaustively analysed comprising energy demand assessment per customer group (residential, services, agricultural, industrial etc.) and per energy source (e.g. primary energy sources such as fuelwood and secondary energy sources such as electricity). The rate of use for each energy source is discussed (i.e. seasonal, month of the year, etc.). Afterwards, energy demand projections per type and consumer category are prepared. The forecast indicates the power demand for electricity and all major primary energy sources applied in The Gambia for a 20-year horizon. Energy demand projections until 2025 are then presented by the means of tables and diagrams. The evolution of the projections in reference to the applied demographic and economic scenarios is thus easily comprehensible [LAHMEYER 2005a].

To consider the individual regional characteristics of current and future energy demand, the assessment and projection follow the administrative classification already applied by the Central Statistics Department for census and other statistical research purposes. The country has been divided into eight Local Government Areas (LGA), each corresponding to an administrative division, municipality or capital city, with the exception of Kuntaur which corresponds to the north of Central River Division [CSD 2005].

3.1 Assessment of Energy Consumption

The Gambia relies almost entirely on biomass (wood fuels) and imported petroleum products to meet its energy requirements. However, in the face of rapid depletion of forest reserves due to bush fires, farming, etc. the energy options based on biomass are very limited [LAHMEYER 2006a]. Furthermore, due to high cost of imported petroleum products, the National Water and Electricity Company (NAWEC) is finding it extremely difficult to service the growing oil import bills particularly for electricity generation.

The Figure 3-1 and Figure 3-2 provide an overview of the increase of primary energy consumption, as well as the utilisation sources such as fuelwood and several petroleum products (diesel, gasoline, liquefied petroleum gas, kerosene, and heavy fuel oil) for the period 1991 – 2004 [LAHMEYER 2005a].

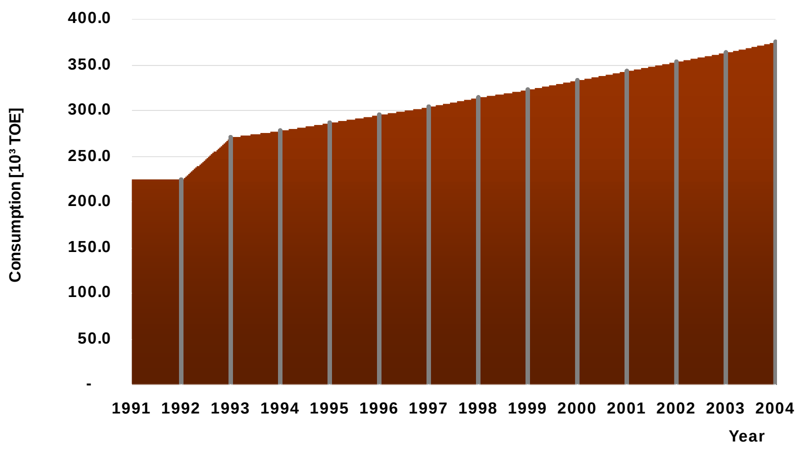


Figure 3-1: Development of Primary Energy Consumption – Fuelwood

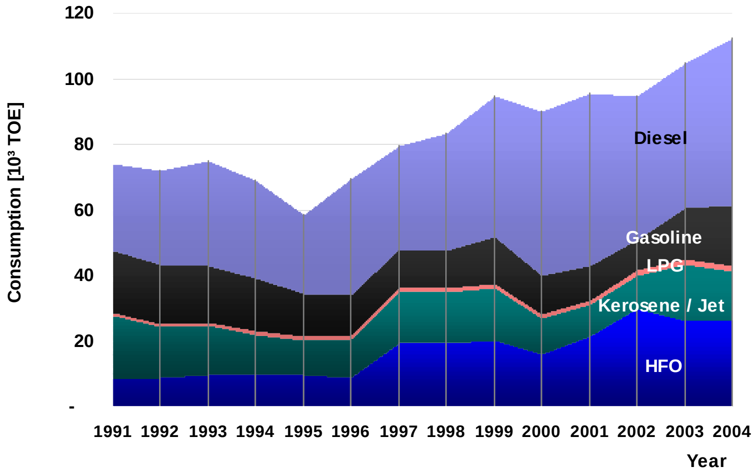


Figure 3-2: Development of Primary E. Consumption – Petroleum Products

The conversion of the petroleum primary energy resources HFO and diesel into electricity basically represents the generation capacity of NAWEC. Over the period 1995 up to 2004, installed generation capacity grew from nearly 14 MW to 46 MW. Figure 3-3 presents the development of electricity generation capacity in the past.

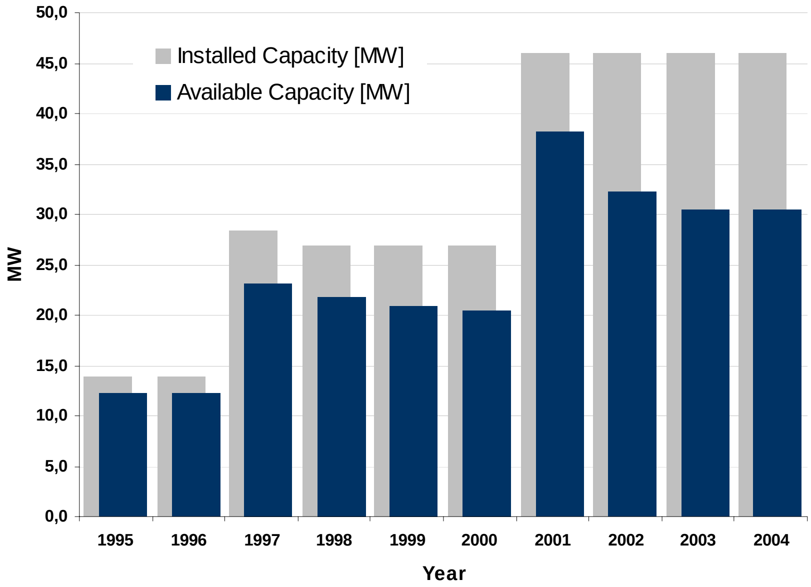


Figure 3-3: Development of Installed and Available Generation Capacity

Six isolated power stations located at Mansakonko (400 kW), Farafenni (400 kW), Kerewan (142 kW), Janjangbureh (270 kW), Bansang (420 kW) and Basse (640 kW) supply electricity to rural areas of The Gambia outside the GBA. All the power stations are equipped with diesel-run generators, which, when available, supply electricity to the surrounding areas through low voltage lines (400 V three phase and 230 single phase). In addition, 11 kV transmission lines transfer energy from the power stations at Mansakonko, Farafenni, Bansang and Basse to 15 remote transformers from where low voltage lines help to supply nearby customers. An AfDB project increased the installed production capacity to 4,260 kW. Table 3-1 gives an overview of the installed capacity of isolated power stations [LAHMEYER 1998, NAWEC 2004a].

Table 3-1: Installed Capacity in Isolated Service Areas

Unit	Capacity Installed [kW]	Units [kW]	Fuel Storage [m³]
Total	**4,260**		
Barra-Essau	460	2x200kW / 1x60kW	60
Kerewan	220	1x100kW / 2x60kW	30
Farafenni	1,400	2x600kW / 1x200kW	180
Kau-ur	180	3x60kW	30
Bansang	600	2x200kW	60
Basse Santa Su	1,400	2x600kW / 1x200kW	180

The development of losses over the period 2000 to 2004 is shown in Table 3-2. The compilation includes the annual gross and net generation, as well as the final/billed electricity consumption (including NAWEC's own electricity requirements). There is no NAWEC estimation with regard to the electrical losses composition (technical and non-technical losses).

Table 3-2: From Generation to Final Electricity Consumption

Item / Years	2000	2001	2002	2003	2004
Total Generation [MWh/a]	116,907	146,859	163,062	150,307	128,061
Station Use [MWh/a]	6,043	6,302	2,697	5,958	2,644
Net Generation [MWh/a]	110,864	140,557	160,365	144,349	125,417
Billed Consumption[MWh/a]	90,714	114,615	128,347	107,718	93,334
Total Losses [MWh/a]	20,150	25,942	32,018	36,631	32,083
Total Losses [%]	17.2%	17.7%	19.6%	24.4%	25.1%

The annual electricity consumption per customer group is provided in the following Table 3-3 [NAWEC 2004b]. The so-called "maximum demand" in NAWEC's statistics are larger commercial and industrial clients (e.g. supermarkets, hotels and telecommunication companies).

Table 3-3: Final Electricity Consumption by Customer Groups

Final Consumption [MWh/a] / Year	2000	2001	2002	2003	2004
Domestic	45,676	55,118	61,887	48,684	38,833
Commercial	14,362	16,902	15,957	9,013	7,771
Maximum Demand	9,467	12,859	17,237	25,122	26,151
Agriculture	39	58	64	6	4
Local Authority	841	740	507	389	279
Central Government	7,168	8,796	8,974	7,076	7,195
Prepayment Domestic	1,030	4,028	6,119	6,403	4,864
Prepayment Commercial	1,046	3,448	4,336	2,929	1,983
Prepayment Maximum Demand	1,046	3,448	4,336	1,202	780
Own Use	10,039	9,218	8,930	6,894	5,474
TOTAL	**90,714**	**114,615**	**128,347**	**107,718**	**93,334**

Nearly half of the annual electricity consumption in NAWEC's service area is related to The Gambia's residential sector. The group of large (mainly industrial) customers comprises almost a third, and the commercial sector is responsible for some 11% of the billed consumption. The institutional sector (including local authorities and central government) ranks in fourth place with some 8.5%. Almost negligible is the requirement of the agricultural sector. As shown in Table 3-3, agriculture's consumption dropped from its maximum value of 64 MWh/a in 2002 to only 4 MWh/a in 2004. This decrease is predominantly the result of the constantly diminishing agricultural crop land in the Greater Banjul Area.

Based on customer numbers and annual electricity consumption figures, the present specific consumption (also called energy intensity) was calculated. Approximately 2,500 kWh is consumed as an average by each customer per year. One household client consumes an average of 1,490 kWh/a. Related to the entire population number, the final electricity consumption is less than 63 kWh per capita and year. The Gambia belongs to those countries with the lowest per-capita-electricity consumption. The electricity average consumption in Germany in the same year is around 6,050 kWh per capita.

3.2 Energy Balance of The Gambia

This section summarises the results determined within the frame of the utilisation assessment of primary and secondary energy sources in the Gambia. The energy balance comprises the entire supply chain, beginning from domestic and imported energy sources, through the transformation and transport processes, to the final consumption by source and sector. The balance is presented in form of a Sankey diagram (energy-flow-diagram) which is presented in Annex 12.1 and considers the following items:

Input	The input considers the primary energy sources applied in the Gambian energy system. It is divided into the both types, imported and domestic sources. While imported energy sources are in particular petroleum products, domestic primary energy sources are fuelwood and a small proportion of solar radiation. It has to be considered, that the energy balance shows the actual amount of energy use by source, and not any potential estimates.

Throughput	Within the balance, any process of transformation of energy is mentioned as throughput. Transformation processes concerning especially the generation of electricity on the basis of fuels or solar radiation. Furthermore, electricity needs to be supplied finally at low-voltage level to the end user. The throughput also deals with transmission and distribution, as well as with transformation processes from higher voltage levels.
Output	The output considers the final energy consumption. It is divided into the major customer sectors, such as the residential sector, agriculture, industry, transport/aviation and the commercial/institutional sector. Beside this sector classification, each primary or secondary energy source is analysed by its final utilisation share.

3.3 Projection of Primary and Secondary Energy

The energy demand forecast is an essential prerequisite for planning activities, in particular for energy supply system expansions and the substitution of one energy source by another. If projected demand levels are too low, serious adverse economic consequences for consumers and the economy at large could occur. If projected demand levels are too high, excess resources can impose undue financial hardships on suppliers and their consumers. In addition, this situation results in unnecessary and high economic opportunity costs associated with resource misallocation.

To provide most realistic results, the methodology applied for the energy demand forecast is based on a mix between Top-Down and Bottom-Up approaches. It includes a strong analytical component, but also takes into account selected (macro-) economic indicators, which is possible due to the stable and growing economy of the Republic of the Gambia. Publications of the Gambia's Department of State for Finance and Economic Affairs gives a clear picture of former and expected future (macro-)economic development of the country. Economic Indicators such as the Gross Domestic Product are typical Top-Down forecast components. Furthermore, demographic data (population number, historical and future growth rate) needs to be evaluated, general previous trends of energy consumption identified and political preferences and objectives considered. At the same time, regional diversification data as well as major customer groups' data can be gathered based on performed field investigations and surveys.

A particular significance has the forecast of the Gambia's electricity demand. As shown in the Energy Balance in the previous Section, the generation of electricity is the major transformation process from primary to secondary energy sources. This means that any increase of conventional primary energy based power generation will have a direct impact to the annual consumption of petroleum products, such as heavy fuel oil and diesel. On the other hand, an increase of power generation would decrease the high proportion of suppressed electricity demand and therefore the use of primary energy sources for self-generation (in particular diesel). Furthermore, a higher electricity access rate will lead to the situation, that currently used energy sources (e.g. kerosene for lighting) will lose their significance in the future due to their substitution with electricity.

The forecast results are important data for other projections in terms of the future requirements of energy sources. Other input data, besides population growth figures, used to forecast the several primary energy sources are annual growth rate of GDP (general and by sector), correlation between annual changes of GDP and related annual change of energy applied within the individual sectors, as well as general energy intensity (specific consumption) figures. The forecast considers the twenty-year-period 2005-2025.

Basically, the electricity forecast follows the procedure described above. Due to its rather complex structure, separate projections are provided, such as the demand at sent-out level [2] and the final demand at end user level. In order to consider the suppressed electricity demand, an adjusted sector break down was applied, which not only considers the billed electricity consumption, but also the presently unserved electricity demand.

The demand forecast results for two of the main primary energy sources until 2025 are described in the following Figure 3-4 and Figure 3-5.

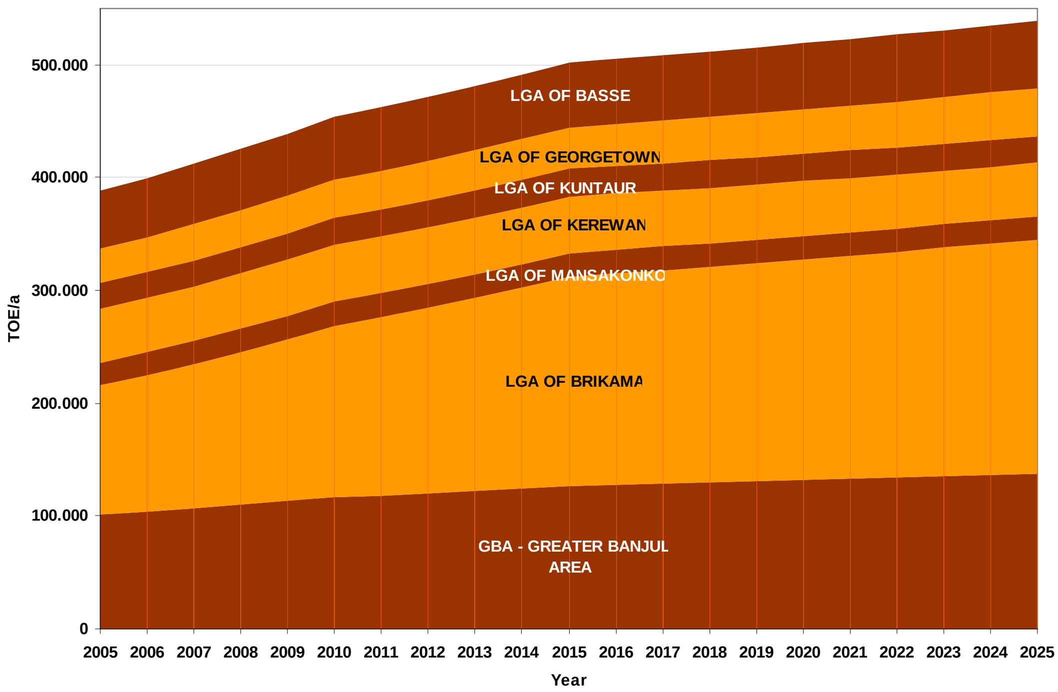


Figure 3-4: Projected Fuelwood Demand in TOE/a

[2] Sent-out is defined as the level at the generation border.

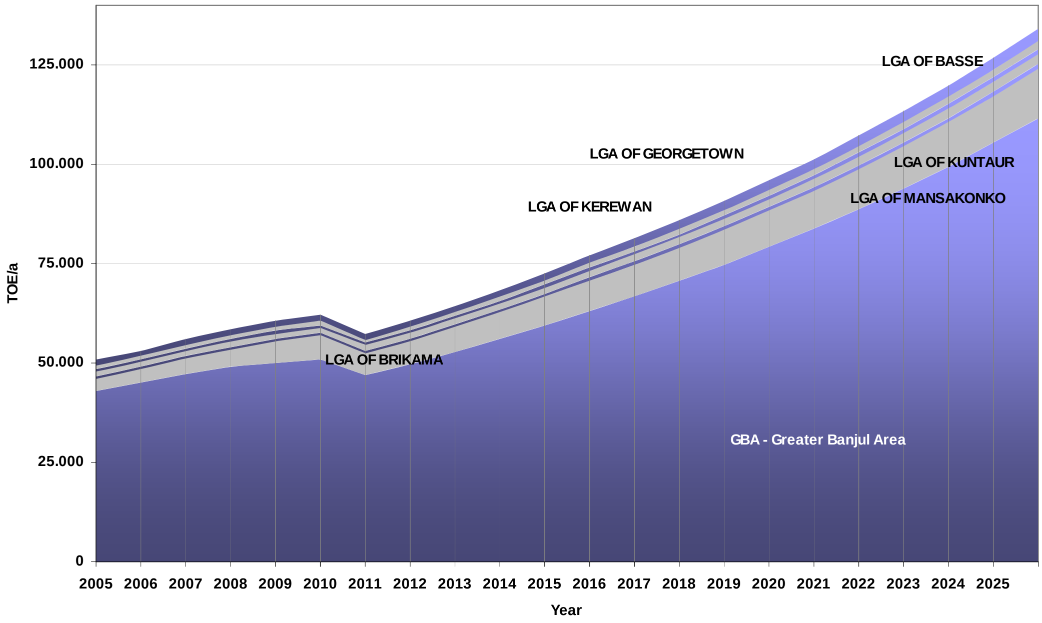


Figure 3-5: Projected Diesel Demand in TOE/a

For the electricity forecast, major future projects at the supply side (short- and middle term until 2010/2011) were additionally considered, including the active participation in electricity trade as member of the West Africa Power Pool [NEXANT 2004]. The next Table 3-4 illustrates actual estimates for the future electricity import of The Gambia):

Table 3-4: Expected Electricity Trade of the Gambia up to 2014

Period	Imports	Exports
2005-2006	0	0
2007-2008	0	0
2009-2010	**235 GWh/a (Senegal)**	0
2011-2012	**269 GWh/a (Senegal)**	0
2013-2014	**303 GWh/a (Senegal)**	0

The electricity forecast includes also the present and expected future suppressed demand. The next Figure 3-6 illustrates the gap between the currently covered electricity demand and the estimated actual requirement, which includes suppressed demand. Furthermore, it is shown that only through additional power supply (imports plus increasing domestic generation) this gap can be closed before 2010. The presented forecast results are comparable to these, published in NAWEC's own projections.

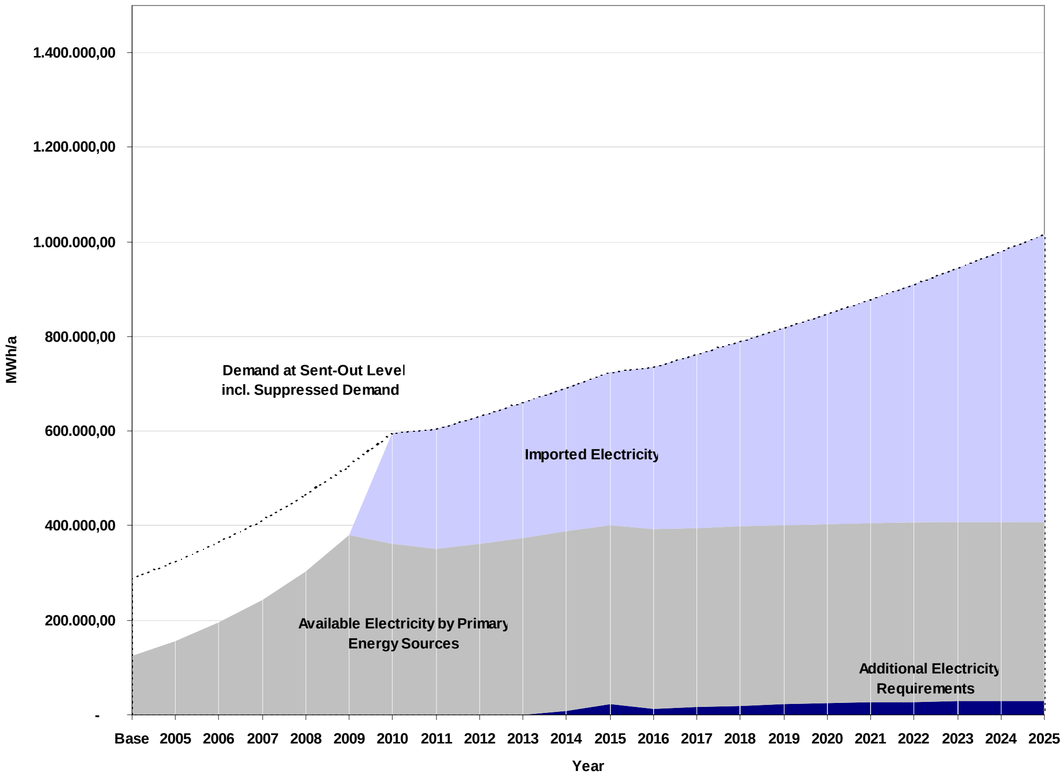


Figure 3-6: Projected Electricity Demand in MWh/a

The average annual growth rate for the electricity demand at sent-out level (including suppressed demand figures) is 12.8% from the base year 2004 on until 2010, 4.0% for the period 2010-2015, and approximately 3.6% in 2016-2025. Based on the assumption that the schedule for the several major electricity generation/supply projects can be followed, the annual average growth rate for the estimated demand, which can be served is thus 29.7% for the period between the base year and 2010. For the rest of the considered forecast period the rate of annual increase is naturally as high as for the entire electricity demand (2010-2015: 4.0%, 2016-2025: 3.6%) [LAHMEYER 2005a].

An overview of the electricity demand development in figures is provided in the next Table 3-5.

Table 3-5: Electricity Demand Projection in MWh/a and TOE/a

Entire Electricity Demand		Base	2010	2015	2020	2025
Total Annual Demand at Sent-Out Level (including Suppressed Demand)	MWh/a	**289,079**	**596,016**	**724,164**	**847,450**	**1,016,900**
Total Final Demand (including Suppressed Demand)	MWh/a	216,665	496,918	638,596	762,705	915,210
Total Losses	MWh/a	72,414	99,098	85,567	84,745	101,690
Total Annual Demand at Sent-Out Level (including Suppressed Demand)	TOE/a	**24,861**	**51,257**	**62,278**	**72,881**	**87,453**
Total Final Demand (including Suppressed Demand)	TOE/a	18,633	42,735	54,919	65,593	78,708
Total Losses	TOE/a	6,228	8,522	7,359	7,288	8,745

It is assumed that measures for diminishing losses (i.e. modernising, refurbishing, better metering and control systems) will be implemented. For this reason, losses are expected to decrease from 25% in the Base Year to 10% in 2025.

The following Figure 3-7 illustrates the expected development of electricity demand for each region of the country. It is displayed, that the GBA will keep the largest proportion, but the figure also illustrates the increasing significance of the other provinces, which play only a minor role in the base year 2004.

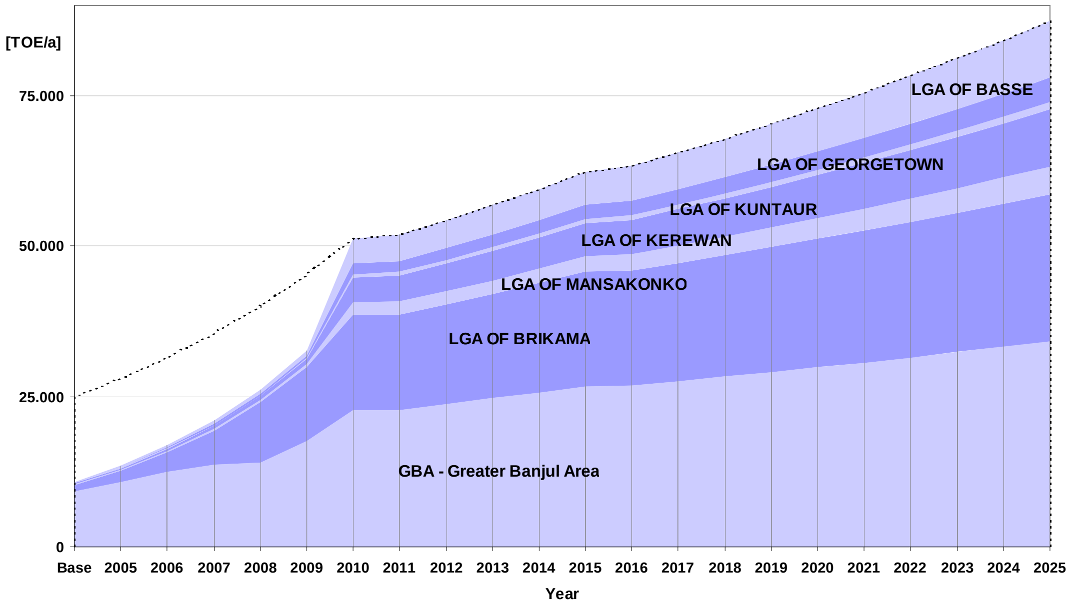


Figure 3-7: Projected Electricity Demand by Region in TOE/a

4 Renewable Sources Assessment

Wind, Solar and Biomass resources for energy generation purposes are assessed. Other sources like geothermal energy and traditional hydro energy can prima face be ruled out as The Gambia does not dispose of the required resources. Tidal energy in the Gambia river is however a permanently mentioned option, but it is not considered in the present study.

4.1 Solar Energy

4.1.1 Methodology for Estimation of Solar Potential in The Gambia

The Gambia appears to enjoy good solar conditions despite some seasonal variations (dry and rainy season). In order to perform a suitable assessment of the solar resource over the whole country, ground-based measurement stations are considered for this evaluation. The Figure 4-1 shows eight measuring stations installed across The Gambia during May/June 2005 and commissioned at beginning of July 2005, in frame of the Renewable Energy Study carried out by Lahmeyer International GmbH. These stations can provide at least one complete year of ground based solar data. Afterwards, these data are applied to the whole country by mean of a spatial interpolation method calculated and written based on the work of Lefèvre and co-authors [LEFEVRE 2002] in order to reach good estimates of solar radiation for different places, using information from the existing measuring network. This interpolation theory is the same as the one applied for satellite solar data in the Helioclim database developed by various European research institutes. By this mean, solar maps are generated for The Gambia.

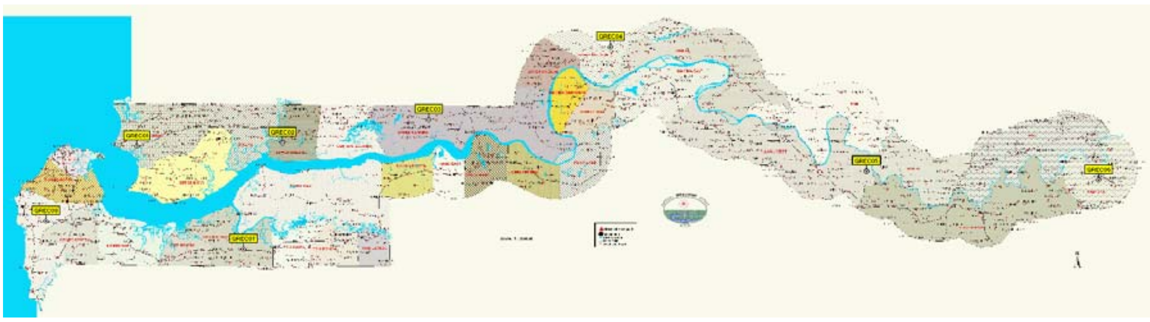


Figure 4-1: Map with location of 8 measurement stations in The Gambia

In terms of renewable energy assessment, due to the volatility of the resources, the sets of data have to cover long periods, i.e. many years, in order to avoid depending on particular phenomena. For instance, using solar data collected for only one year can lead to an under- or overvaluation of the resource if this particular year is very sunny or not. Therefore, after collection and evaluation of ground based solar data over a year, the final step of the methodology implies the correlation of these data with long-term satellite data which are available over about 20 years.

4.1.2 Solar Data Assessment – Results

4.1.2.1 General Trends

The data collected for The Gambia show high solar radiation values in all regions (values and plots for each station are given as Annex 12.3, 12.4 and 12.5). The average solar radiation over the measuring period July 2005 – June 2006 ranges from around 4.4 to 6.7 kWh/m^2.day. The sunniest period is during spring when skies are really clear (the variation between min and max is extremely small at this time). The lowest radiation values are observed during winter, in December and January.

In terms of average values, the temporal variation between low and high values is not significant and even in the "weakest period", good solar radiation values are expected.

It is interesting to note that The Gambia receives large amounts of solar radiation during the rainy seasons (about 5 kWh/m^2.day) but that variations between minimum and maximum daily solar radiation are huge due to the succession of clear sky days and overcast days. "Low values" are still good enough for solar energy applications. The main results for the period July 2005 – June 2006 are shown in the Figure 4-2 and Table 4-1.

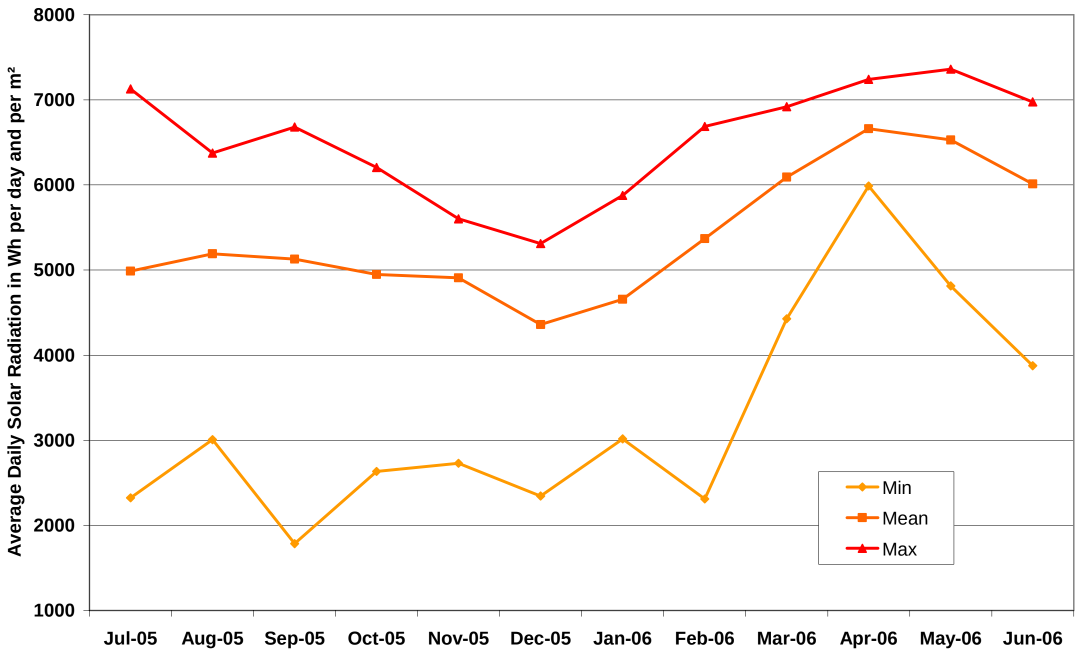


Figure 4-2: Mean, maximal and minimal values of the average solar radiation over the year (average calculated over the eight stations)

Table 4-1: Absolute maximal, mean and minimum value of the average solar radiation (averaged over the eight stations)

Average Solar Radiation in Wh/m².day	
Max	6,660
Mean	5,382
Min	4,360

4.1.2.2 Solar Maps

Based on the above mentioned interpolation model, results can be presented as maps. Three examples are given below in the Figure 4-3, Figure 4-4 and Figure 4-5, for the months December 2005, February 2006 and May 2006, respectively.

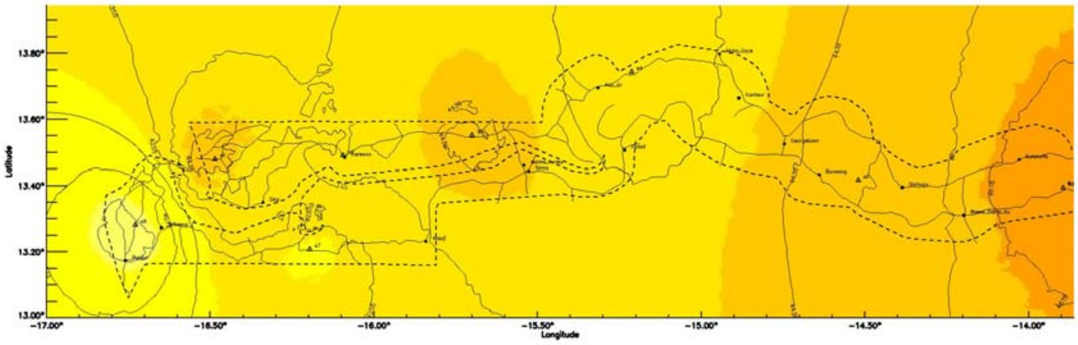


Figure 4-3: Solar map for December 2005

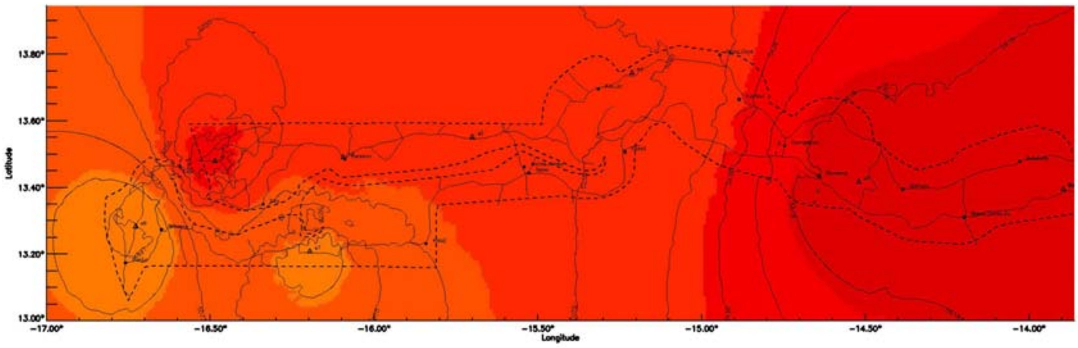


Figure 4-4: Solar map for February 2006

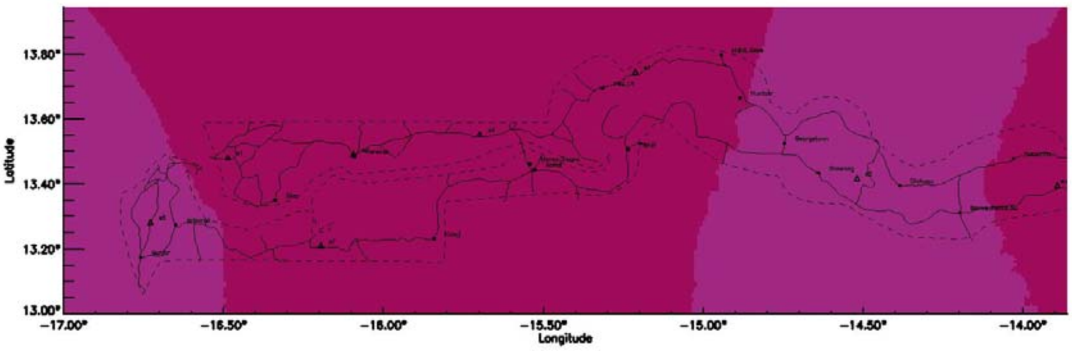


Figure 4-5: Solar map for May 2006

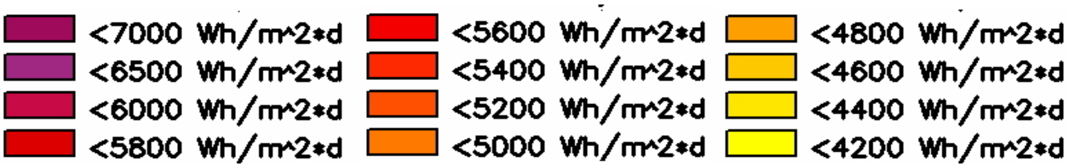


Figure 4-6: Solar Map Legend

From these maps, two trends can be clearly seen: first, the lower values in the south-west region, probably due to the presence of fog in this area; and second the higher values in the west and on the north bank. These trends can be really seen for every month of the year, apart from April and May when the skies are markedly clear over the whole country and solar irradiance high and spatially well distributed.

4.1.3 Correlation between Ground-based Data and Satellite-based Data

4.1.3.1 Collection of Satellite Data

Solar data from satellite are collected from the Helioclim-1 database (developed by cooperation of various research institutes and with the help of the European Space Agency). These data are collected for the exact eight locations of the stations and cover the same period of measuring time.

4.1.3.2 Correlation

Solar maps based on ground-based data (GBD) and satellite data (SD) are generated. Those maps show different general trend in solar repartition over the country. GBD shows a much lower level of solar radiation in the south-west of the Gambia (coastal region and Sibanor area). Contradictorily, this region shows higher irradiation values according to SD. This phenomenon can be clearly seen on the maps presented in the Figure 4-7 and Figure 4-8, as examples. The colour scale is the same for satellite and ground base data.

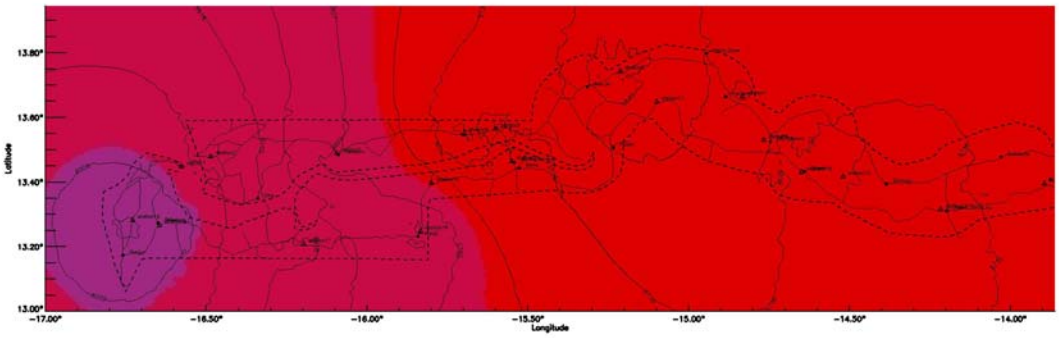


Figure 4-7: Average solar radiation for February 2006, SD 20 years, in Wh/m².day

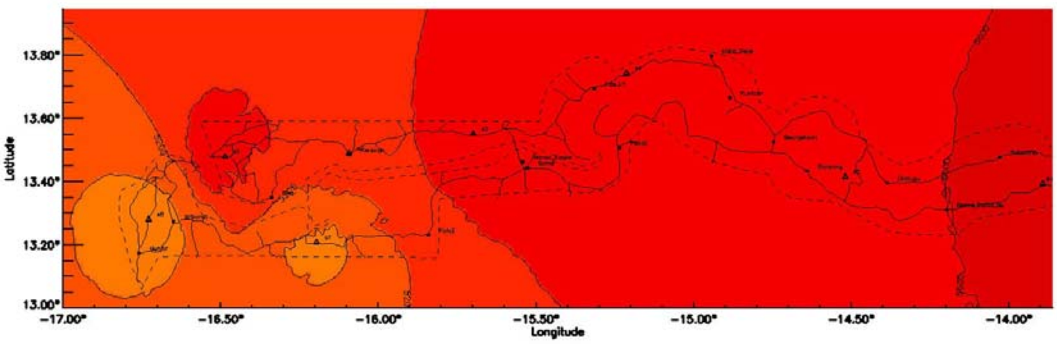
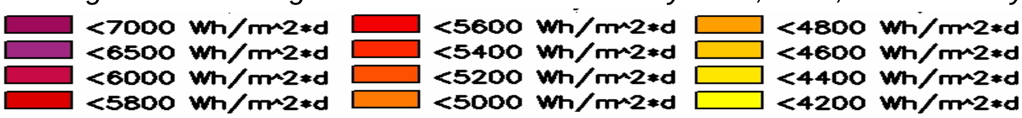


Figure 4-8: Average solar radiation for February 2006, GBD, in Wh/m².day



In the last two figures, it is clear that the general trends are reversed. For satellite datasets, the area receiving the largest amount of solar energy is at the coast, while for ground base data, this is located in the east.

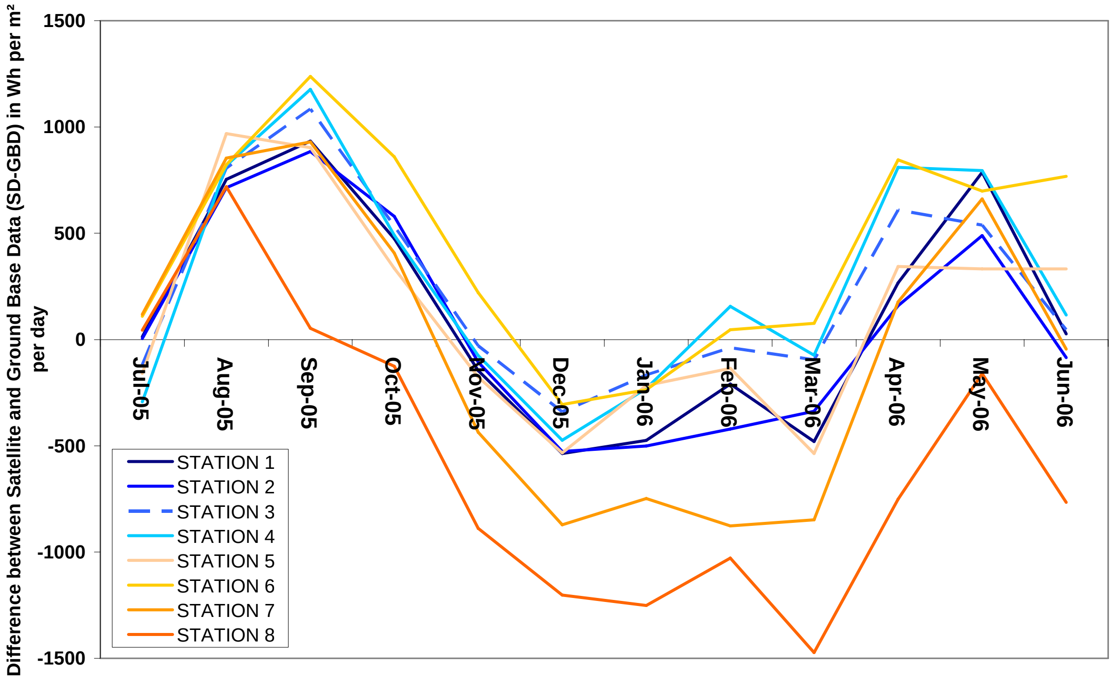


Figure 4-9: Differences between SD and GBD for each Station

Figure 4-9, clearly shows that SD and GBD have different behaviours over the year. Even if they follow the same general pattern (sunny periods are sunny, etc.), the accentuation of the phenomena exhibited through satellite measurement makes the correlation impossible. According to satellite data, sunny periods are more intense (summer and early spring), while the rainy season and winter are less intense as recorded by the ground data. These differences are not linked to a difference in location or in instrument accuracy but rather in the fundamental basis of the measurement itself. Therefore, as the datasets do not follow each other in terms of geography and time period, a valuable correlation is not possible and thus not recommended.

This difference between the two sets of data can be most likely explained by two facts:

- Even if GBD were collected over a year, from July 2005 to June 2006, it is possible that this period weather pattern could be qualified as not normal.
- In the domain of acquisition and treatment of satellite data, R&D work is still ongoing. Such databases are important milestones for solar resource assessment and are proven to be reliable in most cases. However, in certain cases such as coastal or mountainous locations, general algorithms which are actually being used do not take into account any local and particular phenomenon on their own.

Therefore, only Ground-Based Data is utilized as input for the REMP preparation.

4.1.4 Summary of Solar Energy Potential in The Gambia

As solar radiation reaches good values all over the country, several energy (electricity) supply possibilities can be explored. Preliminarily, PV Power Plants, Solar Home Systems (SHS) and Hybrid Diesel-PV Systems could be considered. The existing PV based energy generation projects (i.e. the EU solar PV pumping, SHS projects and PV-Diesel hybrid system in Darsilami) supports this consideration.

Although normal irradiance figures in The Gambia strongly support the present Solar Water Heating applications in the tourism industry, it is very difficult to envisage any solar thermal power generation plant, as electricity supply option in the REMP for The Gambia, due to the relatively small power capacity requirements in the country. At the present technology state of the art, the technical and economic viability of such Concentrated Solar Power (CSP) power plants are in the same or over range of installed capacity in the whole country.

For further analysis, a Solar Energy Information System (integrated to a REIS) is created in order to provide solar energy potential information for a specific location in the country. This SEIS is currently managed und updated with the new collected solar GBD by the Gambian Department of Energy.

4.2 Wind Energy

4.2.1 Methodology for Estimation of Wind Potential in The Gambia

The first step is the preparation of a Zero-Wind Map using the data from the World Wind Atlas (WWA) in order to give a first overview of the wind conditions in the country (see Figure 4-10). The preliminary indication of this wind map is that, mainly due to latitudinal vicinity of The Gambia to the equator, wind conditions are moderate all over the country, above all in the hinterland.

In order to scale, refine and verify the preliminary results of the zero wind map, and to estimate the wind energy potential in The Gambia, ground base wind data is collected from the same eight measurement stations distributed throughout the country, as described in the Paragraph 4.1.1. These wind data are for a period of one year, including the so-called “Harmattan dry wind period” (January-February 2006). With the gained information about the local wind conditions, a first potential estimation is determined. In addition, the mesoscalic KLIMM model, developed by Lahmeyer International GmbH, calculates a Wind Energy Information System (WEIS), which at the same time can generate wind maps for micro-regions or the whole country. Potential estimations and maps can be readjusted und updated with the newest results coming from the evaluation of the wind measurement at the eight sites. Finally, a long term correlation is performed in order to reflect the long term mean wind speed for a “normal wind year” of the considered location or region.

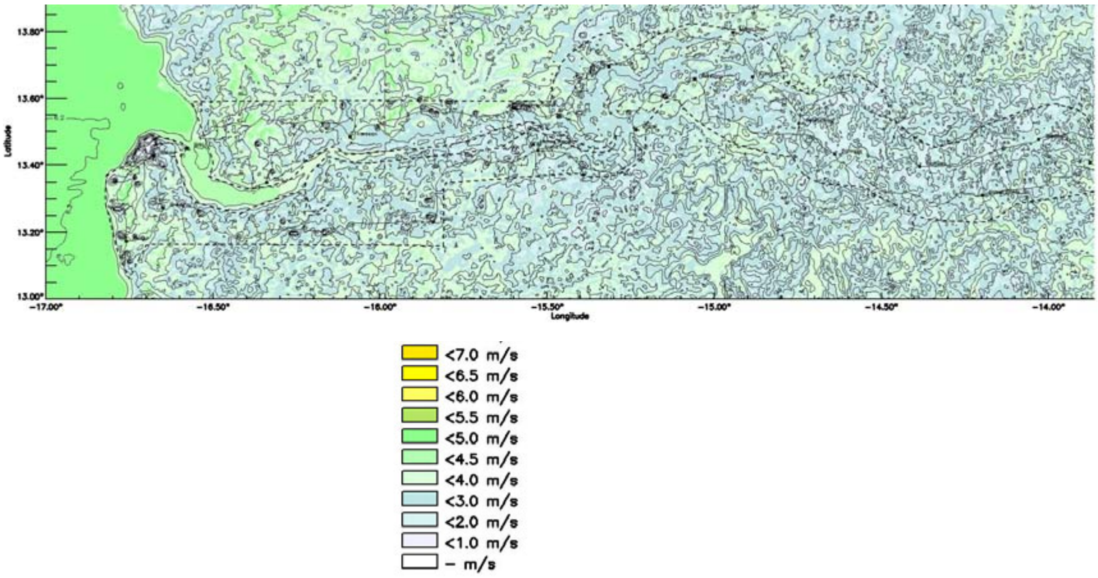


Figure 4-10: Zero wind map of The Gambia at 50m above ground

4.2.2 Wind Data Assessment – Results

All over the year logged wind data show moderate wind conditions for The Gambia, independent of the location of the stations. Near the coast (GREC01 and GREC08, also called Station 1 and Station 8 in the previous Paragraph 4.1, at Kanuma and Jambanjelly, respectively) the wind condition are slightly higher than in the interior due to the free wind flow coming from the sea in the West.

The distribution of the wind direction over the country is not regular. Main directions of North, to West as well as of South to East are found depending of the wind measurement location. The prevailing North-West direction for the station in Kanuma, where higher wind speeds are measured, is an indication of the influence of the coast on the wind conditions.

The monthly mean values for all measurement stations, from GREC01 [3] to GREC08 are shown in Figure 4-11.

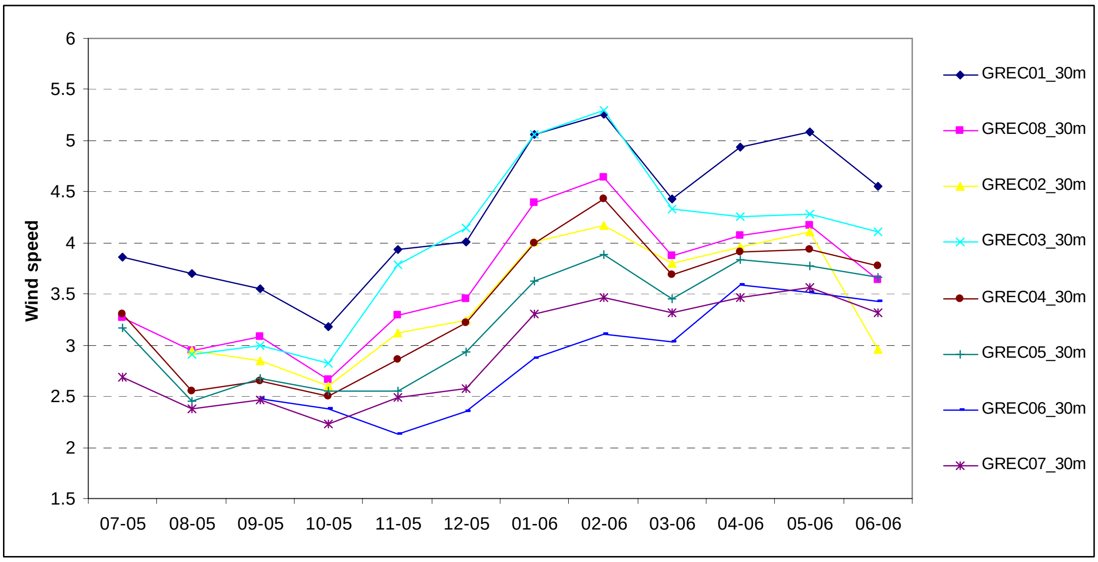


Figure 4-11: Overview of the Measured Monthly Wind Speed

The yearly trend is noticeable with higher wind speed from January until May and lower wind speed from June to December. This trend is getting evident in the next Figure 4-12 adding the yearly wind speed trend of the nearest and representative two WWA Data Base Points, located at position 12.5 North-17.5 West, in the ocean southerly of The Gambia and 15.0 North-15.0 West, in northern part of the country.

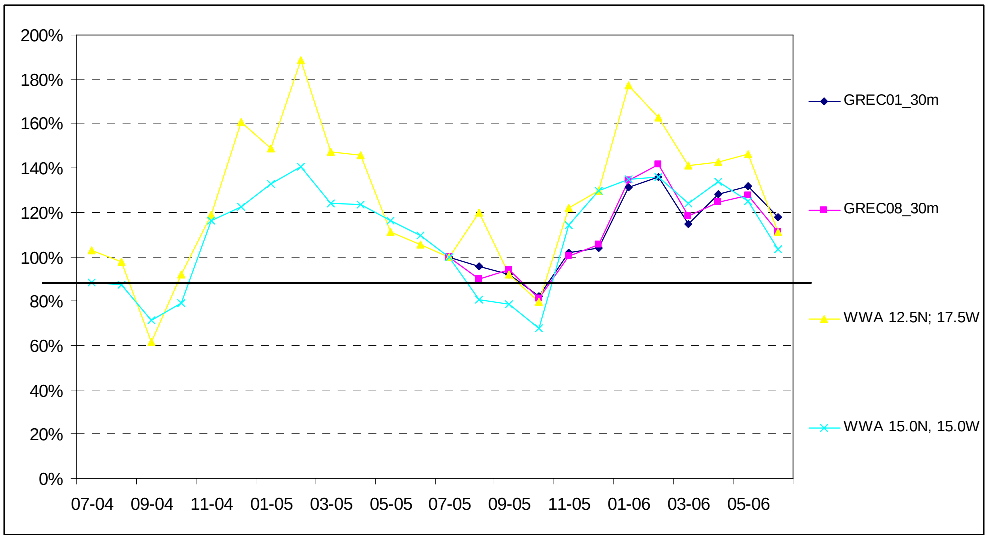


Figure 4-12: Visualisation of the Yearly Trend Using Data from the WWA

[3] These stations are also called Station 1, Station 2 … and Station 8 in the previous Section.

In order to illustrate the difference in the wind direction, the logged wind direction data of the two stations GREC01 and GREC08 are represented in Figure 4-13. Remarkable is the clear increased share of winds from West-North-West at GREC01 station, whereas, GREC08 has more winds coming from East and East-North-East. The main wind direction at station GREC08 is North-West and also as distinctive as the main wind direction of station GREC01.

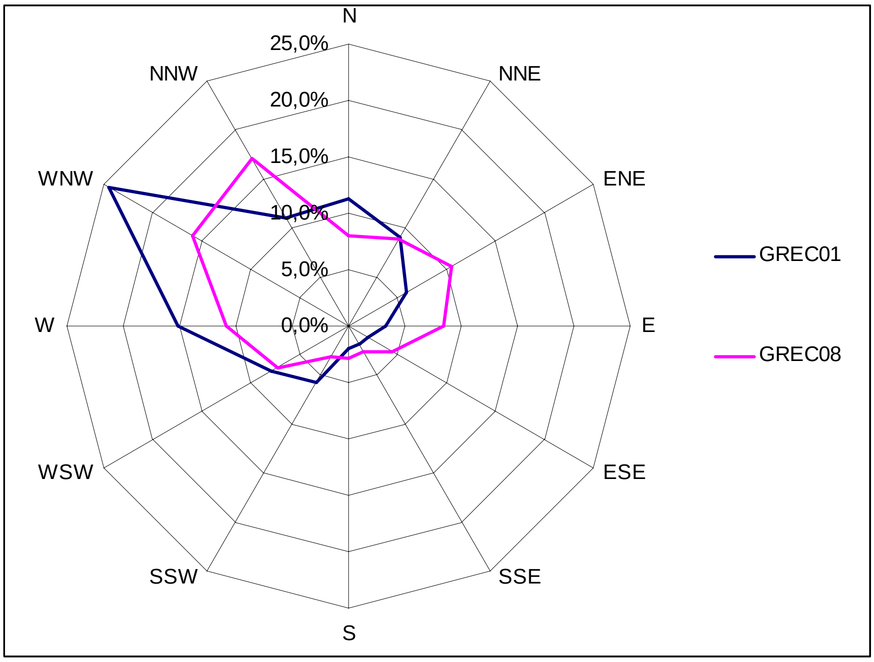


Figure 4-13: Visualisation of the Wind Direction of GREC01 and GREC08

4.2.3 Calculation of Long Term Wind Speeds

The analysed twelve-month measurement period is representing one full weather cycle. However, the meteorological conditions change from year to year. Therefore the measured wind speed values have to be adjusted to reflect a long term wind energy yield. Analyses of several data sets from the WWA, which are located 130 to 230 km around The Gambia, are showing very clearly the wind speed trend over a long term period (20 years), see Figure 4-14. It is remarkable that the two westerly WWA-points, located in the Atlantic Ocean (15.0N-17.5W and 12.5N-17.5W), show the highest monthly wind deviation from the yearly mean value. The months December to May have approximately 52 % higher wind speeds than the rest of the year. Against this, the WWA-points in the interior (15.0N-12.5W and 12.5N-12.5W e.g.) differ only 8 to 13 % around the yearly mean value for the same periods.

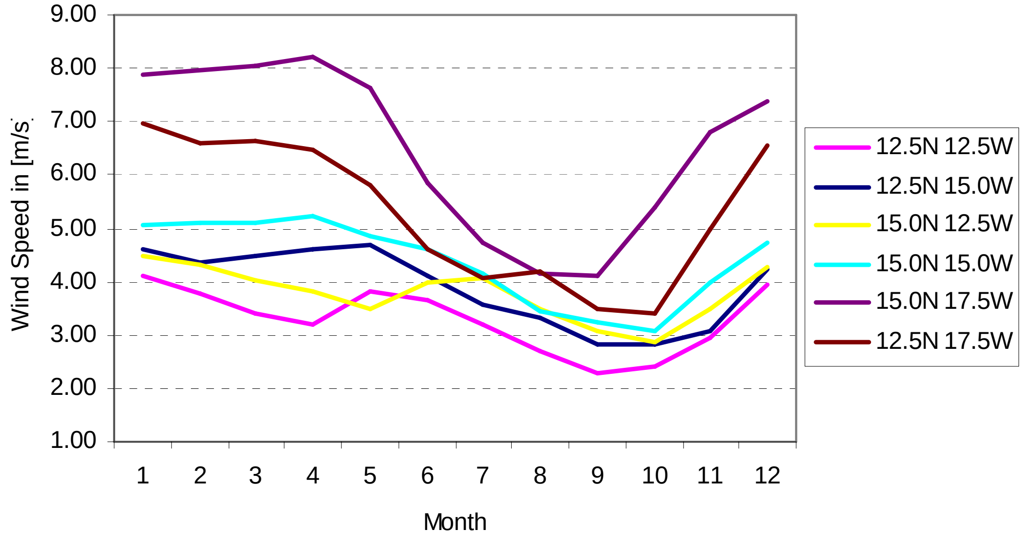


Figure 4-14: Yearly Trend of the Monthly Mean Wind Speeds from Several WWA Based Data Sets at 50m height

Consequently, the considered measurements are adjusted by a correlation factor resulting from the WWA analysis, depending on the location of the measurement masts. The referring correlation coefficients are in the range between 60 % and 90 % for the matching points and can therefore be qualified as good. Figure 4-15 shows the yearly trend of the mean wind speeds of several WWA Based Data Sets. The yearly variation is in the range from 92 % to 106 % compared to the average of a long term period (20 year = 100 %).

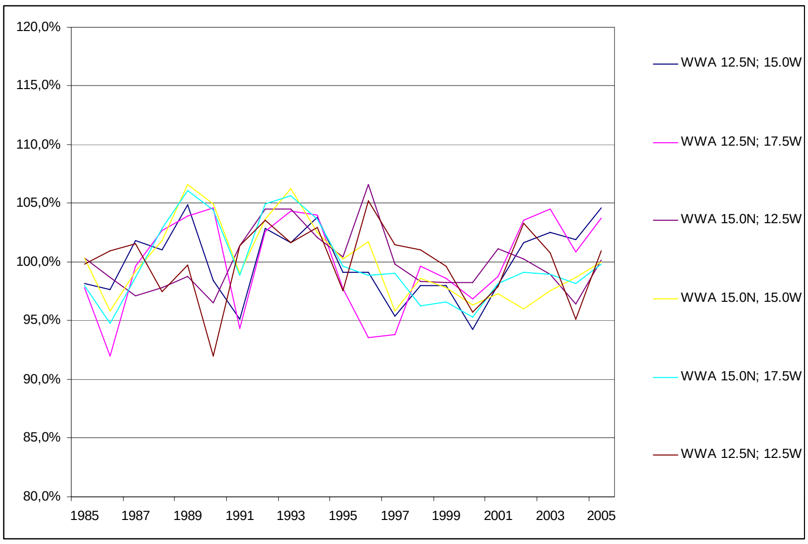


Figure 4-15: Yearly Trend of the Yearly Mean Wind Speeds from Several WWA Based Data Sets at 50m height

With regard to wind direction from WWA, it can be noticed that wind direction is strongly depending on the regarded region. WWA point 12.5N-17.5W, which is located above the Atlantic Ocean, has mainly wind directions from WNW to N whereas the most wind for WWA 15.0N-12.5W (in the north east of The Gambia) comes from ENE and SSW direction, see Figure 4-16. This finding underlines the first wind measurement campaign assessment resulting in a very irregular distribution of wind direction.

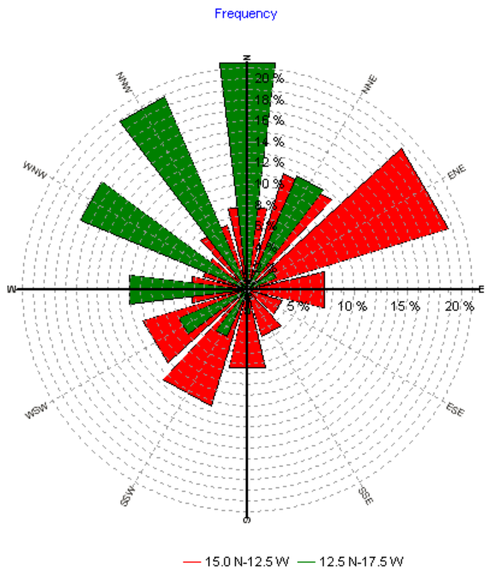


Figure 4-16: Wind Direction Distribution of two WWA Points

For the long term correction of the measured (considered) wind data the scale-factors shown in the Table 4-2 are applied. Depending on the location of the measurement mast and the correlation factors with the WWA points, the measured time period of one year (July 2005 – June 2006) is indicated as a time period with wind speeds slightly above the long term average wind speeds. Therefore the measured wind data are reduced with a scale factor of -2.0 % to -4.6 %.

Table 4-2: Scale Factors for Long Term Wind Speeds

Mast	**WWA-Point**	**Correlation Coefficient**	**Scale factor**
GREC01	12.5N; 17.5W 15.0N; 15.0W	84% 74%	-2.0%
GREC02	12.5N; 15.0W 15.0N; 15.0W	65% 76%	-2.3%
GREC03	12.5N; 17.5W 15.0N; 15.0W	83% 85%	-2.0%
GREC04	12.5N; 15.0W 12.5N; 17.5W	74% 73%	-4.2%
GREC05	12.5N; 15.0W 12.5N; 17.5W	77% 61%	-4.2%
GREC06	12.5N; 15.0W	74%	-4.6%
GREC07	12.5N; 15.0W 12.5N; 17.5W	80% 69%	-4.2%
GREC08	12.5N; 17.5W 15.0N; 15.0W	80% 78%	-2.0%

An overview of the resulting long term corrected wind speeds is shown in the following Table 4-3. The highest wind speeds are measured at the coastal sites with long term corrected wind speeds of 3.4 m/s to 4.2 m/s at 30 m measurement height.

Table 4-3: Overview of the Long-Term corrected Wind Speeds

Mast	GREC01	GREC02	GREC03	GREC04	GREC05	GREC06	GREC07	GREC08
Measurement Period	06.07.2005 - 11.07.2006	06.07.2005 - 11.07.2006	06.07.2005 - 11.07.2006	05.07.2005 - 11.07.2006	05.07.2005 - 11.07.2006	05.07.2005 - 11.07.2006	07.07.2005 - 09.07.2006	07.07.2005 - 09.07.2006
Availability	100%	94%	91%	100%	100%	100%	100%	100%
Adjustment Factor	0.980	0.977	0.980	0.958	0.958	0.954	0.958	0.980
Average Wind Speed 30m [m/s]	***4.2***	***3.4***	***3.9***	***3.2***	***3.1***	***2.8***	***2.8***	***3.4***
Average Wind Speed 10m [m/s]	3.2	2.2	2.6	2.3	2.2	1.5	1.7	2.7
Max Wind Speed 30m [m/s]	14.6	13.5	19.7	15.8	17.6	22.6	13.2	15.9
Max Wind Speed 10m [m/s]	11.6	7.9	15.8	12.9	15.0	15.6	6.2	12.6
Weibull A factor 30m	4.82	3.84	4.46	3.71	3.50	3.17	3.22	3.89
Weibull k factor 30m	2.66	2.50	2.61	2.27	2.37	2.17	2.41	2.60

4.2.4 Summary of Wind Energy Potential in The Gambia

From the previous section, all long-term correlated mean wind speeds, except at GREC01, are below 4.0 m/s at 30 m height, particularly in the inland of The Gambia. Such wind conditions are moderate and hardly suitable for wind powered electricity generation on economical basis. Only at the coast a meaningful use of wind power could be possible. The energy (electricity) supply options for the REMP seem to be then limited to small wind parks or isolated small sized wind turbines in the Gambian coastal areas. All these options should consider suitable turbine technology and integrate wisely wind power to the existing electrical network in the greater Banjul Area.

Due to electrical network capacity size, land availability and infrastructure constraints, it is to expect that the use of medium and small wind turbine sizes will prevail in The Gambia. In addition, scarce technology providers for small size wind energy convertors in the current market justifies to take into account re-powered equipment in The Gambia, as an alternative.

As already mentioned in the Paragraph 4.2.1, the Wind Energy Information System (integrated to a REIS) offers wind energy potential information for a specific location in The Gambia. The WEIS also allows preliminary energy yield calculations for predetermined wind turbine models. This WEIS is currently managed und updated with the new collected wind GBD by the Gambian Department of Energy.

4.3 Biomass Energy

4.3.1 Methodology for Estimation of Biomass Potential in The Gambia

Fuelwood accounts for more than 80 % of the national primary energy consumption and about 97 % of the household energy consumption and is by far the most important renewable energy source in comparison with all other renewable energy sources. Fuelwood is generally used for cooking as tradition and due to the fact that access to firewood is still relatively easy, especially in the rural areas of the country where about half of the population is living [DMC 2005a]. However, the sustainable use of fuelwood for electricity generation demands the existence of very efficient and organised forestry management systems which are not available at the moment in the country [LAHMEYER 2006a]. Consequently, the present biomass resource assessment excludes fuelwood.

Different biomass sources - agricultural crop residues, animal residues, industry residues and municipal residues - are investigated with regard to their suitability for energy (electricity) generation. In addition, the possibilities of energy crops cultivation are analysed. Based on the biomass production in tons per year, the energy potentials can be calculated. The basis for the potential calculation is, in the case of thermo-chemical conversion (for example combustion), the calorific value of the biomass. In the case of bio-chemical conversion (for example biogas), the calculation is done based on the rate of biogas yield of the different substrates. Afterwards, these potentials are assessed with regard to the prevailing boundary conditions of The Gambia and according to the following criteria [IEU 2005]:

- geographic distribution,
- competition of the use of biomass for non-energy applications,
- availability of relevant amounts of biomass (minimum amounts required by the installations) under reasonable transport distances,
- energetic usability of the biomass and
- economic aspects.

4.3.2 Biomass Resource Assessment

The biomass resources assessment for The Gambia can be classified into five main groups, depending on their availability and origin, as follows:

- Agricultural crop residues
- Energy crops
- Animal husbandry residues
- Municipal waste
- Industrial waste

4.3.2.1 Agricultural Crop Residues

The production, harvesting and first processing of crops for human food or for cash crops is connected with the production of agricultural residues. These residues might be an available resource to generate energy. Thus, in the first step the yearly production of crops regarding available land is analysed, as well as the related residues. After this, the availability of the residues and the geographic distribution is investigated. In the third step, the energy potentials for different residues are calculated.

The following Table 4-4 shows the production of the main crops in The Gambia. The crop production varies significantly over the years. These variations result from differences concerning the cultivated areas and the specific yields per hectare, depending on the weather and other factors, changing over the years. Hence, the average of the last three years is calculated to represent the average present situation. The figures are representing the grains of each crop.

Table 4-4: Production of Main Crops [ASRE 2004]

CROP	2002	2003	2004	Average
Early Millet				
Area Planted (ha)	86,523	95,539	108,189	96,750
Total Production (t)	77,341	107,138	115,979	100,153
Late Millet				
Area Planted (ha)	10,459	14,399	14,959	13,272
Total Production (t)	7,277	13,204	16,515	12,332
Sorghum				
Area Planted (ha)	18,337	24,684	26,055	23,025
Total Production (t)	15,209	30,130	28,999	24,779
Maize				
Area Planted (ha)	18,350	21,044	24,200	21,198
Total Production (t)	18,580	33,353	29,209	27,047
Upland Rice				
Area Planted (ha)	6,079	8,862	9,343	8,095
Total Production (t)	4,632	9,783	12,370	8,928
Swamp Rice				
Area Planted (ha)	3,773	6,661	7,264	5,899
Total Production (t)	2,498	8,230	8,734	6,487
Irrigated Rice				
Area Planted (ha)	2,300	2,300	2,227	2,276
Total Production (t)	11,500	11,500	14,925	12,642
Groundnuts				
Area Planted (ha)	105,607	107,937	116,627	110,057
Total Production (t)	71,526	92,937	135,697	100,053
Sessame				
Area Planted (ha)	2,741	3,437	3,437	3,205
Total Production (t)	946	1,230	1,230	1,135
TOTAL COARSE GRAINS				
Area Planted (ha)	133,670	155,667	173,404	154,247
Total Production (t)	118,407	183,824	190,702	164,311
TOTAL RICE				
Area Planted (ha)	12,152	17,823	18,834	16,270
Total Production (t)	18,630	29,513	36,029	28,057
TOTAL ALL CROPS				
Area Planted (ha)	254,170	284,864	312,301	283,778
Total Production (t)	209,509	307,504	363,658	293,557

Agricultural residues can not be generally regarded as available and suitable for energy production due to the following reasons:

- Often they are used for other purposes.
- The generation of residues is not concentrated on few limited locations, so the collection is not cost-effective.
- Certain minimum amounts are required, depending on the end energy use and conversion technology.
- Not all types of biomass can be efficiently converted to all end energy uses.
- Economic aspects, related to above mentioned reasons.

The first two criteria define the factor “availability”. In case the available agricultural residues do not complete a minimum amount for technical and economic viable energy generation, the utilisation rate is defined as zero.

Millet is by far the most important subsistence food crop in The Gambia, in terms of absolute production. Generally, the leaves can be used as fodder but the value is not high though the leaves are dry. The stalks are used extensively for fencing. The rest is usually left in the field where it is destroyed by animals or bush fires. Due to the extensive use of the residues and the distribution all over the fields, a collection rate of 50% can be assumed [DMC 2005b]. That corresponds to a still high amount of residues which can be utilised for energy generation purposes. However, there are critical arguments against the use of millet residues to generate energy (electricity): firstly, the wide distribution of cultivation without mechanised harvesting, including collecting of residues and decentralised processing of harvested products, leads to a wide distribution of the produced residues; secondly, the low density of the residues makes them not favourable for transportation towards centralised places of utilisation for electricity or steam generation; and thirdly, the combustion behaviour is not favourable due to high content of ash. Hence, the energy technical potential of millet for electricity generation is negligible.

Sorghum, sesame and maize (leaves and stalks are a good livestock fodder, and at a village level the cob stalks are sometimes used for direct combustion for cooking) present an insignificant technical potential for electricity generation either due to similar reasons as for Millet.

Rice is the main food in The Gambia, whereas most of the consumed rice is still imported. Rice husk could be used as an energy source, like in Sri Lanka or Brazil. Most of national produced rice is milled at a local level, but some rice is processed in centralised rice mills, especially in the region of Kuntaur. The major rice mill at Kuntaur has the capacity to process up to 4,500 t/a. However, for many farmers it is financially unattractive to sell their rice to the mill. Consequently, the mill only processes about 200 t of rice per year, which means a production of only 30 t/a rice husk. Even with operation at full capacity of 4,500 t/a, husk rice residues would not be enough for a small power plant, but could be used in a boiler for process heat generation – if there is any need.

Groundnuts are a food in The Gambia as well as the main cash crop. About one third of the arable land in the country is used for groundnuts production. They are planted in all districts, whereas the main production is in the rural areas like Kerewan followed by Janjanburegh. In the urban districts like Brikama, fewer groundnuts are produced. During the groundnut harvesting, the groundnut hay is accrued with an amount of about 165,000 t/a. This is intensively used as fodder and therefore it is not recommended for energy generation purposes. The second residue, generated during groundnut processing, is the groundnut shell. The ratio between groundnut kernels to shell is 7:3. With an amount of 100,000 t/a groundnuts, 30,000 t/a of shells are produced. This residue can be used for direct combustion or via briquetting or carbonisation [IEU 2005]. Two main groundnut factories in The Gambia process about 60% of the total production. Consequently, considerable amounts of shells are located on two major locations, one in Kuntaur, the other one on the road between Banjul and Kanifing. The one near Banjul is de-hulling about 30,000 t/a groundnuts under good circumstances, which corresponds to 9,000 t/a of shells. The other one at Kuntaur (out of operation in 2005) can process about the same amount. These groundnut shells present an interesting potential for generating process heat and power. The groundnuts that are not processed in these two factories (the remaining 40%) are exported or used on a local level dispersed in small amounts. If 60% of the total amount of shells is available there is energy technical potential of 306 TJ/a, considering a calorific value of 17 GJ/t. Currently, most of the shells from the factories are burned: the piles from the Banjul factory, lying partly in the mangroves, are set on fire from time to time. This is not only a waste of energy, but due to enormous amounts of generated smoke, as well an environmental hazard.

From the previous paragraphs, it can be summarised that the availability of reasonable amounts of residues at one site for generation of process heat and/or power is very scarce. This is due to current agricultural structures in the Gambia:

- The wide distribution of cultivation without mechanised harvesting including residues collection results in leaving most of harvested residues on the fields.
- Most of the crop production is for subsistence use, though they are not processed in centralised facilities. As a result, there are only small facilities producing on a village scale level limited amounts of residues.

In general, the low density of the residues makes them unfavourable for transportation towards centralised places in order to generate electricity or steam. Thus, energy technical potential of most agricultural crops for electricity generation is irrelevant. Only groundnuts shells are in centralised processing facilities and present therefore a remarkable energy potential for electricity generation.

4.3.2.2 Energy Crops

Crops can be cultivated with the main purpose to produce biomass for energy generation. This is already done in several countries, whereas at least pilot projects are going on in several African countries. A prevalent point of view is that food production in Africa has priority, but this is too simplistic. Some energy plants grow on poor, salty soils (e.g. oil palm), which can hardly be used for agriculture. Others if planted in combination with food crops give better conditions for the food crops: reducing erosion, dropping shadow (e.g. jatropha).

Energy crops can be structured into three classes, depending on the conversion technologies:

- rapidly growing plants (e.g. miscantus grass, eucalyptus) for direct combustion,
- starch or sugar containing plants (e.g. cassava, yam, sweet sorghum, sugar cane) for ethanol production, and
- oil seeds (e.g. soya bean, oil palm, jatropha) for vegetable oils production.

The potential for this kind of energy generation is not assessed in this study due to two main reasons: Firstly, specific yields for different energy crops, particular for The Gambia, with/without irrigation, etc. can only be determined in a reliable way by pilot plantations. Secondly, the acreage of available and suited land is not only depending on geographic information, but on political boundary conditions, which are currently not clear enough defined.

Nevertheless, the future use of energy crops in The Gambia should be supported by the finding of a sustainable solution to shortage of water, which is under practical conditions the most important yield-limiting factor due to high water consumption of energy crops in comparison to typical agricultural plants, the introduction of capital intensive cultivation and harvest technologies (high technical efforts are necessary for higher productivity and economic success), and the implementation of a new infrastructure for harvesting, transportation and handling.

The most promising energy crop (oil seed) for The Gambia appears to be Jatropha (*Jatropha curcas*), a tree which belongs to the family *Euphorbiaceae*. It is a multi-purpose tree of Mexican and Central American origin with a long history of cultivation in tropical America, Africa and Asia. The Jatropha tree is of significant economic importance because of its numerous industrial and medical uses. Jatropha grows throughout most of the tropics and survives on poor, stony soils while being resistant to drought. The plant requires a minimum of 250 mm rainfall per year but grows best on 900 to 1,200 mm. In The Gambia, the annual rainfall is about 800 mm in the north up to 1,200 mm in the south. So there are good conditions for growing Jatropha. It can easily be propagated from seeds or cuttings. It reaches a height of up to 8 m and is cultivated mainly for the production of seeds with an oil content of 55 to 60%. Seed yields of 2.5 tons per hectare have been routinely achieved. Jatropha starts producing seeds within 12 months after seeding but reaches its maximum productivity level after 4 to 5 years. The major product is oil with a hectare yielding approximately 1.6 tons (equal to 57 GJ/ha/a) as well as 1.0 ton of protein-rich feed for animals per year. The oil can serve as fuel for diesel engines, in particular in regions remote from a source of fuel supply. Under the assumption that 50,000 ha are available for Jathropa plantations (10% of country's arable land), the annual production would be 80,000 t Jatropha oil equal to 2,880 TJ/a or 68,700 TOE/a or 81 million litre Diesel. For comparison: the annual diesel consumption in The Gambia in 2005 was 51,000 TOE. The estimation shows then that oil producing plantations can contribute with a significant share to the overall energy supply of The Gambia.

Based on these considerations, Jathropa pilot plantations should be introduced in The Gambia in order to analyse in detail the technical and economic feasibility of this option.

4.3.2.3 Animal Husbandry Residues

Animal waste (solid and liquid manure) can be a good resource for conversion of biomass into energy. There are two pathways of using the residues: in a biogas plant or, only for droppings, through direct combustion. The main problem is the waste collection process.

The only species in The Gambia which produces dung in remarkable amounts for energy generation are cows. Each cow produces an average amount of about 4 kg/day of air-dried dung. In The Gambia there are about 360,000 heads of cattle with an energy theoretical potential of about 650 TJ/a for biogas and 6,000 TJ/a for dung combustion. This is impressive on the first sight, but it is distributed all over the country, since almost all animals spend most of the time outside rather than in stables. For these reasons, the technical potential for electricity generation based on cattle dung is insignificant. Nevertheless, dung from small number of cows could be feedstock for a simple small scale biogas plant, whereas other residues could be added (co-digestion) to increase gas production.

4.3.2.4 Municipal Residues

The main sources for organic municipal wastes are municipal solid wastes, and municipal waste water and human excrements.

4.3.2.4.1 Municipal Solid Waste

The municipal solid waste is partially collected and dumped in landfills. A considerable part is burned in open fires by the households themselves. There are three regular landfills in The Gambia where municipal solid wastes are brought to. The largest one is in Kanifing, the second largest is near Banjul and the smallest is in Brikama.

The waste of 400,000 people is collected in Kanifing with a collection rate of about 50%. The total input material for the landfill is about 40,000 t/a. Around 50 % of the waste is sand, 35 % is organic material, 11% is paper or carton. Glass, wood, metals, textiles and plastics are in sum less than 5% [IEU 2005].

The total input material for the landfill at Banjul is about 20,000 t/a. The collecting rate is 80%. 50% of the material is sand and 32% organic material, the rest is paper/carton, glass, wood, metals, textiles and plastics. Table 4-5 shows some characteristics of the main landfills in The Gambia and estimations about their energy potential.

Table 4-5: Characteristics of the Landfills in Kanifing and Banjul

Landfills	Kanifing	Banjul
Sand	50%	50%
Biogenous organic material	35%	32%
Paper, carton	11%	10%
Other	4%	8%
People	400,000	50,000
Collection rate	50%	80%
Amount (t/a)	40,000	20,000
Potential Combustion (TJ/a)	**276**	**126**
Biogenous organic material	35%	32%
Paper, carton	11%	10%
Heat value organic content (MJ/kg)	15	15
Landfill gas (TJ/a)	**21**	**10**
Biodegradable organic content	35%	32%
Anaerobic zone inside the landfill	70%	70%
Landfill gas collection rate	40%	40%
m^3 methane per ton organic matter	150	150

The energetic conversion of the contained organic material can be realised by incineration or anaerobic digestion.

Incineration of municipal waste is an environmentally acceptable way but is technically demanding, thus expensive. It is more complex than the combustion of pure biomass. The amount of energy generated (402 TJ/a, from 60,000 t/a calculated with 46% fraction of combustible material and heating value of 15 MJ/kg) is by far not enough to compensate expenditures. The reason why increasing shares of municipal waste are being incinerated in industrialised countries is not generation of energy, but reduction of waste and inertisation before land-filling. The lack of profitability, the high investment and the complex technology are reasons why incineration of municipal waste is not regarded as suitable technology for energy generation for The Gambia.

The other possibility to generate energy from waste is collection and burn of landfill gas, whereas the main problems are:

- The waste in Gambian landfills is not compacted. Therefore the aerobic zone goes very deep in the landfill body.
- The waste is very dry, that inhibits the methane generating micro organisms. Water should to be spread over the compacted landfill.
- The investment costs to use landfill gas are high, but much lower than for the option of direct combustion.

It is difficult to estimate the technical potential for landfill gas if no measured data about the current gas production is available. It could be estimated roughly based on the volume, height / length / depth ratio, age of the landfill, yearly input, content of biodegradable material, etc. Since this information is not available either, it was estimated based on the data in the Table 4-5, inclusive the yearly input flow. The assumption is that the old content of the landfill is not contributing to landfill gas generation, since it was already degraded during the uncovered and uncompacted period before. An anaerobic zone in the landfill of 70 %, a gas production rate of 150 m³ methane per ton of organic material and a gas collection rate of 40 % is assumed. Based on these data, the landfill-gas technical potential in Kanifing is 21 TJ/a and in Banjul 10 TJ/a. In fact, the technical potential by converting landfill gas is about 10 times less than direct combustion. Landfill gas is recovered usually on very large landfills only; the ones in The Gambia are too small for an efficient project. From the environmental point of view the recovery of methane is of low importance as well: if the landfill is well aerated and dry, low amounts of methane are emitted.

4.3.2.4.2 Municipal Waste Water and Human Excrements

There is one waste water collecting system in Banjul and other one at the Atlantic coast where the hotels are located. The information available about these systems is poor. There are no exact measurements about the system's capacity and organic content in the waste water, so the energetic potentials can not be calculated.

Another option for the use of human excrements for energy generation in areas without waste water collecting system is to feed them directly in a biogas plant. At the village level, the human excrements can be mixed with other organic residues like kitchen waste and cow dung as feedstock and digested in small scale digesters. In specific cases, a bigger biogas plant in common could serve and be supplied by a group of several hundreds of people. This might be an option for big schools, hospitals, prisons, barracks or other places where lots of people gather. There is usually a hygienic problem with the disposal of the excrements if many people are living in one small area. On the one hand, the main objective of such a biogas plant would be to solve hygienic problems. On the other hand, the production of biogas could substitute fuel wood for cooking. 100 persons produce enough feedstock for up to 2-2.5 m³/day methane (equals up to 4 m³/day biogas). Since methane has a calorific value of 10 kWh/m³ this corresponds to 32 GJ/a.

4.3.2.5 Industrial Residues

There are only very few industries in The Gambia that have an amount of organic residues worth mentioning. These industrial installations are fish factories, slaughterhouses and beverage producing factory.

4.3.2.5.1 Fish Industry

In The Gambia about 43,000 t/a fish are caught and 10,000 t/a of them are processed in fish factories. The residues generated account about 50 %. Apart from the fish factories, the waste of the fish is used as fertilizer and poultry fodder. Industrial processing is carried out in 6 to 8 larger factories as well as in some small factories. The two biggest factories produce about 12 ton fish per month, with about the same amount of residues. The waste is dumped in a landfill [IEU 2005].

It is unfeasible to build up a biogas plant exclusively for the fish waste not only because of the problems caused by high salt content (which impedes the methanisation) but also because of the relative high specific investment and efforts to run the installation. However, it can be additional feedstock to a biogas plant if other substrates are available at the same place. In this case, these fish residues could produce about 28 m³/d methane (equals around 45 m³/d biogas), which corresponds to a technical potential of 0.38 TJ/a.

4.3.2.5.2 Meat Industry

There are only small slaughterhouses in The Gambia. No exact data about the number of them and/or slaughtered cows are available. In Abuko, one of the biggest slaughterhouses, less than 50 cattle per day are slaughtered.

4.3.2.5.3 Beverage Producing Industry

There is one beverage production site generating relevant amounts of residues in The Gambia: the Banjul Breweries LTD, where about 6,000 m³ beer and other refreshing drinks are produced. From the total beverage production an amount of 36,000 m³/a waste water is produced. Since this waste water has a relatively high biodegradable organic content, an anaerobic treatment generating biogas could be advantageous.

Regarding the organic load, the waste water has an average biological oxygen demand (BOD) of about 5,000 g O_2/m³ of waste water. The technical energy potential of the biogas generated is about 3.4 GJ/a, assuming a chemical oxygen demand (COD) of 8,000 g O_2/m³ and a biogas production of 0.35 m³ methane per kg COD.

Other beverage producing factories are on such a small scale that the energetic conversion of their residues can not be considered if no other residues were added.

4.3.3 Summary of Biomass Energy Potential in The Gambia

The following Table 4-6 summarizes the available resources and estimations for biomass energy in The Gambia.

Table 4-6: Biomass energy potentials in The Gambia

Biomass source	Theoretical Potential in TJ/a	Technical Potential in TJ/a
Agricultural residues		
Millet	3,968	0
Sorghum	874	0
Maize	973	0
Rice straw	635	0
Rice husks	67	0
Groundnuts		
Facility Kuntaur	255	153
Facility Banjul	255	153
Energy crops		
for direct combustion	-	0
for ethanol production	-	up to 107 GJ/ha/a
for vegetable oil production	-	57 GJ/ha/a
Animal husbandry residues		
dung combustion	6,000	0
dung for biogas	650	16 grazing cows: 29 GJ/a
Municipal residues		
Waste incineration (Banjul+Kanifing)	-	402
Landfill gas Kanifing	-	21
Landfill gas Banjul	-	10
Waste water	-	0
Human excrements	-	unit 100 persons: 32 GJ/a
Industrial residues		
Fish industry	-	facility with 144 t/a: 0.38
Meat industry	-	0
Banjul Brewery	-	0.0034

Based on this assessment, promising options for biomass electricity generation are very restricted. Due to scale (quantity) and resource availability (disperse) constraints, several options are discarded after first evaluations. The only concrete biomass based electricity supply option for the REMP appears to be the use of groundnut shells.

A Biomass Energy Information System BEIS (in Data Base form) is available and integrated to the REIS. The BEIS basically allows technical potential calculations for five different resources groups (see Paragraph 4.3.2) and is currently managed und updated by the Gambian Department of Energy.

5 Renewable Energy Supply Options

Several supply options are analysed, based on the assessed renewable energy potential. This review begins with the evaluation of the different available conversion technologies and finalizing with the dimensioning of power supply solutions, since the REMP is focussed on the generation of electricity. The evaluation is performed taking into consideration technologies which are applicable and appropriate under the special conditions of The Gambia.

Technical and economic parameters for each proposed option are determined in order to be used afterwards in the economic evaluation. The technical parameters come from preliminary designs performed by commercial software, while the economic parameters follow to some estimation for each specific considered option. The investment cost estimation includes grid interconnection expenditures, roads, transport costs and decommissioning costs. The O&M costs comprise spare parts, personal expenses, as well as preventive and corrective maintenance costs.

5.1 Solar Energy

Due to good solar radiation values all over the country, mainly solar photovoltaic based power supply possibilities are considered. PV Power Plants, Solar Home Systems (SHS) and Hybrid Diesel-PV Systems are analysed in the following sections. Solar thermal power generation plant is excluded because of technical and economic constraints mentioned in Paragraph 4.1.4.

5.1.1 Large PV Power Plant

This application is only explored for the western region, the only one benefiting from a larger power grid (around 40 MW of total capacity). This grid runs from Banjul, to Kanifing and down to Brikama. It is proposed that the PV power plant should be located around Brikama in order to take advantage of some existing large inhabited areas (although land availability has still to be checked in detail).

The main purpose of this plant would be to save fuel as the power for this grid is generated through the use of large diesel aggregates. Given the high values of solar irradiance in GBA and a large size PV plant, fuel savings would reach significant levels and release a part of this burden on Gambia's economy. The calculation is therefore performed for a grid connected 1 MW PV power plant, since it is assumed a linear growth of investment costs for plants larger than 1 MW, as a result of the PV technology modularity. Thus, the 1 MW plant is thought to be used as a "unit-plant" for larger PV plants, which could then be planned by simply summing up such "unit-plants" (use of a scale factor). This simplification is only done for evaluation purposes in the REMP preparation. The "final" size of the PV power plant is mainly limited by the admissible penetration factor and should be determined by a Feasibility Study.

At this point, it is assumed that the penetration factor [4]should not be higher than 5.0 -10% attributable to Gambian grid's stability restrictions and simultaneity with other renewable energy supply options i.e. wind energy. Starting from a 40 MW grid capacity, this means that maximum PV installed capacity should lie between 6 and 12 MW, depending also on the selected PV technology as well.

[4] Penetration factor is defined as the quotient between the renewable energy based electricity and conventional (thermal) generated electricity during the same time period and fed into the same grid.

The PV power plant technical design is performed using the software PV-SOL. Various combinations of industry proven components with different layouts are compared and the system offering the best overall efficiency is selected. The sizing of the components (size of the modules, inverters, etc.) is optimised in terms of performance and efficiency to allow the highest energy yield at lowest turnkey investment, in addition to easier and quicker construction.

The technical and economic (based on costs of 2006) parameters for the 1 MW PV power plant are given in the following Table 5-1.

Table 5-1: Technical and economic parameters of 1 MW PV plant (2006)

Technical and economic parameters			
Module type		Polycrystalline	
Capacity per module		200	W
Number of modules		5,000	-
Capacity total		1	MW
Structure type	No trackers	Free-standing in open space	
Turnkey Investment cost		**6,008,471**	**USD**
O&M over 20 years			
1 - 10 year	2% of Investment Cost	120,169	USD/a
11 - 20 year	3% of Investment Cost	180,254	USD/a
Energy Production		**First Year**	
System Efficiency	9.9 %	PV Array Efficiency	10.4 %
Performance Ratio	74.2 %	Inverter Efficiency	95.5 %
Energy to Grid		1,536,936	kWh/a
Self Consumption		485.8	kWh/a
Net Energy Sold to Grid		1,536,450	kWh/a

The amount of fuel saved over the 20 years of the project is also calculated. It is based on the average amount of solar resource (according to the information from SEIS) and includes all aspects related to losses, cell degradation, etc. Indeed, the tendency of reduction in fuel savings throughout the operation of the PV plant, which is observed in the Table 5-2, is proportional and related to the reduction of generated PV solar electricity due to cell degradation.

It is foreseen that the construction and connection of a 1 MW PV power plant onto the western grid would allow The Gambia to save the equivalent of about 10 million litres Diesel over the whole project's lifetime.

Table 5-2: Fuel saved per year due to the operation of the PV plant

Diesel Fuel saved in l per year	
Year	Amount in l/a
1	512,150
5	506,032
10	498,487
15	491,054
20	483,732

In order to preliminarily determine implementation schedules for large PV power plants in The Gambia, a specific detailed analysis with regard to PV competitiveness on global markets suggest as break-even year 2017 [STATTHORST 2006]. Therefore, larger PV power plants, as supply option for the REMP in The Gambia, are initially being considered from 2015 on with a conservative growth rate of 100% for each 5-year period, as shown in Table 5-3. This assumption is afterwards verified with the economic evaluation in order to decide its suitability for the definitive investment plan formulation.

Table 5-3: Implementation schedule for large PV power plants

	2006	2010	2015	2020	2025
Large PV power plant	-	-	1,000 kW	1,000 kW	1,000 kW

5.1.2 Solar Home Systems

SHS are a good power supply option for remote communities or small villages, where grid connection is not practical in cost-effective terms [LEONI 1997].

For the design of a SHS program, different products (SHS options) corresponding to diverse categories of incomes are determined. These applications are limited to villages with less than 450 households, since larger communities could gain increased benefit from isolated power supply systems or grid extension plans [EDF 1992, LAHMEYER 2005a]. As shown in Table 5-4, five different levels of income are defined and a suitable SHS for each one is proposed, as described in Table 5-5. After designing the systems, the monthly payment rate was assumed within an acceptable range for the people of rural areas of The Gambia (basically below 25 % of net income) [DMC 2005a, LAHMEYER 2006b].

Table 5-4: The different SHS options for diverse income levels

Class 1	Class 2	Class 3	Class 4	Class 5
Solar lantern	Pico SHS	Mini SHS	Standard SHS	Large SHS
Very low income		Medium income		High income

Table 5-5: Technical Specifications of the Solar Home Systems

System	Components
Solar Lantern	A lantern composed of a 5W PV module, a 4W/150 lumen low energy bulb and a 5h autonomy battery
Pico SHS	12 W PV module, 3 A charge controller, 45 Ah/12V solar battery, 3 low consumption bulbs (7W/400 lumen)
Mini SHS	40 W PV module, 12 A charge controller, 60 Ah/12V solar battery, 4 low consumption bulbs (2 at 9W/600 lumen and 2 at 11 W/900 lumen)
Standard SHS	75 W PV module, 12 A charge controller, 130 Ah/12V solar battery, 5 low consumption bulbs (2 at 9W/600 lumen and 3 at 11 W/900 lumen)
Large SHS	120 W PV module, 20 A charge controller, 180 Ah/12V solar battery, 6 low consumption bulbs (2 at 9W/600 lumen and 4 at 11 W/900 lumen)

The following Table 5-6 presents some preliminary costs for the considered SHS options.

Table 5-6: Preliminary costs for the different SHS options

		Class 1	Class 2	Class 3	Class 4	Class 5
		Solar lantern	Pico SHS	Mini SHS	Standard SHS	Large SHS
Specific energy cost	USD/kWh	2.79	5.74	2.58	1.98	1.55
NPV investment + O&M	USD	91.1	749.6	1,125.3	1,614.4	2,028.9
NPV O&M	USD	31.1	279.2	341.7	514.0	621.3
Total levelised costs	USD/month	1.53	9.42	14.15	20.30	25.51
Levelised O&M + replacement	USD/kWh	0.95	2.14	0.78	0.63	0.48

After a definition of socio-economic levels, SHS technical options and costs, the market dissemination is evaluated in order to provide SHS to about 9,000 rural households in the Gambia in 20 years from 2006 (Base Year). The Table 5-7 presents the penetration rate evolution over time for these 9,000 households.

Table 5-7: Coverage of the considered population by SHS

	2006	until 2010	until 2015	until 2020	until 2025
Solar lantern	0%	8%	36%	83%	100%
Pico SHS	0%	3%	20%	70%	100%
Mini SHS	0%	5%	38%	88%	100%
Standard SHS	0%	7%	51%	95%	100%
Large SHS	0%	7%	51%	95%	100%

Taking into account the cost of SHS in 2006 as base year, its evolution over time (a price reduction of 5% per year was considered), coverage ratios and replacements costs, the investment costs needs for a SHS program with 20-year horizon are estimated and shown in Table 5-8.

Table 5-8: Investment costs of a complete SHS program in The Gambia

	until 2010	until 2015	until 2020	until 2025
Solar lantern	7,716	19,902	30,800	23,237
Pico SHS	24,198	93,621	217,328	114,351
Mini SHS	60,465	311,913	362,029	98,046
Standard SHS	113,214	584,022	451,905	97,909
Large SHS	144,820	747,064	578,064	125,242
Total investment [USD]	**350,416**	**1,756,525**	**1,640,127**	**458,786**

Over 20 years, the total amount of investment is estimated to be about 4.2 million USD for the equipment of more than 9,000 households, positively affecting the life of more than 90,000 people [CSD 2005].

5.1.3 Small PV power plants as fuel saver

This third option is only proposed for the six isolated grids (diesel generation) located in the country-side. The installation of PV generation capacity would allow savings on fuel and on maintenance expenses. It is assumed that with a correct load management, the diesel generators could run at good efficiency levels during day and be stopped some parts of the night. Of course, this last case would only be possible with the installation of battery banks.

Unlike as in the Paragraph 5.1.1, the considered upper limit for a penetration factor in these grids is higher, namely 20%, due to the recently installed generation systems and better maintained electrical networks. Three renewable energy penetration factor scenarios: 10, 15 and 20% are defined for each grid in order to analyse the electricity cost generation sensitivity with regard to this variable.

The design of these fuel-saving PV systems is performed using HOMER, well-known software developed by the National Renewable energy Laboratory (NREL, USA). The components of the whole energy production system are specified in the program: existing diesel generators, PV modules, battery banks, inverters, and daily load of the considered grid. Afterwards, the resources are indicated: diesel fuel (price) and solar resource. At last, all financial parameters are defined: investment and replacement costs for the various elements, O&M costs, components lifetime, interest rate and project duration. Investment costs for diesel gen-sets are not included as the diesel aggregates are already in place and as the PV systems are only seen as fuel saver. The goal of this part of the analysis is not to provide power to a remote region where there is not already generation capacity existing.

As stated before, main criteria for the PV systems sizing is the renewable energy penetration factor, which is set at 10, 15 and 20%. As different designs can comply this factor, a second criterion is the levelised cost of produced energy (in USD/kWh). If Homer proposes different systems, then the one with the lowest generating cost is selected.

The existing six isolated grids in The Gambia, powered by diesel generators, are considered. Table 5-9 presents in detail this Diesel generation capacity.

Table 5-9: Diesel generation capacity for isolated grids of The Gambia

Grid Name / City	Bansang	Barra	Basse	Farafenni	Kuntaur	Kerewan
Installed Capacity in kW						
Total	**600**	**460**	**1400**	**1400**	**180**	**220**
Generator 1	*200*	*200*	*600*	*600*	*60*	*100*
Generator 2	*200*	*200*	*600*	*600*	*60*	*60*
Generator 3	*200*	*60*	*200*	*200*	*60*	*60*

The following Table 5-10, Table 5-11 and Table 5-12 present the selected design options for the six considered grids, including the Diesel fuel saved thanks the integration of the PV power plants.

Table 5-10: Selected Design option for PV plants, penetration factor 10%

Grid	Bansang	Barra	Basse	Farafenni	Kuntaur	Kerewan
PV Generator in kW	**130**	**90**	**310**	**270**	**37**	**45**
Energy produced in kWh/day	643	478	1,418	1,430	195	237
Batteries (number)	85	35	90	90	50	50
Inverter in kW	105	80	230	230	50	50
Diesel Consumption in l/a	691,403	513,017	1,562,049	1,558,265	204,182	244,846
Fuel saved in l/a	**107,855**	**78,205**	**236,145**	**239,929**	**35,625**	**44,451**

Table 5-11: Selected design option for PV plants, penetration factor 15%

Grid	Bansang	Barra	Basse	Farafenni	Kuntaur	Kerewan
PV Generator in kW	**190**	**130**	**470**	**410**	**55**	**65**
Energy produced in kWh/d	939	715	2,150	2,171	290	343
Batteries (number)	85	105	95	95	55	65
Inverter in kW	155	80	340	340	50	55
Diesel Consumption in l/a	655,706	493,091	1,492,153	1,486,622	194,708	233,529
Fuel saved in l/a	**143,552**	**98,131**	**306,041**	**311,572**	**45,099**	**55,768**

Table 5-12: Selected design option for PV plants, penetration factor 20%

Grid	Bansang	Barra	Basse	Farafenni	Kuntaur	Kerewan
PV Generator in kW	**260**	**185**	**650**	**550**	**75**	**90**
Energy produced in kWh/d	1,285	982	2,974	2,912	395	474
Batteries (number)	90	105	120	115	75	65
Inverter in kW	160	140	470	440	50	65
Diesel Consumption in l/a	631,008	466,085	1,425,225	1,425,227	181,524	220,622
Fuel saved in l/a	**168,250**	**125,137**	**372,969**	**372,967**	**58,283**	**68,675**

The installations of these small systems are scheduled earlier than large PV power plants, due to their smaller sizes and expected faster implementation. These supply options are considered in the REMP for The Gambia from 2010 on with a conservative growth rate of 100% for each 10-year period. Table 5-13 presents the implementation schedule for small PV plants with 10% penetration factor, geographically divided. The grids Farrafeni and Barra are added up to Kerewan and registered under LGA Kerewan (given that grids sometimes cover two different LGA, it is assumed that PV generators are installed at the same place as the diesel generators), whereas the grid Bansang is compiled under LGA Janjanbureh.

Table 5-13: Development of small PV plants, penetration factor 10%

Year	LGA of Mankasonko	LGA of Kerewan	LGA of Kuntaur	LGA of Janjanbureh	LGA of Basse
Base	**-**	**-**	**-**	**-**	**-**
2010	**-**	**405 kW**	**37 kW**	**130 kW**	**310 kW**
2015	**-**	**-**	**-**	**-**	**-**
2020	**-**	**405 kW**	**37 kW**	**130 kW**	**310 kW**
2025	**-**	**-**	**-**	**-**	**-**

All above defined options have to be evaluated under economic considerations in order to refine the supply options selection.

5.1.4 PV-Diesel Small Hybrid Systems

This option for small sized villages relies on the installation of isolated stand-alone systems including a PV array, a small sized Diesel generator and a battery bank for energy storage.

In a previous analysis (Paragraph 5.1.2), villages with less than 450 households are considered to be supply by SHS systems, under the assumption that every household can afford electricity. For villages with more than 450 households but less than 900 households, it is assumed that around a third of the local population can afford electricity. These villages are then divided into three groups, as presented in Table 5-14.

Table 5-14: Villages considered for implementing PV-diesel hybrid systems

Village Type	Number of Households purchasing power	Total Number of Households in the village	Hybrid system designed for
1	150-200	450-600	175 Households
2	200-250	600-750	225 Households
3	250-300	750-900	275 Households

The next Table 5-15 presents the preliminary supply option designs for the considered village types, calculated by the program HOMER.

Table 5-15: Technical description proposed PV-Diesel hybrid systems

Proposed Solutions for PV-Diesel Hybrid Systems	175 Households	225 Households	275 Households
Diesel generator in kW	20	17	30
PV generator in kW	15	25	25
Batteries (number of pieces)	26	20	45
Inverter in kW	11	12	20
Diesel consumption in l/a	30,845	42,385	46,648
Diesel Generator running time in h/a	4,760	4,475	4,849

Based on demographic information from Gambian Central Statistics Department (CSD), villages are sorted out according to their population and classified under above defined types 1, 2 or 3.

For the Greater Banjul Area, there is absolutely no village under those categories because of the great density of population. These villages are currently being supplied by the Gambian western grid.

For the other regions, except Brikama, the selected villages are already (or will be soon) connected to the isolated grids running on diesel.

In the case of the Brikama's LGA, since all rural areas in this region will experience negative population growth rates over the next years, there could be a chance for the implementation of small PV-Diesel hybrid systems. However, they are not considered as supply option for the REMP, as the "bigger" hybrid options (PV plants as fuels savers integrated to existing Diesel powered electrical systems) may provide a more extensive benefit at national level.

5.1.5 Summary of Proposed Solar Supply Options

All identified supply options based on solar energy are presented in Table 5-16.

Table 5-16: Overview of proposed solar supply options

	LGA		Supply Option	2006	2010	2015	2020	2025
1	**GBA**			-	-	-	-	-
2	**Kanifing**			-	-	-	-	-
3	**Brikama**							
			PV_1	-	-	1,000 kW	1,000 kW	1,000 kW
			PV_2					
			SHS	1.9 kW	5.8 kW	43.7 kW	85.9 kW	93.6 kW
			10%	0	0	0	0	0
		PV_3	15%	0	0	0	0	0
			20%	0	0	0	0	0
4	**Mansakonko**							
			PV_2					
			SHS	0.9 kW	2.7 kW	20.4 kW	40.0 kW	43.6 kW
			10%	0	0	0	0	0
		PV_3	15%	0	0	0	0	0
			20%	0	0	0	0	0
5	**Kerewan**							
			PV_2					
			SHS	2.0 kW	5.9 kW	44.7 kW	87.8 kW	95.7 kW
			10%	-	405 kW	-	405 kW	-
		PV_3	15%	-	605 kW	-	605 kW	-
			20%	-	825 kW	-	825 kW	-
6	**Kuntaur**							
			PV_2					
			SHS	2.0 kW	5.9 kW	44.7 kW	87.8 kW	95.7 kW
			10%	-	37 kW	-	37 kW	-
		PV_3	15%	-	55 kW	-	55 kW	-
			20%	-	75 kW	-	75 kW	-
7	**Janjanbureh**							
			PV_2					
			SHS	2.0 kW	6.1 kW	46.3 kW	90.9 kW	99.0 kW
			10%	-	130 kW	-	130 kW	-
		PV_3	15%	-	190 kW	-	190 kW	-
			20%	-	260 kW	-	260 kW	-
8	**Basse**							
			PV_2					
			SHS	0.4 kW	1.2 kW	8.7 kW	17.1 kW	18.6 kW
			10%	-	310 kW	-	310 kW	-
		PV_3	15%	-	470 kW	-	470 kW	-
			20%	-	650 kW	-	650 kW	-

Code	Technology
PV_1	Large PV Power plant
PV_2	
SHS	Solar Home Systems
PV_3	Small PV Power plant as fuel saver

5.2 Wind Power

As the wind speed in the interior of The Gambia is significant lower than the minimum for economically viable application of wind power, no wind energy based supply options are proposed for these regions. Typical hybrid systems like stand-alone Wind-Diesel systems of different size with or without battery banks are not applicable because of their higher generation costs due to low wind speeds. The contribution of the wind power to the entire electricity supply of a standard medium sized village with known demographic development in the hinterland of The Gambia would be too low.

On the other hand, Gambian coastal areas present wind regimes which are worthy for further analysis. Small wind parks and isolated small sized wind turbines integrated to the existing electrical network in the GBA, as well as stand alone hybrid wind-Diesel systems in the coastal area are options to be analysed.

5.2.1 Small Wind Parks

Possible application of wind power is focused on integration of fuel-save options in existing electrical networks at the western coast. Locations near Tujering in the west of LGA Brikama (District of Kombo South) and in the north of Essau, LGA of Kerewan (District of Lower Niumi) are of interest. Land availability has still to be checked in detail.

Six different scenarios with new and also with repowered (refurbished) wind turbines of the 30-660kW class are set up including their economic parameters, i.e. turnkey investment, O&M costs. A possible extension of the installed capacity after 5 and 10 years is also considered. The wind turbine size is selected taking into account similar wind power studies on the western part of Africa and Gambian infrastructure characteristics. Grid stability, one of the most important factors, should not be affected by wind power with the proposed sizes.

In 2006, the available installed power generation capacity in LGA of Brikama and GBA is approximately 40 MW. In general, the wind penetration factor for the Gambian western grid should not be higher than 15% taking into consideration similar cases in Africa [LAHMEYER 2003, GTZ 2004]. Simultaneity with other renewable energy supply options i.e. solar energy is also considered for this limitation.

In order to avoid grid instability risks in the Brikama area a capacity of 3.96 MW is chosen as one preliminary possible scenario, which means a penetration factor less than 5%. Six wind turbines with capacity of 660 kW each will be installed. An extension of additional 3.96 MW after 5 and 10 years are considered for the REMP formulation, which has to be verified depending of grid development and land availability in the future.

The design data of the proposed small wind park, as well as technical and economic parameters based on data from 2006 are presented in Table 5-17.

Table 5-17: Technical and economic parameters Small Wind Park 1a

Technical and economic parameters		
WEC type	Vestas V47	New
Capacity	660	kW
Number	6	
Total capacity	3.96	MW
Hub height	65	m
Turnkey Investment cost	5,712,000	USD

O&M over 20 years		
1 - 10 a	169,182	USD
11 - 20 a	253,773	USD
Energy production per WEC	313	MWh/a
Total net energy production	1,878	MWh/a
Full load hours	474	h/a
Fuel Saving	626,000	l/a
Lifetime	20	a

A second option for Brikama LGA could be the installation and grid integration of six smaller sized wind turbines with capacity of 250 kW each. Total capacity will be then 1.5 MW with optional enlargement in the future (after 5 and 10 years, as well). This also depends on land availability. Grid stability problems caused by these turbines are not expected due to the conservative low penetration factor. However, space problems may occur in Brikama region, where the population density is said to increase extremely mid-term.

In case of increasing grid capacity by conventional power or by (inter-)connecting other existing grids, the fluctuation in the grid will be better compensated and some additional wind turbines can be installed, also with regard to the suppressed demand, which will directly make use of the new power.

Another factor of site selection is the existing infrastructure of the surrounding of the selected wind park sites, which has to allow easy transportation and erection of the towers and the nacelle. Most of Gambian territories are relatively flat and not very complex, which can be regarded as advantageous for wind turbine transportation and installation.

Technical and economic parameters for the proposed second option based on data from 2006 are presented in Table 5-18.

Table 5-18: Technical and economic parameters Small Wind Park 2a

Technical and economic parameters		
WEC type	Fuhrländer FL 250	New
Capacity	250	kW
Number	6	
Total capacity	1.5	MW
Hub height	50	m
Turnkey Investment cost	2,609,981	USD
O&M over 20 years		
1 - 10 a	86,193	USD
11 - 20 a	129,290	USD
Energy production per WEC	114.80	MWh/a
Total net energy production	688.78	MWh/a
Full load hours	459	h/a
Fuel Saving	229,594	l/a
Lifetime	20	a

Third scenario for small wind parks is set up near the villages of Barra/Essau in LGA of Kerewan, District of Lower Niumi. Grid exists but relative small compared to GBA and Brikama. Therefore the proposed wind turbine size is significant smaller. New diesel generators will feed the grid with a total capacity of 460 kW. Two wind turbines with capacity of 30 kW each will be considered for the small grid near the coast. Here, the penetration factor is a bit higher, but as the wind condition is quite moderate grid problems may occur only at higher wind speeds. In this case, a switch off automatic and a dump load (water pumping system for example) can take care of grid stability.

The proposed third scenario presents the technical and economic parameters based on data from 2006 summarised in Table 5-19.

Table 5-19: Technical and economic parameters Small Wind Park 3a

Technical and economic parameters		
WEC type	Fuhrländer FL 30	New
Capacity	30	kW
Number	2	
Total capacity	60	kW
Hub height	27	m
Turnkey Investment cost	256,614	USD
O&M over 20 years		
1 - 10 a	8,117	USD
11 - 20 a	12,176	USD
Energy production per WEC	27.96	MWh/a
Total net energy production	55.92	MWh/a
Full load hours	932	h/a
Fuel Saving	18,642	l/a
Lifetime	20	a

For these scenarios, the energy generation is, compared with the installed capacity, relative small. The technical minimal average wind speed for wind power utilization is reached at these two regions, LGA Brikama and LGA Kerewan.

5.2.2 Stand Alone Wind Diesel System

Another electricity supply option for small sized villages could be the installation of isolated stand alone systems including one or more wind turbines, a small sized Diesel generator, and a battery bank for energy storage. The Kerewan region, which shows better wind conditions than the hinterland of The Gambia, is considered for this option. The villages in the LGA of Brikama are not taken into account for hybrid systems as they will be grid connected soon anyway. For this scenario the base case is a village with around 150 households and a population development of +1.3% per year for the next 20 years. This scenario is applicable for approximately 20% of the rural villages in Kerewan [CSD 2005]. The majority of the other villages has a lower population and is considered for other options i.e. Solar Home Systems.

The wind diesel hybrid system is modular extendable with regard to the basic energy need and the medium-term development of population and electricity consumption. An inverter with a flexible power range between 30 and 120 kW will manage the battery charging and the automatic regulation of the auxiliary generator. Three wind turbines with capacity of 25 kW each will feed the grid and load the accumulators in case of surplus electricity generation. A 30 kW Diesel generator will be available as backup electricity generation option in case of increased energy consumption or during low wind speed periods or calms. A possible installation and arrangement of a hybrid system as represented for the villages is shown in Figure 5-1. PV integration is also technically possible but is not considered.

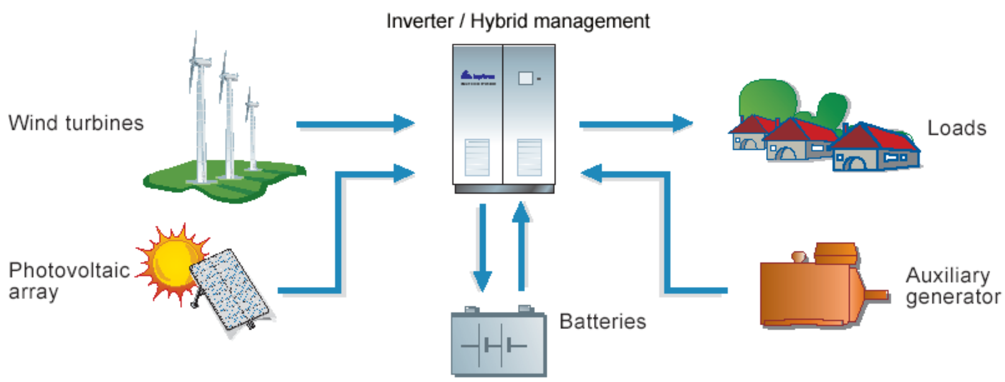


Figure 5-1: Possible Stand Alone Electrical Grid [5]

This energy supply option, too, results in a remarkable yearly fuel saving and helps the villages to be more independent with regard to the conventional energy supply (Diesel). In case of growing population, an additional wind turbine can easily be installed or the auxiliary generator can be exchanged with a bigger one.

However, the cost for O&M should not be neglected. Most of the components have a lifespan of less than 20 years and need to be replaced (batteries and inverter) or need at least technical overhauls (Diesel generator).

The design data of the stand alone wind Diesel system including their technical and economic parameters based on data from 2006 are presented in Table 5-20.

Table 5-20: Technical and economic parameters Wind- Diesel system

Technical and economic parameters		
WEC type	Eoltec WindRunner	New
Capacity	25	kW
Number	3	
Total capacity	75	kW
Hub height	25	m
Diesel generator capacity	30	kW
Accumulator capacity	300	kWh
Turnkey Investment cost	392,000	USD
O&M over 20 years	8,389	USD
Energy production per WEC	19.9	MWh/a
Total net energy production	59.7	MWh/a
Full load hours	797	h/a
Fuel Saving	19,918	l/a
Lifetime	20	a

5.2.3 Summary of Proposed Wind Supply Options

The following Table 5-21 shows an overview of the proposed supply options according to regional utilisation and expected implementation schedule. For most LGA in the interior of The Gambia, no wind energy supply option can be suggested due to the low wind speed conditions.

[5] Source: Ingecon Hybrid

Table 5-21: Overview of proposed wind supply options

	LGA	Supply Option	Year				
			2006	2010	2015	2020	2025
1	**GBA**	n.a.*					
2	**Kanifing**	n.a.					
3	**Brikama**	SWP_1a (new) SWP_1b (used) SWP_2a (new) SWP_2b (used)	3.96 MW 3.96 MW 1.5 MW 1.5 MW	1.98 MW 1.98 MW 0.75 MW 0.75 MW	1.98 MW 1.98 MW 0.75 MW 0.75 MW		
4	**Mansakonko**						
5	**Kerewan**	SWP_3a (new) SWP_3b (used) WSAS_1	60 kW 60 kW 105 kW		30 kW 30 kW 25 kW		
6	**Kuntaur**	n.a.					
7	**Janjanbureh**	n.a.					
8	**Basse**	n.a.					

* n.a. Not applicable

Code	Technology
SWP	Small Wind Park
WSAS	Wind stand alone system Diesel

5.3 Biomass Energy

Following the performed resource assessment, potential options for biomass electricity generation are very limited. Due to scale (quantity) and resource availability (disperse) constraints, concrete biomass based electricity supply options are linked to the direct combustion of groundnut shells and utilisation of industrial residues from the Banjul brewery for biogas generation.

5.3.1 Existing Biomass Energy Facilities in The Gambia

Two industrial scale facilities do exist in The Gambia for energy production from biomass. Both are part of the two major groundnut processing factories: The one in Banjul has two boilers fired with groundnut shells**,** which are connected to a generator of 1.5 MW. The produced electricity was used for the factory. The boilers require reparation, as they are not in operation.

The second one in Kuntaur is a briquetting facility. It has the capacity to make about 7,500 t/a briquettes out of groundnut shells. That is nearly the total amount of shells that are produced in the peanut factory in the best years. But there are some problems getting the facility into operation again: the existing generator at the factory has a capacity of 265 kW, what is sufficient for the dehulling machines. However, the briquetting process itself would need at least 200 kW. Thus, either a new engine and generator has to be installed or the factory has to be operated in changing shifts (only dehulling or briquetting). Another problem with the briquetting facility is that the main pressing engines are missing today (4 engines with about 50 kW) as well as the belts and the pulleys. Finally, the most important problem is the acceptance of the briquettes by the customers due to its difficulty to be burned (they easily broke up and a lot of smoke is generated during combustion). Nevertheless, these problems might be solved with some technical improvement (better binder, milling and water content), teaching and information. Thus, also this facility is actually not in operation.

Both above mentioned experiences demonstrate on the one hand that biomass energy is not an unknown concept in The Gambia. On the other hand, the installation of new biomass projects with high reliability is demanded in order to renovate the trust on RET.

5.3.2 Groundnut Shell Heat and Power Plant at Banjul (LGA Kanifing)

The resource potential assessment shows that only at two locations relevant amounts of groundnut shells are available, if the factories are in full operation:

- 9,000 t/a are generated in the factory next to Banjul on the road to Kanifing
- 9,000 t/a are generated in the factory in Kuntaur

A power plant for the first location, in LGA Kanifing, seems to be the most promising due to its near access to the existing grid. The maximum nominal power capacity resulting from the available amount of fuel (9,000 t/a groundnut shells) is around 600 kW. The base (minimum) load of the GBA grid is substantially higher, so the power plant could operate continuously on nominal load and the electricity can be feed into the grid, if not used locally.

Two possible locations for the power plant could be:

- A place where the shells are generated. Herewith transportation is minimised, but utilisation for the produced heat should be found. This option is particularly advantageous if the existing power plant can be rehabilitated.

- The other location could be next to Banjul Breweries in Kanifing. Transportation will not be expensive since both factories are located in the same main road within a short distance one from each other. Relevant amounts of produced heat can be used by the brewing process. Another advantage might be the private ownership of the project, which ensures reliable maintenance and proper operation.

The second location (option) is chosen as the only biomass energy supply option for the REMP. Hence, a conceptual design is prepared for this alternative [LOO 2002]. The design data of this heat and power plant as well as some technical and economic parameter based on data from 2006 are presented in Table 5-22.

Table 5-22: Technical and economic parameters Heat and Power plant

Technical and economic parameters		
Fuel	Groundnut shell	
Amount of fuel	9,000	t/a
Specific heating value fuel	17 (4.7)	MJ/kg (MWh/t)
Capacity total	600	kW
Nominal operating hours	7,000	h
Turnkey Investment cost	**2,376,000**	**USD**
O&M over 20 years	42,768	USD/a
Energy production	4,200,000	kWh/a

In terms of available fuel, a similar power plant as for Banjul / Kanifing could be installed in Kuntaur. Kuntaur is being connected with Janjanburegh and Bansang to a local grid. This grid will be powered by three 200 kW diesel generators in Bansang. No information about the future base load demand is available, however it can be estimated that it will not be more than 200 kW. The installation of a steam/water cycle power plant of this size is not recommended due to the low electric efficiency in combination with high investment cost for the plant. In case, there were facilities which require process heat in relevant amounts (order of magnitude 2,000 MWh) the total energy efficiency could be improved and a heat and power plant could be of interest.

5.3.3 Biogas Plants

The energy potential of biomass which is suitable for biogas generation plants (biomass with high water content) is low in The Gambia.

Two promising sites with enough biomass for a medium sized plant on a good technical standard are identified: Banjul Breweries and slaughterhouse Abuko. Both facilities will generate no surplus of power or only negligible capacity. Therefore they are not regarded as supply options for the REMP. However, their realisation is recommended because they contribute to energy supply on a local level and due to environmental and hygienic reasons.

Most of the biomass suitable for biogas production is available locally only in amounts which do not justify the construction of a plant on their own (animal husbandry residues, fish industry residues, among others). However, they could all be added (provided local availability) to a biogas plant and altogether represent sufficient feedstock.

The options for biogas plants can be structured into the following categories:

Rural Biogas Plants for a group of families

In general the experience with implemented biogas installations in Africa is not very promising. In contrast to Asian countries, several conditions are not favourable for rural biogas plants in The Gambia:

- Cattle and other animals does not spend significant time in stables, so manure and dung can not be collected and used easily,
- population is dispersed (density is relatively low),
- fuel wood supply is not yet scarce and
- biogas plants are not a traditional part of agriculture, so acceptance is small.

However, there might be a few farms with favourable conditions concerning number of cattle, husbandry conditions and management of a biogas plant.

Biogas Plants for Institutional Groups

Another approach is a biogas plant in common for a group of several hundreds of people. This might be an option for big schools, hospitals, prisons or barracks. There is usually a hygienic problem with the disposal of the excrement if many people are living in one small area. The main aim of such a biogas plant is to solve hygienic problems. On the other hand it would be connected with the production of biogas to substitute fuel wood for cooking. These installations present the following advantages:

- lower specific investment and other efforts per energy unit,
- more continuous feedstock supply,
- one or several persons can be in charge of the installation as their main activity, which ensures permanent care and more professional operation, and
- money and labour required for reparations is available more continuously.

Biogas Plants professionally operated by Industry

For Banjul Breweries an anaerobic waste water treatment is recommended. This company is obliged to implement a water treatment plant. Since aerobic conventional treatment plants require a higher amount of space and relevant amounts of electric energy, the management prefers an anaerobic treatment. The biogas produced compensates approximately the energy needed to run the process, so this plant will not contribute to the power supply of The Gambia.

There are different kinds of treatments, but usually an Up-flow Anaerobic Sludge Blanket (UASB) reactor is recommended in the case of brewery waste water. The main task of this conversion route is to treat organic waste or residues to reduce the environmental pollution of the waste water. The reduction of the organic matter can be about 75 to 90%. The production of energy is only a by-product in most cases. Hence, an industry standard plant is recommended. Owned by the company, professional operation and maintenance is ensured. All further details as feedstock availability, location of the installation, financing etc. has to be discussed with Banjul Breweries.

The slaughterhouse in Abuko seems to have good potential for a biogas plant. This option is recommended for further investigation. Several crucial issues have to be clarified first like feedstock availability, possible other feedstock for co-digestion, heat and power requirements, responsibility for operation, etc. The hygienic advantage of this kind of waste treatment should be highlighted.

Co-digestion of other feedstock represents an attractive opportunity to increase biogas production for all categories above mentioned. With increasing size, especially in urban areas, the transportation of liquid residues from the digester to the fields becomes more important. Since residues have very good fertilising properties, it should be easier to find cooperating farmers to dispose them.

Recommendation

The above described biogas plants for Banjul Breweries and slaughterhouse Abuko are recommended for realisation, as well as two to three in each case of the "rural" and "institutional" types. Because of their low amounts of generated energy, the contribution of these options to the energy supply of The Gambia is negligible and is therefore not included in the REMP.

As pilot projects, these options could help with the identification of suited technologies, increase of acceptance and training of local operators. If the projects prove success, they should be multiplied throughout The Gambia where conditions are favourable (feedstock, operating personal), even with smaller capacity.

5.3.4 Summary of Proposed Biomass Supply Options

Table 5-23 presents an overview of the proposed biomass energy supply options. The heat and power small biomass power plant is assumed to be implemented in the second five-year period due to lack of interest from the potential project owner side on the short term.

Table 5-23: Overview of proposed biomass supply options

	LGA	Supply Option	Year				
			2006	2010	2015	2020	2025
1	**GBA**	n.a.					
2	**Kanifing**	BM_1	-	600 kW	-	-	-
3	**Brikama**	n.a.					
4	**Mansakonko**	n.a.					
5	**Kerewan**	n.a.					
6	**Kuntaur**	n.a.					
7	**Janjanbureh**	n.a.					
8	**Basse**	n.a.					

* n.a. : not applicable

Code	Technology
BM	Small Biomass Heat and Power Plant

5.4 Renewable Energy Supply Summary

The Table 5-24 summarizes the initial renewable energy supply options for the master plan focused on electricity generation. Various energy supply alternatives for solar, wind and biomass are geographically distributed per LGA. All numbers are given in kW of installed power and at the initial phase of each supply option (also called product) development program.

Regarding the installed power for the case of solar PV-diesel hybrid systems, it is only considered the installed capacity of the PV generator.

Table 5-24: Overview of RE Supply Options (Initial Power Capacity)

Products per LGA (initial capacity in kW)

Renewable Energy Source	Product / LGA	LGA OF BANJUL	LGA OF KANIFING	LGA OF BRIKAMA	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA
Solar Radiation	PV_1			1,000.0						1,000.0
	PV_2_SL			0.05	0.02	0.05	0.06	0.05	0.01	0.2
	PV_2_SHSp			0.05	0.02	0.05	0.06	0.05	0.01	0.2
	PV_2_SHSm			0.24	0.11	0.25	0.28	0.26	0.05	1.2
	PV_2_SHSs			0.61	0.48	0.63	0.71	0.65	0.12	3.2
	PV_2_SHSl			0.98	0.46	1.00	1.14	1.04	0.19	4.8
	PV_3_10%					405.0	37.0	130.0	310.0	882.0
	PV_3_15%					605.0	55.0	190.0	470.0	1,320.0
	PV_3_20%					825.0	75.0	260.0	650.0	1,810.0
Wind Energy	SWP_1a			3,960.0						3,960.0
	SWP_1b			3,960.0						3,960.0
	SWP_2a			1,500.0						1,500.0
	SWP_2b			1,500.0						1,500.0
	SWP_3a					60.0				60.0
	SWP_3b					60.0				60.0
	WSAS_1					105.0				105.0
Biomass	BM_1		600.0							600.0

The overview shows that most part of the proposed initial new installed capacity is concentrated in the LGA Brikama, where the majority of Gambians live. Wind energy based supply options offer the major initial new installed capacity, followed by solar PV power plants. This is explained by the maturity and competiveness of wind energy technology in comparison with other renewable energy technologies like solar PV.

6 Supply-Demand Balance

Prior to preparing the demand-supply balance, technical parameters i.e. net energy generation and fuel saving are completed and summarised, as well as economic input parameters (data to be used in Chapter 7) for each proposed supply option. Results are shown in the following Table 6-1.

Table 6-1: Technical and Economic Parameters for Supply Options

Renewable Energy Source	Item / Product	Capacity in KW	Net Energy Generation per Year in kWh/a	Fuel Saving in liter per Year	Investment in USD	Lifetime in a	Operation and Maintenance Costs in USD per year	Operation and Maintenance Costs in USD per year (1-10a)	Operation and Maintenance Costs in USD per year (11-20a)
Solar Radiation	PV_1	1,000	1,536,450	512,150	6,008,471	20		120,169	180,254
	PV_2_SL	0.005	6.57	2.19	60	7	2	*Reinvest of 60 USD (new latern) after 14 years*	
	PV_2_SHSp	0.012	19.71	6.57	470	20	6	*each 3rd year Reinvest of 132 USD (Battery)*	
	PV_2_SHSm	0.040	65.70	21.90	784	20	12	*each 3rd year Reinvest of 156 USD (Battery)*	
	PV_2_SHSs	0.075	123.19	41.06	1,100	20	18	*each 3rd year Reinvest of 240 USD (Battery)*	
	PV_2_SHSl	0.120	197.10	65.70	1,408	20	24	*each 3rd year Reinvest of 288 USD (Battery)*	
	PV_3_10% (*)	270	521,950	239,929	1,269,000	20	12,690	*each 6 years Reinvest of 54,000 USD (Battery) after 15 years Reinvest of 135,000 USD (Inverter)*	
	PV_3_15% (*)	410	792,415	311,572	1,902,000	20	19,020	*each 6 years Reinvest of 57,000 USD (Battery) after 15 years Reinvest of 205,000 USD (Inverter)*	
	PV_3_20% (*)	550	1,062,880	372,969	2,544,000	20	25,440	*each 6 years Reinvest of 69,000 USD (Battery) after 15 years Reinvest of 275,000 USD (Inverter)*	
Wind Energy	SWP_1a	3,960	1,878,000	626,000.0	5,712,000	20	105,739	169,182	253,773
	SWP_1b	3,960	1,878,000	626,000.0	2,454,144	20	253,773	253,773	338,364
	SWP_2a	1,500	688,782	229,594.0	2,609,981	20	53,871	86,193	129,290
	SWP_2b	1,500	688,782	229,594.0	1,272,701	20	129,290	129,290	172,386
	SWP_3a	60	55,926	18,642.0	256,614	20	5,073	8,117	12,176
	SWP_3b	60	55,926	18,642.0	137,446	20	12,176	16,235	16,235
	WSAS_1	105	59,754	19,918.0	392,000	20	8,389		
Biomass	BM_1	600	4,200,000	1,630,000	2,376,000	20	42,768		

(*) *Data for the Farafenni PV Power Plant*

Afterwards, the development of installed generation capacity for the different supply options in the proposed Renewable Energy based Electricity Master Plan (2006 – 2025) is compiled and presented in the Table 6-2 and Figure 6-1.

Table 6-2: Cumulated Installed Capacity in kW (2006 – 2025)

Product / Year	PV_1	PV_2 SL	PV_2 SHSp	PV_2 SHSm	PV_2 SHSs	PV_2 SHSl	PV_3_10%	PV_3_15%	PV_3_20%	SWP_1a&b	SWP_2a&b	SWP_3a&b	WSAS_1	BM_1	TOTAL GAMBIA* Base Scenario
Base	-	0.2	0.2	1.2	3.0	4.8	-	-	-	3,960	1,500	60	105	-	5,634.5
2010	-	0.7	0.7	3.6	9.0	14.4	882	1,320	1,810	5,940	2,250	60	105	600	10,303.5
2015	1,000	3.2	4.3	27.6	69.0	110.4	882	1,320	1,810	7,920	3,000	90	105	600	14,249.5
2020	2,000	7.5	15.1	63.6	129.0	206.4	1,764	2,640	3,620	7,920	3,000	90	105	600	16,776.7
2025	3,000	9.1	21.8	72.6	136.8	218.9	1,764	2,640	3,620	7,920	3,000	90	105	600	17,814.1

** The total amount considers for the product PV_3, only the 15% penetration rate*

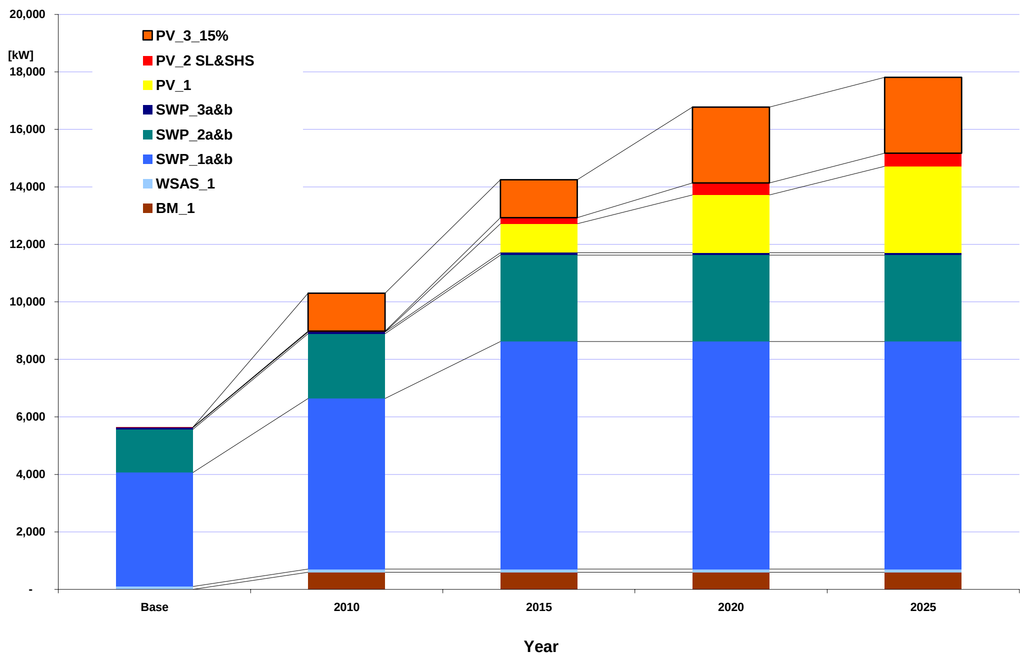


Figure 6-1: Development of Installed Capacity in kW divided by sources

The presented table and figure clearly show that wind energy based supply options offer the major new installed capacity in the drafted Master Plan. The role of solar PV will be more important in the future once its competiveness in markets like the African ones has been achieved.

The supply options (installed capacity) are also classified geographically per LGA and presented in the Annex 3.

The yearly electricity generation for all considered supply options in the REMP is assembled and shown in the Table 6-3 and Figure 6-2.

Table 6-3: Annual Electricity Output in MWh/a (2006 – 2025)

Product / Year	PV_1	PV_2 SL	PV_2 SHSp	PV_2 SHSm	PV_2 SHSs	PV_2 SHSl	PV_3_10%	PV_3_15%	PV_3_20%	SWP_1a&b	SWP_2a&b	SWP_3a&b	WSAS_1	BM_1	TOTAL GAMBIA* Base Scenario
Base	-	0.3	0.4	1.9	4.9	7.9	-	-	-	1,878.0	688.8	55.9	59.8	-	2,697.9
2010	-	1.0	1.2	5.9	14.7	23.5	1,606.4	2,411.9	3,293.0	2,817.0	1,033.2	55.9	59.8	4,200.0	10,624.0
2015	1,536.5	4.3	7.1	45.3	113.4	181.1	1,606.4	2,411.9	3,293.0	3,756.0	1,377.6	83.9	59.8	4,200.0	13,776.8
2020	3,073.0	9.9	24.8	104.4	212.3	339.2	3,212.7	4,823.8	6,586.1	3,756.0	1,377.6	83.9	59.8	4,200.0	18,064.7
2025	4,609.5	12.0	35.7	119.2	225.0	359.5	3,212.7	4,823.8	6,586.1	3,756.0	1,377.6	83.9	59.8	4,200.0	19,662.0

** The total amount considers for the product PV_3, only the 15% penetration rate*

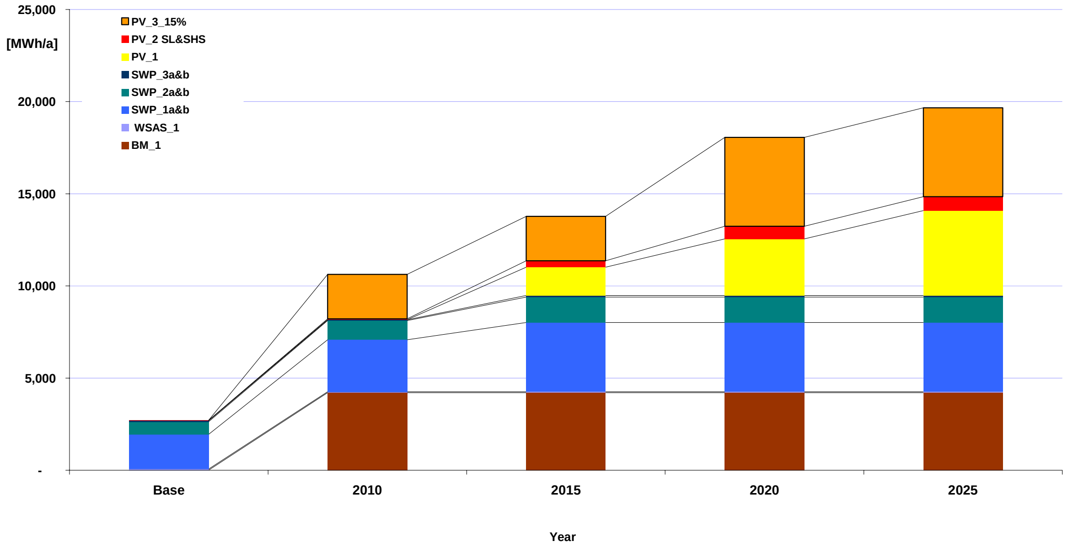


Figure 6-2: Annual Electricity Output in MWh/a divided by sources

The previous table and figure denote the relevance of solar and biomass based electricity generation in the proposed Master Plan. This is justified by the high operation full load hours for both technologies compared to the low amount of operation full load hours for the wind energy supply options.

Based on the demand analysis and forecast as described in Chapter 3, and the renewable energy resource assessment and supply options per LGA described in the Chapter 4 and 5, a supply-demand balance can be prepared.

This supply-demand-balance indicates present supply gaps, as well as to which extent renewable energies can cover expected actual and future energy (electricity) demand. In addition, one important outcome is the annual savings of conventional energy resources due to the introduction of the renewable energy powered supply options.

The following Table 6-4 and Table 6-5 give an overview on the results.

Table 6-4: Annual Savings of Conventional Energy Sources in TOE/a

Product / Year	PV_1	PV_2 SL	PV_2 SHSp	PV_2 SHSm	PV_2 SHSs	PV_2 SHSl	PV_3_10%	PV_3_15%	PV_3_20%	SWP_1a&b	SWP_2a&b	SWP_3a&b	WSAS_1	BM_1	TOTAL* GAMBIA Base Scenario
Base	-	0.1	0.1	0.5	1.4	2.3	-	-	-	538.4	197.5	16.0	17.1	-	773.4
2010	-	0.3	0.3	1.7	4.2	6.7	460.5	691.4	944.0	807.5	296.2	16.0	17.1	1,204.0	3,045.5
2015	440.5	1.2	2.0	13.0	32.5	51.9	460.5	691.4	944.0	1,076.7	394.9	24.0	17.1	1,204.0	3,949.3
2020	880.9	2.8	7.1	29.9	60.9	97.2	921.0	1,382.8	1,888.0	1,076.7	394.9	24.0	17.1	1,204.0	5,178.5
2025	1,321.4	3.4	10.2	34.2	64.5	103.1	921.0	1,382.8	1,888.0	1,076.7	394.9	24.0	17.1	1,204.0	5,636.4

** Considers for the product PV_3, only the 15% penetration rate*

Table 6-5: Supply-Demand Balance in TOE/a

Supply-Demand Balance in TOE/a	Base Year	2010	2015	2020	2025
Total Demand (Conventional energy sources)	151,240	182,391	225,303	269,805	332,146
Energy Industry Demand (Conventional * energy sources)	55,135	81,704	90,818	91,395	92,201
Fuel Savings through use of renewable energy sources	773	3,046	3,949	5,179	5,636
Electricity provided by renewable energy sources	**232**	**914**	**1,185**	**1,554**	**1,691**
Electricity provided by conventional energy sources	10,786	31,047	34,511	34,730	35,036
Proportion of Electricity provided by Renewable Energy	2.2%	2.9%	3.4%	4.5%	4.8%

***** Conventional energy sources = Primary energy sources = Oil products

The Supply-Demand balance clearly shows that the implementation of all proposed RET projects for electricity generation in the REMP for The Gambia would lead to significant savings of fuel (oil products). At the same time, around 2.2% (in base year) and 4.8% (in 2025) of the electricity demand in 2025 would be supplied by renewable energy based power supply systems.

The REMP model allows some other calculations and sensitivity analysis. If the PV installed capacity in LGA Brikama by 2025 would reach 10 MW instead of the proposed 3 MW, the proportion of electricity provided by renewable energy would account 7.5%. With a PV installed capacity of 25 MW in LGA Brikama by 2025, 13.1% of the electricity would come from renewable energy.

The last assumptions should be verified with regard to some restrictions like technical feasibility (grid stability), land availability and financial resources accessibility, provided that governmental support through its national utility continues.

7 Economic Analysis

Various supply options are elaborated and proposed for each of the individual regions in The Gambia. These supply options are conceptualised in accordance with region specific characteristics and are referred to as “products”. The purpose of the economic analysis is thus to differentiate between the various products according to their economic feasibility in order to encourage investment in projects which promote the most efficient use of a nation’s resources. As the evaluation is done from the viewpoint of the national economy, inflation and other factors which distort the market prices are not taken into consideration.

7.1 Approach & Methodology

A spreadsheet based model is developed for the economic analysis. The model allows a direct comparison between the individual products with the ultimate aim of producing a ranking of them. The ranking is based on the respective dynamic unit production costs [6](DUC).

Furthermore, the following economic indicators are also derived:

- economic internal rate of return (EIRR);
- benefit / cost ratio; and
- economic net present value (ENPV).

Supply option (project) costs are classified as the relevant investment and O&M costs, whereas project benefits are taken as the foregone expenses which would have been incurred for diesel fuel to produce the same amount of electricity.

The conclusion of the analysis is thus to evaluate the economically most feasible product per region based on the relevant economic and technical data available.

The economic analysis of the individual products is carried out in a conventional cost-benefit analysis, where the project costs are compared to its benefits. The basic technique for comparing costs and benefits occurring at different times during the project period is to discount both costs and benefits, and to express them in a common value at one point in time. In this way, the time value of money is taken into account. Costs and benefits are set up as annual streams over the study period (cash flows) and then discounted to their present values. The evaluation period covers the construction period and the operating period over the project lifetime. All costs and benefits of the project are expressed in monetary terms at their economic prices. As the economic analysis should reflect the true costs of the project to the economy, government taxes, subsidies, duties and other factors that inhibit the pricing of labour and materials at their economic value are excluded from the economic valuation of costs and benefits. Shadow pricing is used in economic analysis where economic prices differ from the market prices.

The Figure 7-1 illustrates a flow chart with above described methodology.

[6] DUC is the specific energy (electricity) generation cost over the project life cycle considering as main revenues the fluctuating savings of fuel oil costs.

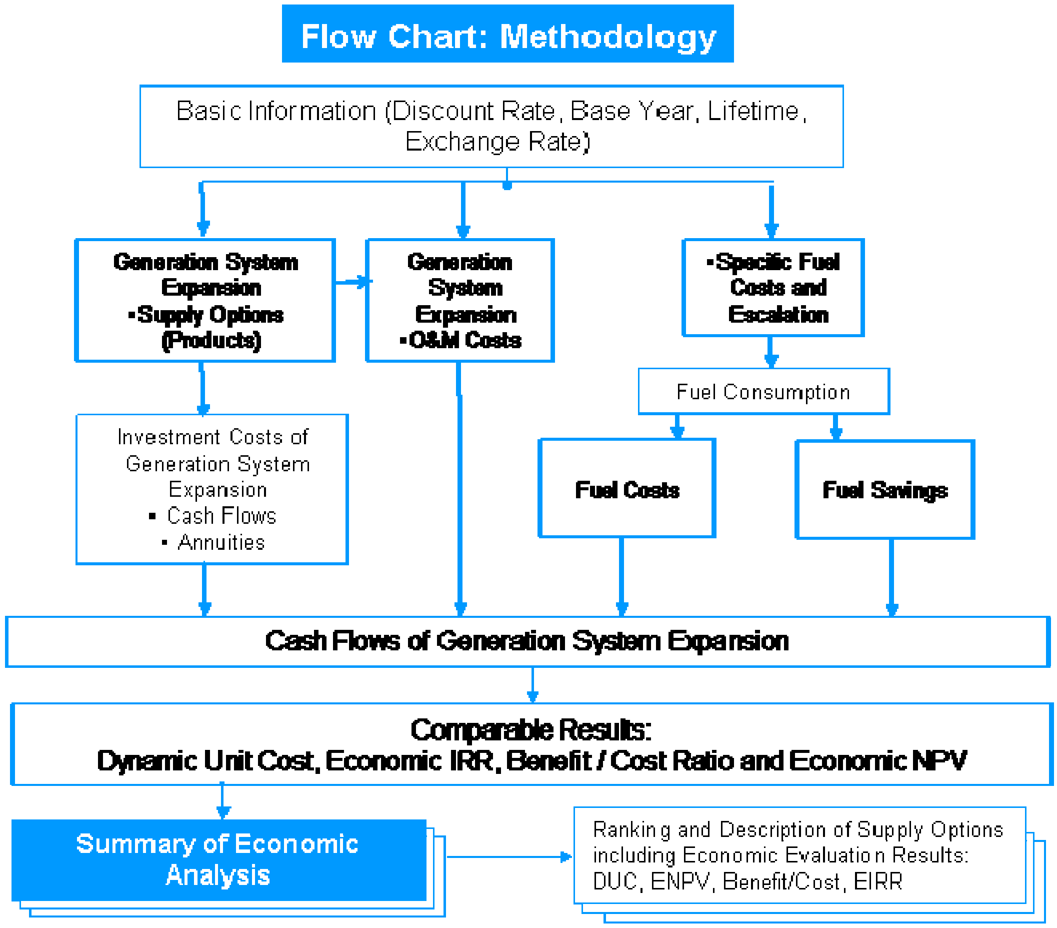


Figure 7-1: Flow chart of economic analysis methodology

7.2 Basic Assumptions

To facilitate the economic analysis, the following general assumptions are used and shown in Table 7-1.

Table 7-1: Basic Assumptions

Item	Value
Base discount rate	10%
Project lifetime	20 years
Base year	2006

Given the fact, that service lifetime of several components can differ, reinvestments are considered as additional part of the fixed operation and maintenance cost (see Table 6-1).

Within the frame of the economic analysis, the official foreign exchange rates of Table 7-2 are applied, as applicable on February, 2006.

Table 7-2: Exchange rate assumptions

Currencies	Exchange Rate
EUR / USD	1.1880
USD / GMD	27.8920

Based on recognised methodology [7], a standard conversion factor (SCF) of 0.889 is derived using the relevant current trade figures [8]. By implication, the shadow exchange rate factor (SERF) is calculated as 1.123. Details regarding the derivation of the SCF and SERF are shown below:

International Currency I	USD
International Currency II	EUR
Local Currency	GMD
SCF	1 : 0.889
SERF	1 : 1.123
USD / GMD, SER	1 : 31.344

Whilst the cost of the individual products can be rather easily determined as capital expenditures (CAPEX) and operational expenditures (OPEX), the benefits of any product are more difficult to assess. Generally spoken, the benefits of the products are the savings, achieved by its application to cover the final energy demand, compared to the use of conventional primary energy sources (any kind of oil products). The economic analysis considers a unique approach to determine the benefits of the individual products which is based on the savings of diesel fuel. The initial diesel price amounts to 22 GMD per litre. This price is inflated at an annual rate of 2% over the evaluation period (20 years).

7.3 Results

The analysis outcomes are presented for all products separately according to each type of renewable energy source.

Figure 7-2 illustrates the comparison of solar energy products. Within the comparison one needs to deal with the first three products (PV_3_20%, PV_3_15%, PV_3_10%) separately. While all other solar products could be implemented in parallel way, only one of these PV_3 options could be implemented in the future, because all of them consider the same target area and Diesel powered generation system, but with different solar penetration factors (10, 15 and 20%). From the economic point of view the most promising option is the PV_3_20% product. The DUC for this alternative amounts to 10 GMD/kWh, compared to 10.1 and 10.3 GMD/kWh, for the PV_3_15% and PV_3_10% options, respectively. The DUC for these three options are however almost the same. Thus, no remarkable influence of penetration factor in the DUC is noticed.

The solar product PV_1 (large PV power plant) presents a DUC 17.2 GMD/kWh.

Finally, all SHS products show the highest DUC and vary between 40.0 GMD/kWh (PV_2_SHSl) and 158.4 GMD/kWh (PV_2_SHSp).

[7] Shadow Exchange Rates for Project Economic Analysis: "Toward Improving Practice at the Asian Development Bank", Lagman-Martin, February 2004.

[8] The Gambia: Statistical Appendix, IMF Country Report No. 06/10, McDonald, et al., January 2006.

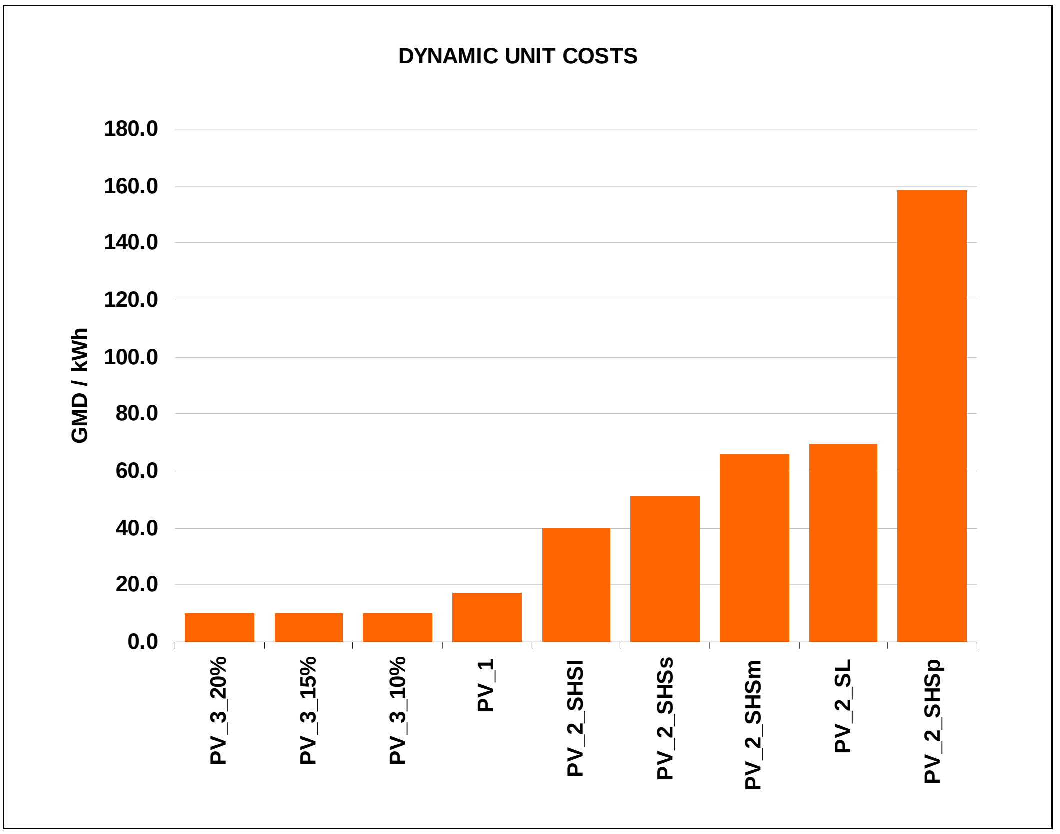


Figure 7-2: Dynamic Unit Costs – Solar Energy Products

Figure 7-3 shows the results of the economic analysis presenting a ranking of wind energy products, as per the dynamic unit costs. The product SWP_1b (used) is the economically most attractive alternative, where the DUC amounts to 9.2 GMD/kWh equivalents to 33.0 USDct/kWh. The product WSAS_1 ranks at the end of the compared supply options, with a DUC of about 29.9 GMD/kWh equivalents to more than 1 USD per kWh.

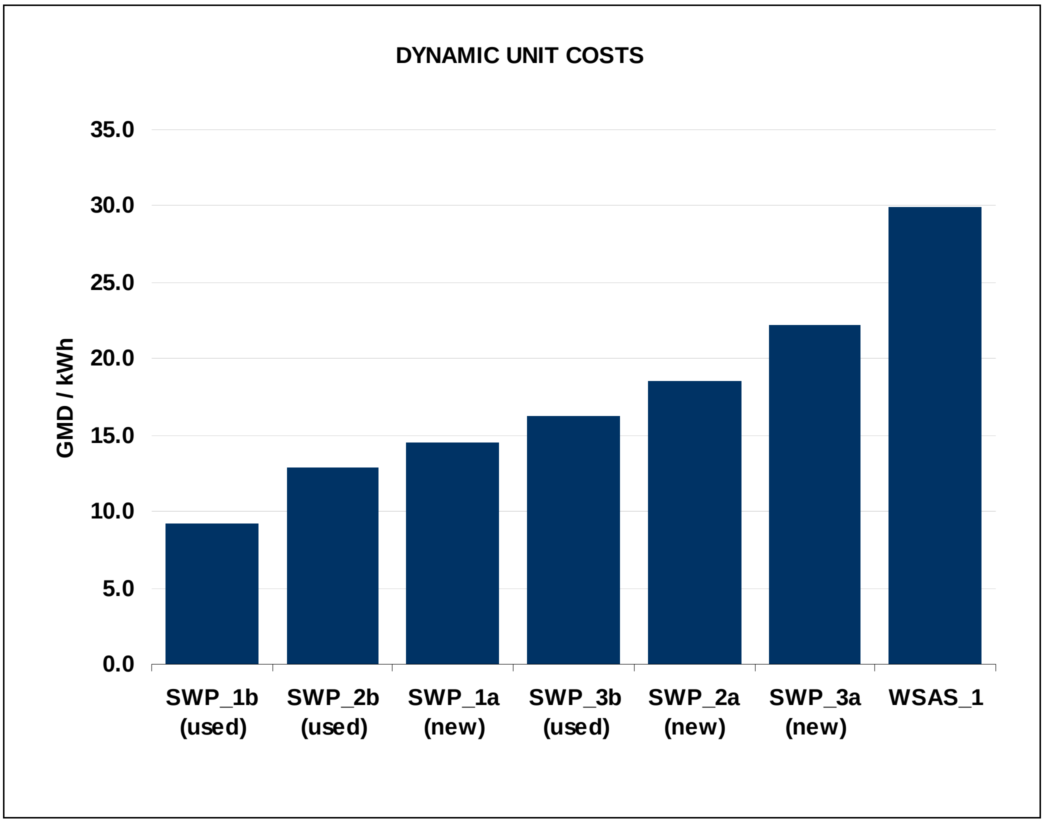


Figure 7-3: Dynamic Unit Costs – Wind Energy Products

Figure 7-4 shows the results of the economic analysis for the biomass product BM_1. The DUC for this options amounts to 3.5 GMD/kWh (12.5 USDct/kWh).

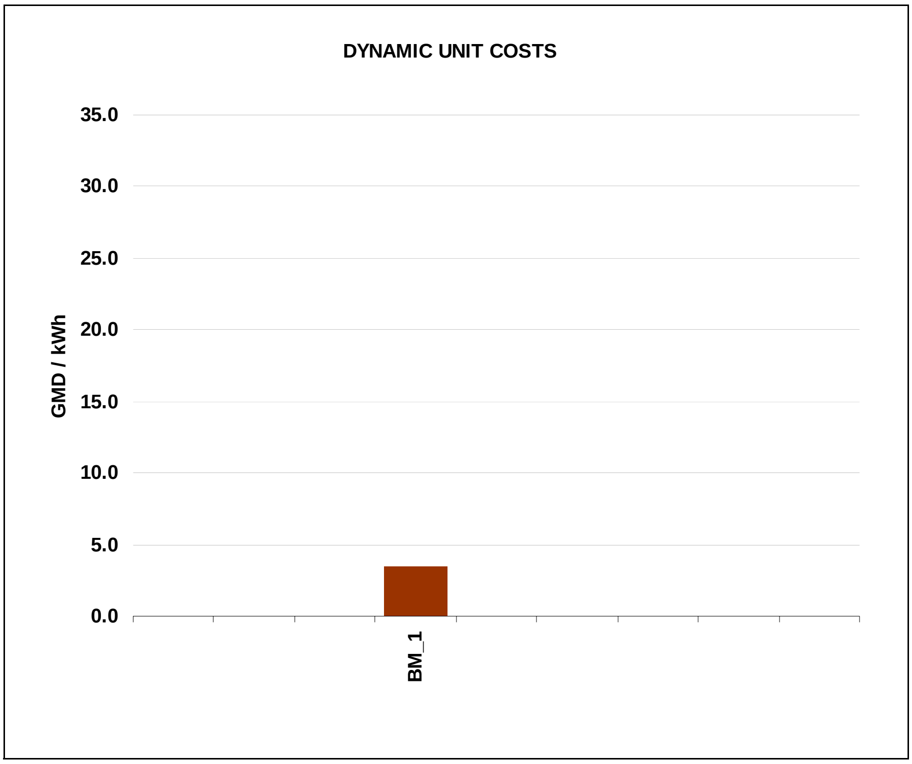


Figure 7-4: Dynamic Unit Costs – Biomass Products

A comparison of the DUC of all renewable energy based power supply options for The Gambia (products) is provided in the Figure 7-5 and Annex 4.

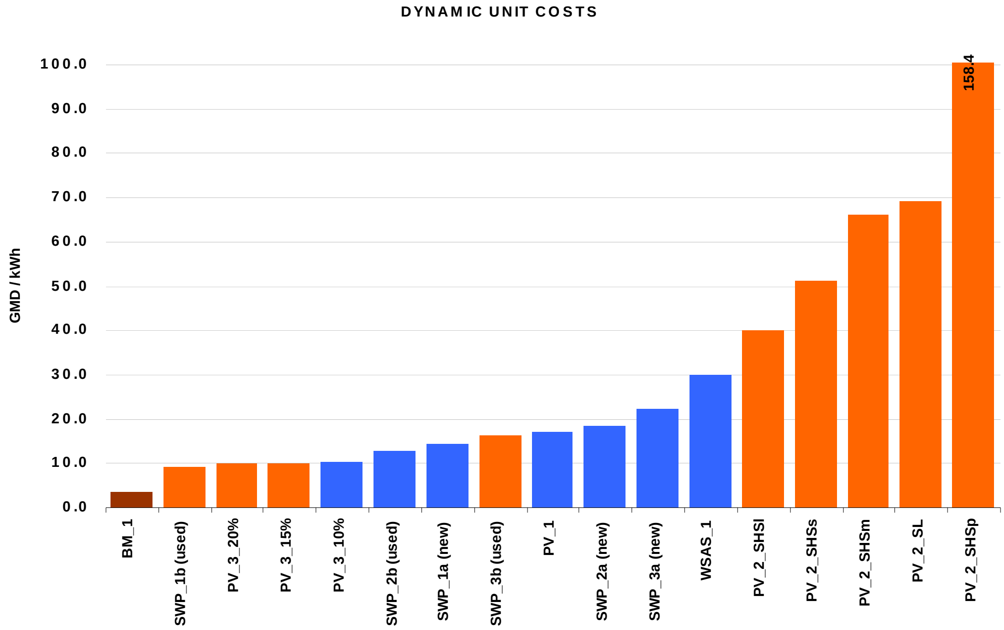


Figure 7-5: Dynamic Unit Costs – Comparison of all products

In addition, Table 7-3 presents the ranking of the products according to the type of renewable resource, geographical division and economic results parameters: ENPV, benefit / cost ratio and dynamic unit costs (DUC).

Table 7-3: Ranking of RE based supply options by Region

Region	Supply Option	ENPV T GMD	Benefit / Cost Ratio	DUC GMD/kWh
Brikama & GBA	BM_1	237,045	2.9	3.5
Brikama & GBA	SWP_1b (used)	-8,234	0.9	9.2
Brikama & GBA	SWP_2b (used)	-24,806	0.7	12.9
Brikama & GBA	SWP_1a (new)	-93,394	0.6	14.5
Kerewan & Mansakonko	SWP_3b (used)	-3,584	0.5	16.2
Brikama & GBA	SWP_2a (new)	-57,470	0.5	18.5
Kerewan & Mansakonko	SWP_3a (new)	-6,435	0.4	22.2
Kerewan	WSAS_1	-10,776	0.3	29.9
Kerewan and others	PV_3_20%	-10,328	0.9	10.0
Kerewan and others	PV_3_15%	-8,067	0.9	10.1
Kerewan and others	PV_3_10%	-6,413	0.9	10.3
Brikama & GBA	PV_1	-100,364	0.6	17.2
All except GBA	PV_2_SHSl	-53	0.2	40.0
All except GBA	PV_2_SHSs	-44	0.2	51.1
All except GBA	PV_2_SHSm	-32	0.1	66.2
All except GBA	PV_2_SL	-3	0.1	69.3
All except GBA	PV_2_SHSp	-25	0.1	158.4

It is clear to conclude from the last figure and table, that the product BM_1 is the most promising supply option from the economic point of view, followed by SWP_1b (used) and PV_3 with 20% penetration factor, which are at the same time the best ranked options from biomass, wind and solar energy sources, respectively.

The less attractive options from the economic standpoint are SHS. Nevertheless, away from these purely economic results, the implementation of a SHS program could still be considered as a good alternative according to other criteria like simplicity of technology, poverty fighting strategies and rural development promotion measures, among others.

Annexes 5 to 7 show in detail the structure of the economic analysis as well as the results for each considered alternative.

8 Investment Plan

The analysis performed until now enables the definition of an investment plan for a 20-year period. Based on the ranking of power supply options from the economic analysis (Chapter 7), as well as under consideration of mutually exclusive implementation constraints, a least-cost investment plan is derived. For this task, a heuristic approach is used, which carefully addresses:

- Renewable energy resource availability constraints,
- Substitutive interrelations between demand-supply-options,
- Investment needs, and
- Future market (technology) trends.

The proposed investment plan is broken down into 5-year investment periods and consists of individual renewable energy projects for electricity generation. These projects include basically on-grid renewable energy applications as well as those applications, which will be connected to the existing isolated grids in The Gambia. Villages beyond the existing electrical Gambian networks are not considered as investment plan beneficiaries.

The total required investment for implementing the proposed renewable energy master plan for electricity generation in The Gambia is around 28 Millions USD and is subdivided and described in Table 8-1

Table 8-1: Investment plan for the REMP in The Gambia

Period	Investment in kUSD
I: 2006 - 2010	4,967
II: 2011 - 2015	2,496
III: 2016 - 2020	7,303
IV: 2021 - 2025	13,291
Total	**28,057**

The following Table 8-2, Table 8-3, Table 8-4 and Table 8-5 present details of the investment plan for the periods I, II, III and IV, respectively.

From this detailed information it can be concluded the following:

- The full implementation of the REMP would lead to the installation of more than 12 MW of new power supply capacity based on renewable energy in a 20-year period.
- The most applied (proposed) technology is solar PV with an expected investment of around 20.6 Millions USD, whereas the wind energy projects demand an investment of about 5.2 Millions USD.
- The first technology to be implemented is wind energy with repowered (refurbished) wind turbines, followed by the biomass heat and power plant. The PV power plants are scheduled to be installed from 2013.

Table 8-2: Investment Plan - Period I: 2006 - 2010

Project/Programm Description	Total kUSD	LGA	Local components %	Imported components %	Total %	2006	2007	2008	2009	2010	Total %	2006	2007	2008	2009	2010	Total kUSD
						Annual investment (% of total investment and kUSD)											
Groundnut shell heat and power plant 600 kW for Banjul Breweries	2,376	Kanifing	10%	90%	100%	0%	0%	0%	35%	65%	100%	-	-	-	832	1,544	2,376
Small wind park 3,960 kW with used equipment	2,454	Brikama	5%	95%	100%	0%	0%	30%	70%	0%	100%	-	-	736	1,718	-	2,454
Small wind park 60 kW with used equipment	137	Kerewan	5%	95%	100%	0%	30%	70%	0%	0%	100%	-	41	96	-	-	137
	4,967										Period I	-	41	832	2,549	1,544	4,967

Table 8-3: Investment Plan - Period II: 2011 - 2015

Project/Programm Description	Total kUSD	LGA	Local components %	Imported components %	Total %	2011	2012	2013	2014	2015	Total %	2011	2012	2013	2014	2015	Total kUSD
						Annual investment (% of total investment and kUSD)											
Small PV Power Plant as fuel saver with 10% of penetration factor: 270 kW (Farafenni)	1,269	Kerewan, Basse	5%	95%	100%	0%	0%	30%	70%	0%	100%	-	-	381	888	-	1,269
Small wind park 1,980 kW with used equipment (extension - 2nd Phase)	1,227	Brikama	5%	95%	100%	0%	0%	60%	40%	0%	100%	-	-	736	491	-	1,227
	2,496										Period II	-	-	1,117	1,379	-	2,496

Table 8-4: Investment Plan - Period III: 2016 - 2020

Project/Programm Description	Total kUSD	LGA	Local components %	Imported components %	Total %	2016	2017	2018	2019	2020	Total %	2016	2017	2018	2019	2020	Total kUSD
						Annual investment (% of total investment and kUSD)											
Large PV Power Plant of 1,000 kW interconnected to GBA grid	6,008	Brikama	5%	95%	100%	55%	45%	0%	0%	0%	100%	3,304	2,704	-	-	-	6,008
Small wind park 1,980 kW with used equipment (extension - 3rd Phase)	1,227	Brikama	5%	95%	100%	0%	0%	80%	20%	0%	100%	-	-	982	245	-	1,227
Small wind park 30 kW with used equipment (extension - 2nd Phase)	68	Kerewan	5%	95%	100%	0%	100%	0%	0%	0%	100%	-	68	-	-	-	68
	7,303										Period III	3,304	2,772	982	245	-	7,303

Table 8-5: Investment Plan - Period IV: 2021 - 2025

Project/Programm Description	Total kUSD	LGA	Local components %	Imported components %	Total %	2021	2022	2023	2024	2025	Total %	2021	2022	2023	2024	2025	Total kUSD
						Annual investment (% of total investment and kUSD)											
Large PV Power Plant as fuel saver 2,000 kW (extension - 2nd Phase)	12,016	Brikama	10%	90%	100%	0%	35%	40%	25%	0%	100%	-	4,206	4,806	3,004	-	12,016
Small PV Power Plant as fuel saver to complete 20% of penetration factor: 550 kW (Farafenni - adittional 280 kW)	1,275	Kerewan, Basse	5%	95%	100%	100%	0%	0%	0%	0%	100%	1,275	-	-	-	-	1,275
	13,291										Period IV	1,275	4,206	4,806	3,004	-	13,291

9 Renewable Energy Priority Project

There is consensus in the reviewed literature with regard to the next step after the preparation of a master plan. Feasibility studies should be prepared for the most promising identified projects.

These feasibility studies should comprise in much more detail:

- the electricity demand patterns,
- an evaluation of available resources for electricity generation,
- characterization of available technologies and hardware to be installed,
- localisation of project installations,
- determination/prediction of electricity generation,
- estimation of investment and O&M costs,
- evaluation of economic feasibility, and
- analysis of the sensitiveness with regard to the most important variables.

Since solar PV based projects are the most relevant technology in the proposed REMP and investment plan, there is no doubt about which project should be analysed deeper: a PV power plant integrated to the Diesel powered main electrical system in The Gambia. A more detailed alternative evaluation appears to be even more necessary taking into consideration the increase of fuel prices as well as reduction of investment cost for the photovoltaic technologies in the future. This priority project is analysed by economic competitiveness under the current conditions in addition to sensitivity analysis with regard to oil and new-technology market conditions in the medium and long term.

Since the entire energy (electricity) sector information and proposed REMP is limited to its preparation year: 2006, an actual and updated evaluation of the priority project requires a new assessment of electricity installed capacity and electricity consumption in the GBA grid. This assessment is performed based on data provided by the national utility NAWEC at the end of 2008.

The following Table 9-1 and Table 9-2 give an overview of installed and available capacity of Kotu and Brikama power stations in 2008, which supply electricity to the GBA and Brikama.

Table 9-1: Capacity in the Kotu Power Station (KPS) in 2008

Unit	Capacity		Status	Commissioning Year
	Installed [MW]	Available [MW]		
Total	**52.4**	**28.0**		
KPS-G01	3.0	2.0	Operation	1981
KPS-G02	3.0	0.0	Standby	1981
KPS-G03	3.4	2.0	Operation	1997
KPS-G04R	6.4	6.0	Operation	2001
KPS-G06	6.4	6.0	Operation	1990
KPS-G07	6.4	6.0	Operation	2001
KPS-G08	6.4	0.0	Standby	2001
KPS-G09	6.4	6.0	Operation	2008
KPS-G11	11.0	0.0	Standby	1997

Table 9-2: Capacity in the Brikama Power Station (BRK) in 2008

Unit	Capacity Installed [MW]	Capacity Available [MW]	Status	Commissioning Year
Total	**25.6**	**24.0**		
BRK-G01	6.4	6.0	Operation	2006
BRK-G02	6.4	6.0	Operation	2006
BRK-G03	6.4	6.0	Operation	2007
BRK-G04	6.4	6.0	Operation	2007

Over the period 1995 up to 2008, available generation capacity grew from nearly 12 MW to 52 MW. The Figure 9-1 presents this development in the past years.

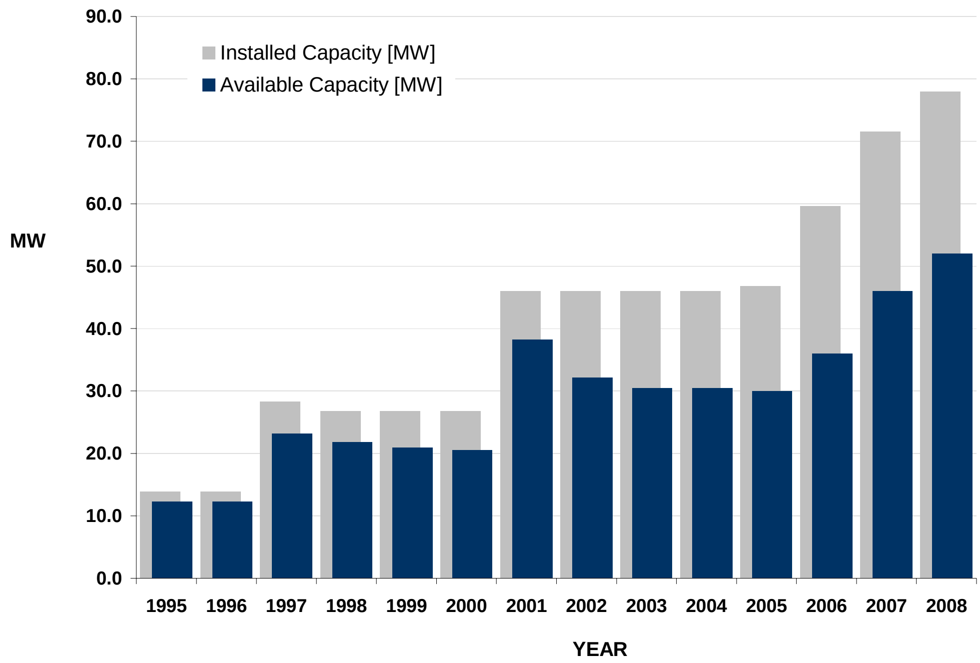


Figure 9-1: Development of Installed and Available Capacity up to 2008

The development of annual gross and net generation over the period 2005 to 2007 is shown in Table 9-3. The compilation includes the final/billed electricity consumption and losses [NAWEC 2008].

Table 9-3: From Generation to Final Electricity Consumption 2005-2007

Item / Years	2005	2006	2007
Total Generation [MWh/a]	156,274	162,617	202,337
Own Station Consumption [MWh/a]	6,251	6,505	9,764
Net Generation [MWh/a]	150,023	156,112	192,572
Billed Consumption[MWh/a]	102,013	112,145	135,343
Total Losses [MWh/a]	48,011	43,967	57,230
Total Losses [%]	32.0%	28.2%	29.7%

9.1 Solar Data Evaluation

First of all a resource assessment for the considered location (in the GBA) is performed. Results from the measuring station 1 and SEIS are compared with two other sources used currently in the solar sector: PVGIS [9] and Meteonorm [10]. The following Figure 9-2 shows the three sets of data. Data from station 1 correlate very well with the other two data sets. For only two months, namely July and October, the discrepancies are higher and for this reason, these two months are slightly adjusted in order to obtain a consistent correlation.

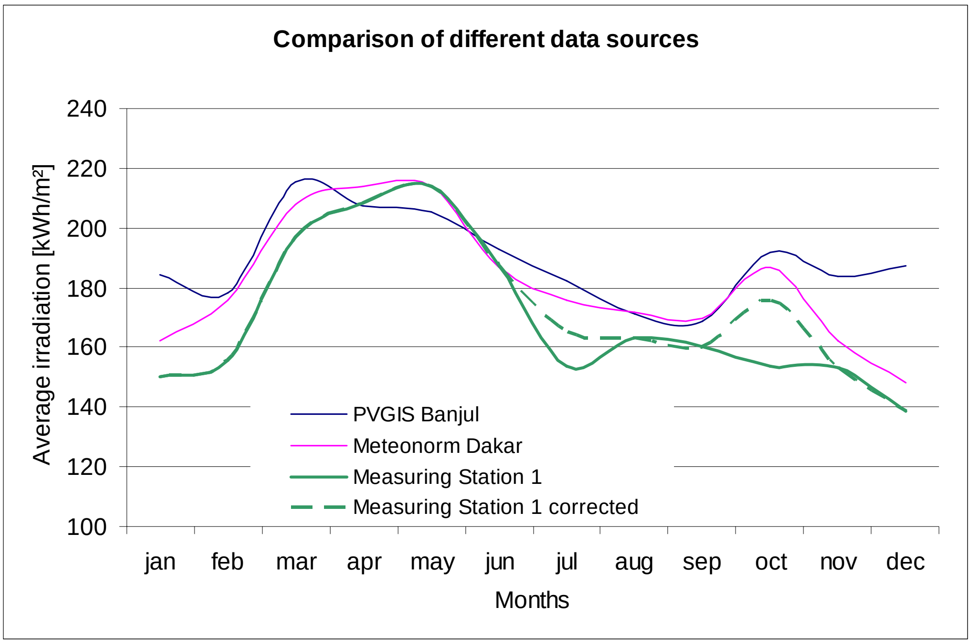


Figure 9-2: Comparison of Monthly Solar Irradiation Data Sets

The total corrected annual incident irradiation taken as the basis for the PV Plant technical design and electricity yield calculation is shown in Table 9-4.

Table 9-4: Corrected Annual Irradiation data for the PV Plant in GBA

Month	Irradiation [kWh/m²]
January	150
February	156
March	197
April	208
May	214
June	187

[9] The Photovoltaic Geographical Information System (PVGIS) has been set up by the Joint Research Centre of the European Commission (Ispra, Italy) as an information database for policy decision makers, as well as developers of PV installations.

[10] METEONORM 4.0 (by Meteotest, Switzerland) is a comprehensive world-wide climate database and simulation tool for solar energy applications. METEONORM can be considered as one of the most widespread data sources for simulations of PV power plants.

July	165
August	163
September	160
October	176
November	153
December	139
Total	**2,068**

9.2 PV Technology Selection

Three technology alternatives are assessed for this project. All three technologies are proven and installed in many large projects around the world and appear to be appropriate for The Gambia. These technology alternatives are: Conventional Crystalline Silicon modules, fixed system; Amorphous Silicon (Thin film) modules, fixed system; and 1-axis tracking system with crystalline modules. Some characteristics and remarkable aspects for proposing these technologies are:

Crystalline Silicon Technology

These modules have the longest experience on the market and are readily available from many different manufacturers. They have a relatively high efficiency. Their performances are well known and they can be regarded as most reliable.

Amorphous Silicon (Thin Film) Technology

These modules are not as long on the market and have lower efficiencies than crystalline modules. Nevertheless they now have good references around the world. They might not be as easy to source as crystalline modules but are much cheaper.

1-Axis Tracking System with Crystalline Silicon Technology

Tracking systems are moving planes following the course of the sun over the day. 2-axis tracking systems adapt their azimuth (East to West) as well as their tilt (horizontal to vertical). However, given the solar path in Banjul – GBA (see Figure 9-3), it can be seen that the sun mainly rises sharp from the East to its highest position and then falls sharp again to the West (in higher latitudes such as in Europe, the course of the sun travels more along the horizon). In view of this, it makes sense to use a 1-axis tracking system with a fixed tilt and moving from East in the morning to West in the afternoon. 1-axis tracking systems have the advantages over 2-axis in that they are cheaper and are less demanding in terms of area requirement and maintenance.

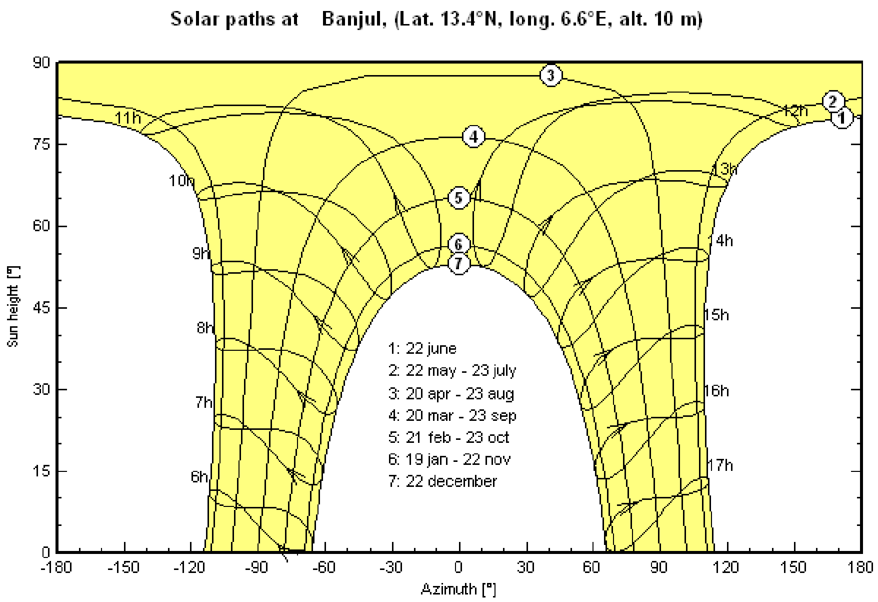


Figure 9-3: Solar paths at Banjul – GBA, The Gambia

9.3 System configurations for the PV Plant

As in Paragraph 5.1.1 stipulated, the penetration factor should not be higher than 10%, at this stage, due to Gambian grid's stability restrictions and simultaneity with other renewable energy supply options. For this specific project, a penetration factor range between 5.0-7.0% is predetermined, which could correspond to a nominal power of 7 MWp. The proposed configuration, also called system, considers therefore for each technology a PV power plant capacity of 7 MWp, according to the following technical details:

System 1: Crystalline silicon modules Suntech Power STP 180/Ac, 180 Wp

The modules are clamped on a mounted system at fixed tilt 15° and facing south. The modules are in single rows and in the upright position. The distance between the rows is in the range of 3.5 m. All modules are connected in strings of 18 modules and then to a central inverter type SMA. The total PV plant capacity is 7 MWp divided into 7 equal 1 MWp sub-plants.

System 2: Amorphous Silicon modules Type Ersol Nova T80

The modules are placed in the same manner like the crystalline modules. They are connected in strings of 6 modules and then to a central inverter. The total PV plant capacity is 7 MWp, as well.

System 3: Tracking System 1-axis with fixed tilt Sunpower T0

The modules have the same technical features as System 1 and are also placed in the same form. The total PV plant capacity is 7 MWp. The 1-axis tracking system is shown in Figure 9-4.

Figure 9-4: Axis Tracking System with Sunpower T0

9.4 Technical design and electricity yield calculation

PVSyst stands among the most powerful software tools for the simulation of grid-connected and stand-alone PV systems. It has been developed by the Center of Energy of the University of Geneva [11]. PVSyst contains an extensive database of technical and electrical properties of the most common PV components (modules, inverters) available on the market. The 4.21 version of this software is then used for the technical design of the PV power plant. The simulation is based on input parameters shown in the next Table 9-5.

Table 9-5: Simulation Input Parameters for the PV Plant Design

	Parameter	Data/Setting	
Site data	Site	Banjul, The Gambia, 13°26' N, 6°34' E	
	Irradiation	Corrected Measurement station 1	
	Time step	Hourly	
	Used Parameters	Horizontal global, horizontal diffuse. Ambient temperature, wind velocity.	
	Albedo	0.2	
	Irradiation transposition	Perez Model	
PV system definition	**Module type**	**Crystalline (e.g. SunTechpower)**	**Amorphous Silicium (e.g. Ersol)**
	Number of modules per MWp	5,670	12,744
	Nominal Power (STC)	180 Wp	80 Wp
	In series / parallel	18 / 315	6 / 2124
Inverter	**Model**	**Central Inverter (e.g. SMA Sunny Central 1000)**	**Central Inverter (e.g. SMA Sunny Central 1000)**

11 Switzerland www.pvsyst.com

Array loss factors	Heat loss factors	-0.46%/°C	-0.21%/°C
	Wiring (ohmic) loss	1.0 %	1.0 %
	Voltage drop series diode	0.7 V	0.7 V
	Array soiling loss (yearly)	2 %	2 %
	Module quality loss	2 %	2 %
	Mismatch Losses	2.0 % at MPP, 4.0% at fixed voltage	2.0 % at MPP, 4.0% at fixed voltage
Orientation	Azimuth	0°	
	Tilt	15°	
	Row spacing	3.5 m	
	Collector width	1.5 m	
	Near shading	String shading caused by previous row Shading angle is 11°	
	Horizon	Free horizon	

The Table 9-6 shows the simulation results for the electricity yield estimation of each system type, whereas Table 9-7 presents the economic and technical parameters for each projected PV Power Plant type (system).

Table 9-6: Electricity Yield Simulation Results by System Type

	System 1	**System 2**	**System 3**
Power Plant Capacity	7 MW	7 MW	7 MW
	Monthly production in MWh		
January	908.8	918.8	1,006.1
February	906.6	921.0	1,041.3
March	1,093.9	1,114.9	1,348.4
April	1,079.6	1,102.8	1,431.0
May	1,049.6	1,072.6	1,450.5
June	884.6	906.8	1,236.2
July	787.3	813.0	1,034.1
August	809.8	837.4	1,012.3
September	838.6	865.7	1,021.3
October	988.5	1,012.2	1,170.8
November	901.9	915.8	1,006.8
December	843.1	851.6	916.9
	11,092.3	**11,332.6**	**13,675.7**

Table 9-7: Economic and Technical Parameters by System Type

	System 1	System 2	System 3
Power Plant Capacity	**7 MW**	**7 MW**	**7 MW**
CAPEX	**28,350 T€**	**26,530 T€**	**33,040 T€**
Module price	18,900 T€	13,300 T€	18,900 T€
Inverter	1,750 T€	2,240 T€	1,750 T€
Balance of system (excl. Inverter)	4,200 T€	5,600 T€	6,300 T€
Installation and Indirect costs	3,500 T€	5,390 T€	6,090 T€
OPEX (O&M and Insurance) per year	**210 T€**	**210 T€**	**420 T€**
Technical Parameters			
Global Horizontal irradiation (kWh/m²)	2,068	2,068	2,068
Global Horizontal irradiation on module plane (kWh/m²)	2,117	2,117	2,559
Energy output (kWh/kWp)	**1,584**	**1,620**	**1,953**
Technical availability (%)	95%	95%	90%
Power output first year (MWh/a)	**10,533,600**	**10,773,000**	**12,303,900**
Degradation (%/a)	0.30%	0.30%	0.30%
Power output after at life end (MWh/a)	9,901,584	10,126,620	11,565,666

9.5 Economic Analysis for the PV Power Plant

As this project focuses on the penetration of the GBA electricity generation grid by PV-technology based electricity generation, the marginal cost increment for two different penetration scenarios are assessed.

- ***Scenario 1: No Project*** <> 0% PV-Penetration
- ***Scenario 2: With Project*** <> 5-7% PV-Penetration (7 MW plant capacity)

In each scenario, a respective amount of conventionally generated (i.e. thermal) electricity is substituted by the same amount of electricity produced by the proposed PV Power Plant. The technical inputs (i.e. yield results) and economic inputs (i.e. OPEX and CAPEX) to the calculation are provided in the previous section. The net electricity generation record for 2007 amounting 192,572 MWh serves as basis and reference for both scenarios.

9.5.1 Fuel Consumption in the GBA grid

In order to assess the marginal operation costs, fuel input per produced MWh of electricity in the NAWEC grid needs to be determined. The data for 2007 is adjusted through extrapolation from available detailed information for 2005.

Two types of fuels are being used for electricity production, heavy fuel oil (HFO) and light fuel oil (LFO) or diesel fuel. In November 2008, HFO was obtained for about 42.44 USD per barrel (i.e. 0.20 EUR/l [12]) and LFO for about 173.24 USD per barrel (i.e. 0.80 EUR/l [13]) in The Gambia.

In 2005, a total of around 38.45 million litres of fuel has been consumed for electricity generation in the biggest NAWEC grid of The Gambia. Of this 2% was LFO while the remaining 98% accounted for HFO. Due to the higher heating values of LFO the shares swing a little towards LFO in terms of energy yields when compared to the fuel input. Here, LFO accounts for 2.4% while HFO yielded 97.6% of the produced electricity. For extrapolating relevant data for 2007, the individual shares are assumed to remain stable.

After comparing the fuel input and the net produced electricity, a net efficiency level of 34.1% has been calculated for the entire generation system. In order to extrapolate 2005 data for the reference year 2007, it is assumed that this efficiency level could also be maintained through scheduled replacements and overhauls.

While LFO might be easier obtainable, in comparison and taking into account current prices, HFO is by far the more economical choice of fuel. The Table 9-8 shows the specific electricity costs for each type of fuel under the assumption that the electricity generated system is powered 100% by each fuel type.

Table 9-8: Specific Electricity Cost by Fuel Type [14]

Type	EUR/MWh
Heavy Fuel Oil	50.80
Light Fuel Oil	170.41

The next Table 9-9 presents the fuel prices, fuel consumption data and levelised unit cost for the generated electricity in the reference year 2007, which is taken as basis for further calculations.

Table 9-9: Fuel Consumption & Marginal Operation Costs for 2007

	[NAWEC 2008]
HFO cost in EUR/l	0.20
LFO cost in EUR/l	0.80
LFO Fuel Consumption in l	0.99 Millions
HFO Fuel Consumption in l	48.93 Millions
Total Fuel Costs in TEUR	10,348
Net Efficiency in %	34.1
Levelised Unit Cost (EUR/MWh)	53.74

9.5.2 Economic Calculation Results

The calculation is performed for the previously defined scenarios, namely:

[12] USD/EUR: 0.73082 (Average 2007)

[13] EUR/GMD: 35.01464 (Average 2007)

[14] Fuel price as of November 2008

Scenario 1: In this scenario no PV power supply capacity is added. Hence, the levelised unit costs mirror the extrapolated fuel consumption results for 2007 (see Table 9-9).

Scenario 2: In this scenario, as the provided PV power supply capacity of 7 MW for each type of PV option constitute a degree of penetration varying in the range of 5 and 7%, depending on the applied technology, a new sub-scenario is defined for an exact 5% PV penetration factor. A fixed penetration factor will similarly lead to different nominal power supply capacities for each proposed technology. Thus, the calculation is carried out for two sub-scenarios: **(2a)** 7 MW plant capacity and **(2b)** 5% PV penetration factor. Investment costs and yield data for Scenario 2b are downscaled from the data of Scenario 2a.

The PV-penetration benefits or marginal operation costs are calculated for the first year of operation only. A more detailed estimation of fuel benefits and marginal costs would, however, require a price projection for fuel prices and a confirmed expansion plan of the installed thermal generation capacity. Due to the extrapolation of relevant data and the application of current fuel prices, these results represent a preliminary estimation only.

In all scenarios, the LUC - levelised unit costs (in EUR/MWh) for the individual PV-options (systems) comprise the individual present values of CAPEX and OPEX divided by the yielded electricity for the first operational year. These differ only by PV-option (system), however, not by sub-scenario, due to the same price-to-power ratio. The following Table 9-10 presents the individual LUC by PV-option for sub-scenarios 2a and 2b.

Table 9-10: Levelised Unit Costs by PV-option (System) in EUR/MWh

System 1 **Fixed System with Crystalline Modules**	**System 2** **Fixed System with Amorphous Modules**	**System 3** **1-Axis Tracked System with Crystalline Modules**
241.53	222.29	255.57

The Figure 9-5 illustrates a summary of the individual levelised unit costs for all scenarios.

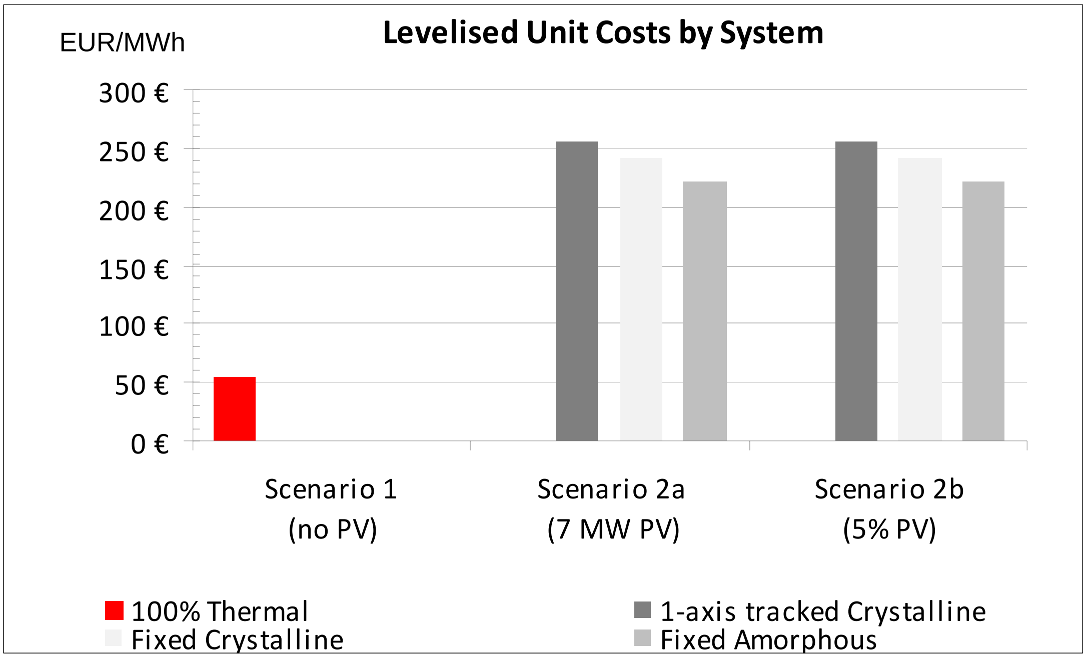


Figure 9-5: Individual Levelised Unit Costs by System

While the LUC for the mere PV-component of the entire generation system currently in place remains the same, the variation in the degree (i.e. 5.47%, 5.59% and 6.39% with scenario 2a and 5% with scenario 2b) of the actual penetration lead to different LUC when both thermal and photovoltaic generation systems are to be considered.

The Table 9-11 and Table 9-12 illustrate the LUC in the respective generation mix, fuel as well as generation benefits when the total "penetrated" generation costs are compared to the previous fuel costs without any PV-options integrated.

Table 9-11:LUC, Fuel and Generation Costs - Scenarios 1 and 2a

	Scenario 1	Scenario 2a		
	No PV	System 1	System 2	System 3
PV Power Plant Capacity	0 MW	7 MW	7 MW	7 MW
Penetration Factor	0%	5.47%	5.59%	6.39%
LUC (Mix) EUR/MWh	53.74	64.01	63.16	66.63
Fuel Benefits EUR/MWh	0	-10.27	-9.43	-12.90
Generation Costs (2007) EUR	10,347,902	12,326,099	12,163,705	12,831,312
Generation Benefits EUR	0	-1,978,198	-1,815,804	-2,483,411

Table 9-12: LUC, Fuel and Generation Costs - Scenarios 1 and 2b

	Scenario 1	Scenario 2b		
	No PV	System 1	System 2	System 3
PV Power Plant Capacity	0 MW	6.08 MW	5.95 MW	4.93 MW
Penetration Factor	0%	5%	5%	5%
LUC (Mix) EUR/MWh	53.74	63.13	62.16	63.83
Fuel Benefits EUR/MWh	0.00	-9.39	-8.43	-10.09
Generation Costs (2007) EUR	10,347,902	12,156,143	11,970,817	12,291,334
Generation Benefits EUR	0	-1,808,241	-1,622,915	-1,943,432

The LUC of the individual options integrated into the generation mix by either (i) 5% penetration factor or (ii) 7MW power capacity are visualised in the Figure 9-6.

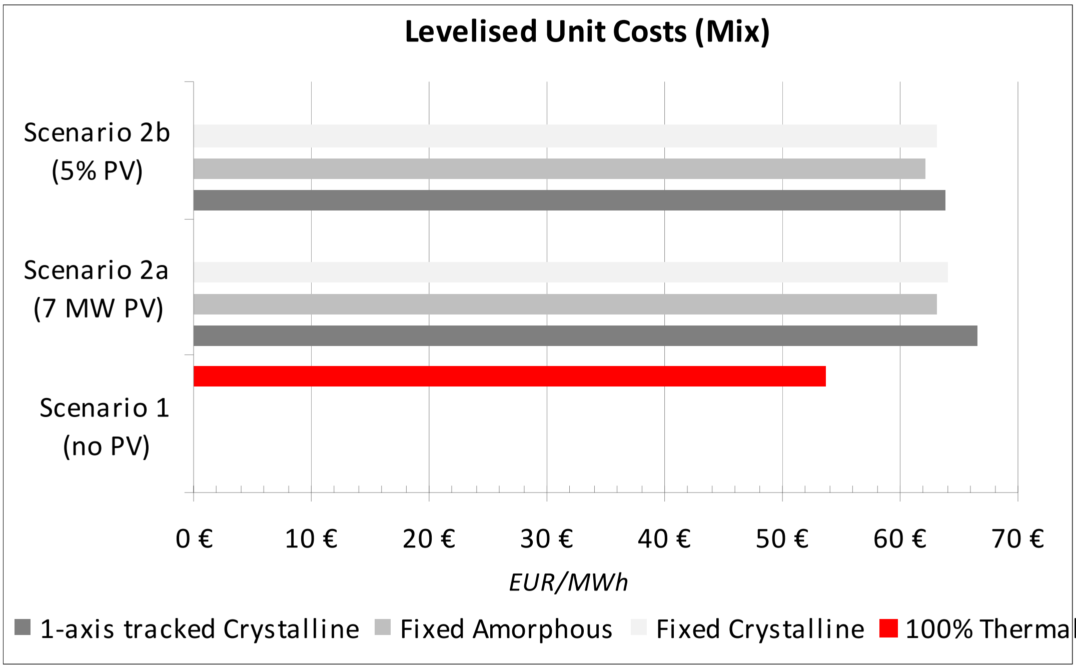


Figure 9-6: Levelised Unit Costs for Mix Generation

The LUC increment of the individual options compared to the current LUC with a 100%-thermal generation system ranges between 16% for the Fixed-Amorphous-option (System 2) in the strict 5% sub-scenario (2b) to 24% with the Crystalline-tracking system-option (System 3) in the 7 MW sub-scenario (2a). These increments are shown in the Figure 9-7.

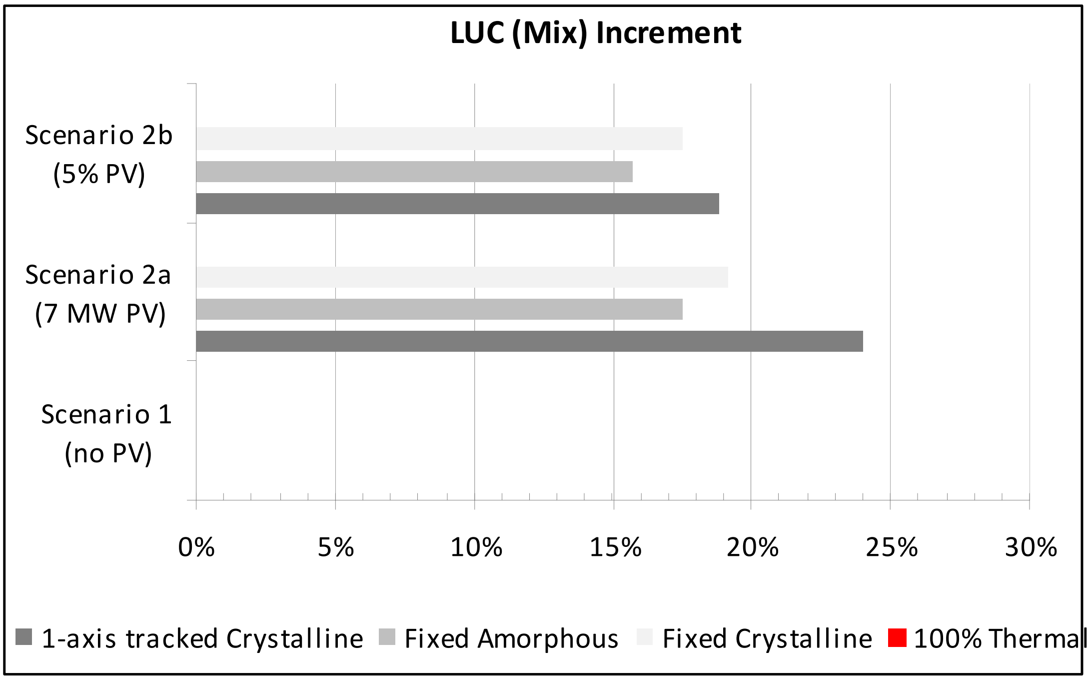


Figure 9-7: Increment of Levelised Unit Costs by Options 2a and 2b

9.5.3 Sensitivity Analysis with regard to Fuel Price and CAPEX

It is expected that increases of the LUC could be compensated somehow in the medium or long term. This could either happen by fuel (oil) price increase, as it proportionally increases the LUC of the thermal generation system or by a reduction of the investment costs for the individual PV-options (due to the market development in the future), which may decrease the LUC of the PV-options.

The following Table 9-13 shows further results with regard to the required fuel price increase in the reference condition for each individual scenario.

Table 9-13 Reference Condition: "Fuel prices increase" (1, 2a, 2b)

	Scenario 1	Scenario 2a & 2b		
	No PV	System 1	System 2	System 3
LFO Price in EUR/l	0.80	3.59	3.31	3.80
HFO price in EUR/l	0.20	0.88	0.81	0.93
HFO price in USD/barrel	42.44	190.77	175.56	201.86
Fuel Price Increment %	**0 %**	**+ 449.5 %**	**+ 413.7 %**	**+ 475.62 %**

On the one hand, the following Figure 9-8 illustrates the required fuel price increases in order to compensate the additional investment costs for the individual PV-options. The fuel price level above which the evaluated PV-options turn an economically viable investment is named marginal fuel price. HFO was chosen to be the marker as it accounts for 98% of the total fuel consumed for electricity production in The Gambia. The relative price increase, however, remains the same for both HFO and LFO.

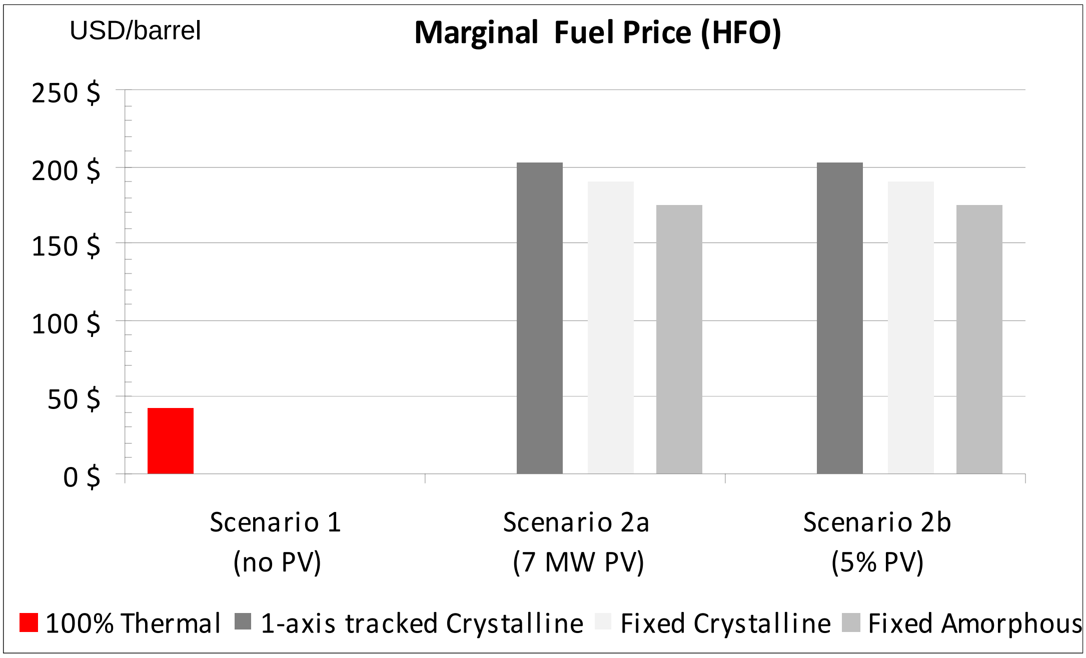
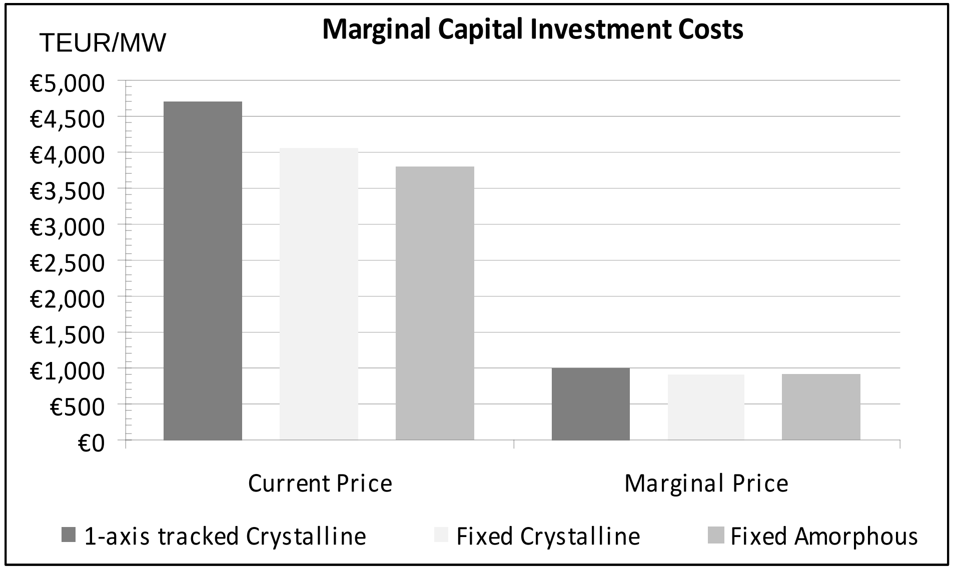


Figure 9-8: Marginal Fuel Prices, HFO

On the other hand, the next Figure 9-9 shows the required decreases of capital investment costs compared to the current prices which served as basis for this calculation. The level of capital investment costs above which the individual PV-options become economically viable is named marginal capital investment cost. The ratio of decrease corresponds to the increase share of the required marginal fuel price.



Unit	Current Price			Marginal Price		
	Fixed Crystalline	Fixed Amorphous	1-Axis Tracking Crystalline	Fixed Crystalline	Fixed Amorphous	1-Axis Tracking Crystalline
TEUR/MW	**4,050**	**3,790**	**4,720**	**901**	**916**	**993**
CAPEX Decrement	**0%**	**0%**	**0%**	**- 449.5 %**	**- 413.7 %**	**- 475.6 %**

Figure 9-9: Marginal Capital Investment Costs

9.6 Main Outcome of the Priority Project Evaluation

The calculation results show that currently, assuming a fuel price of about USD 42.50 per barrel of HFO, no PV-penetration would be economically feasible. For PV power plants becoming a viable option interconnected to the GBA grid, there are two possible ways: either the fuel price would increase about 4.5 times or the PV power plant investment costs would go down by the same ratio. Only by these two alternatives, a PV power plant would become economically competitive and a reasonable option in an electricity system dominated by thermal generation. This is a statement based purely on economic considerations and do not examine any other important criterion i.e. environmental aspects.

Both developments could congregate at some middle point in the future and presumably moving in parallel. Thus, the fuel price will increase while the production and investment costs required for a PV power plant will decrease.

10 Summary of Results – Conclusions

The principal objective of this thesis has been to develop a methodology for the formulation of a master plan for renewable energy based electricity generation in The Gambia. Such a master plan aims to develop and promote renewable sources of energy as an alternative to conventional forms of energy for generating electricity in the country. Wind, Solar and Biomass resources for energy generation purposes were assessed, while other alternatives like geothermal energy and traditional hydro energy were prima face ruled out as The Gambia does not dispose of the required resources. The permanently discussed tidal energy option in the Gambia River was not considered in the present study.

A tailor-made methodology for the preparation of a 20-year renewable energy master plan focussed on electricity generation was proposed in order to be followed and verified throughout the present dissertation, as it was applied for The Gambia. The main input data for such a master plan are (i) energy demand analysis and forecast over 20 years and (ii) resource assessment for different renewable energy alternatives including their related power supply options. The balance of these two input data gives a quantitative indication of the substitution potential of renewable energy generation alternatives in primarily fossil-fuel-based electricity generation systems, as well as fuel savings due to the deployment of renewable resources. Afterwards, the identified renewable energy supply options are ranked according to the outcomes of an economic analysis. Based on this ranking, and other considerations, a 20-year investment plan is prepared and consists of individual renewable energy projects for electricity generation. Finally, a priority project of the master plan is identified and selected for further deeper analysis including a sensitivity analysis with regard to oil and technology market conditions in the future.

The energy demand analysis basically confirmed The Gambia´s reliance almost entirely on biomass (fuelwood) and imported petroleum products to meet its primary energy requirements. The transformation from primary sources (mainly HFO and diesel) into electricity is basically related to the generation capacity of the national utility NAWEC, which grew from nearly 12 MW to 52 MW of available capacity over the period 1995 up to 2008, whereas the total capacity of the six isolated service areas from NAWEC in the Gambian country-side was 4.26 MW in 2008. The electrification rate of The Gambia reached in 2007 only around 40%, with more than half the population having no access to electricity supply at all. Moreover, the annual net electricity generation at sent-out-level in the same year was 195,572 MWh/a with a billed consumption of 135,343 MWh/a resulting in 29.7% of total losses. These last facts fully justify the Gambian government commitments to increase of generating capacity that is presently inadequate and unable to meet the demand and to invest in the improvement of transmission and distribution system conditions across the country and to abate non-technical losses. An electricity consumption of less than 63 kWh per capita and year was calculated. Thus, it has been determined that The Gambia belongs to those countries with the lowest per-capita-electricity consumption. At last, based on the results of the utilisation of primary and secondary energy sources assessment in The Gambia, a national energy balance comprising the entire supply chain, beginning from domestic and imported energy sources, over transformation and transport processes to the final consumption by source and sector was prepared. This balance is presented in form of a Sankey diagram (energy-flow-diagram).

The energy demand forecast was based on a mix between Top-Down and Bottom-Up methodologies and considered a 20-year-period. The results are important data for other projections in terms of future requirements of (primary) energy sources. The electricity forecast was separated in projections at sent-out level and at end-user level. The suppressed electricity demand was considered by applying a sector break down, which considered not only the billed electricity consumption, but also the presently unserved electricity demand. The forecasted average annual growth rate for the electricity demand at sent out level (including suppressed demand) is 12.8% from the base year on until 2010, 4.0% for the period 2010-2015, and approximately 3.6% in 2016-2025. The estimated annual electricity demand at sent-out-level in 2025 is 1,017 GWh/a.

On the supply side, Solar, Wind and Biomass, as sources of energy, were investigated in terms of technical potential and economic benefits for The Gambia. Other criteria i.e. environmental and social were not considered in the evaluation.

For the Solar and Wind resource assessment, Zero-Maps for The Gambia were prepared based on satellital data bases and mesoscalic calculations. Next, in order to scale and refine the preliminary results of the zero maps and to define the technical potential of solar and wind energy in The Gambia, eight solar-wind measurement stations covering the whole country were installed and commissioned in July 2005. Later on, solar and wind data for a one-year period were collected and evaluated.

- The solar data collected for The Gambia show good radiation values in all regions. The average daily solar radiation over the considered one-year period (2005-2006) ranges from 4.4 to 6.7 kWh/m^2. The sunniest period is during spring when skies are characteristically clear (the variation between min and max is extremely small at this time). The lowest radiation values are observed during winter, in December and January. In terms of average values, the temporal variation between low and high values is not significant and even in the “weakest period”, good solar radiation values are expected. Hence, several energy (electricity) supply possibilities were preliminarily defined: PV Power Plants, Solar Home Systems and Hybrid Diesel-PV Systems supported, in addition, by the existing PV based energy generation projects (i.e. the EU solar PV pumping, SHS projects and PV-Diesel hybrid system in Darsilami). It is very difficult to envisage any solar thermal power generation plant, as electricity supply option for The Gambia, due to the relatively small power capacity requirements in the country. At the present CSP technology state of the art, the technical and economical viability are in the same or over range of installed capacity in the whole country.
- The wind resource measurement campaign confirms, that mainly due to latitudinal vicinity of The Gambia to the equator, the wind conditions are moderate all over the country, above all in the hinterland. Long-term correlated mean wind speeds, except at Station 1, are below 4.0 m/s at 30 m height, particularly in the inland of The Gambia. Such wind conditions are moderate and hardly suitable for wind powered generation on economical basis. Thus, the energy (electricity) supply options were initially limited to small wind parks or isolated small sized wind turbines in the Gambian coastal areas. All these options should consider suitable turbine technology and integrate wisely wind power to the existing electrical network in the greater Banjul Area. Due to electrical network capacity size, land availability and infrastructure constraints, it was predefined the use of medium and small wind turbine sizes in The Gambia. In addition, scarce technology providers for small size wind energy convertors in the current market justifies to take into account re-powered equipment, as an alternative.

- Fuelwood is by far, with more than 80% of the national primary energy consumption and about 97% of the household energy consumption, the most important renewable energy source. However, the sustainable use of fuelwood for electricity generation demands the existence of very efficient and organised forestry management systems which are not available in the Gambia. Consequently, the evaluation of biomass electricity generation opportunities comprised the utilisation of other sources like agricultural crop residues, energy crops, animal residues, industry residues and municipal residues. After a detailed resource potential assessment with regard to suitability for electricity generation, most options were discarded due to scale (quantity) and resource availability (disperse) constraints. The use of groundnut shells was identified as the most promising biomass based electricity supply option.

Diverse supply options were proposed and technically designed based on the assessed renewable energy potential. This process included the evaluation of the different available conversion technologies and finalizing with the dimensioning of power supply solutions, taking into consideration technologies which are applicable and appropriate under the special conditions of The Gambia.

- PV power supply options were explored. The installation of a large PV power plant integrated to the largest power grid from NAWEC in GBA was proposed. This plant should be located around Brikama in order to take advantage of available large inhabited areas and should be installed around 2015, when grid parity is achieved. The main purpose of this plant would be to replace fossil-fuel powered generation capacity by renewable energy. A 1 MW power plant capacity was thought to be used as a "unit-plant", whereas larger PV-units could be then planned by only summing up such "unit-plants". A penetration factor limited to 10% was initially recommended in order to ensure the grid's stability. The construction and connection of a 1 MW PV power plant onto the GBA grid would allow NAWEC to save the equivalent of about 10 million litres Diesel over the whole project's lifetime, releasing a part of this burden on Gambia's economy.

  A SHS program was planned for small villages (less than 450 households) because larger communities could rather benefit from hybrid systems or grid connection plans. Then, five different levels of income were defined and a suitable SHS for each one was proposed. Such a program over 20 years would require a total investment of 4.2 million USD for the equipment of more than 9,000 households, positively affecting the life of more than 90,000 people.

  As third option, small PV plants as fuel savers were proposed for the six isolated grids (diesel generation) located in the country-side. Scenarios with renewable energy penetration factors of 10, 15 and 20% were defined and evaluated. Small PV-Diesel hybrid systems seemed to be restricted to few rural villages in The Gambia and were therefore not considered for the master plan.

- The wind power generation options were focused on integration of small wind parks and wind turbines in existing electrical networks at the western coast near Tujering in the West of LGA Brikama and in the North of Essau, LGA of Kerewan. Different scenarios with new and also with repowered (refurbished) wind turbines of the 30-660 kW class were set up. The Kerewan region, which has shown better wind conditions than the hinterland of The Gambia, was considered for Stand Alone Wind Diesel Hybrid Systems. Three wind turbines with capacity of 25 kW each will feed the grid and load the accumulators in case of surplus electricity generation. A 30 kW Diesel generator will be available as backup electricity generation option in case of increased energy consumption or during low wind speed periods or calms.

- The only biomass power supply option considered was a 600 kW heat and power plant (fuel: 9,000 t/a groundnut shells), to be installed next to Banjul Breweries.

Based on the electricity demand analysis, electricity forecast and proposed renewable energy based power supply options, the supply-demand balance was prepared. Previously, the development of installed capacity and yearly energy output for all supply options during the master plan period (Base Year – 2025) was compiled, including geographical classifications per LGA. The supply-demand balance indicated that the implementation of all proposed renewable energy projects for electricity generation in the master plan for The Gambia could offer fuel savings from 773 TOE/a in the base year up to 5,636 TOE/a in 2025. At the same time, around 2.2%, in base year, and 4.8% of the electricity demand in 2025 would be supplied by renewable energy based power supply systems. The REMP model allows a sensitivity analysis: if the PV installed capacity in LGA Brikama by 2025 would reach 10 MW or 25 MW instead of the proposed 3 MW, the proportion of electricity provided by renewable energy would account 7.5% or 13.1%, respectively.

An economic analysis of the supply options resulted on the biomass supply option as the best option from the economical point of view (least dynamic unit cost), followed by the small wind park with refurbished turbines in GBA (SWP_1b (used)) and the small PV power plant as fuel saver with 20% penetration factor (PV_3_20%). The less attractive options are SHS. Nevertheless, away from these purely economical results, the implementation of a SHS program could still be considered as a good alternative according to other criteria like simplicity of technology, poverty fighting strategies and rural development promotion measures.

Subsequently, based on this ranking as well as under consideration of mutually exclusive implementation constraints, a least-cost investment plan for 20 years was prepared, broken down into five-year investment periods and consisting of individual renewable energy projects. These projects included basically on-grid renewable energy applications. The total required investment for implementing the proposed renewable energy master plan for electricity generation in The Gambia is around 28 Millions USD, which would mean more than 12 MW of additional power supply capacity based on renewable energy in a 20-year period, with PV as the most applied (proposed) technology. Wind energy would be, however, the first technology to be implemented.

Once the master plan methodology was successfully applied and verified, a priority project from the projects portfolio of the master plan for The Gambia was selected for further deeper analysis. Since solar PV based projects are the most relevant technology in the proposed renewable energy master plan and investment plan, there was no doubt about which project should be considered: a PV power plant integrated to the Diesel powered main electrical system in The Gambia. A more detailed alternative evaluation appeared to be even more necessary taking into consideration the increase of fuel prices as well as reduction of investment cost for the photovoltaic technologies in the future. Thus, the priority project was analysed by economic competitiveness under the current conditions in addition to sensitivity analysis with regard to oil and new-technology market conditions in the future.

In order to perform an actual and updated project analysis, the Gambian power sector information was actualised to the end of 2008. Three technology options were considered for this evaluation: Crystalline Silicon modules, fixed system; Amorphous Silicon (Thin film) modules, fixed system; and 1-axis tracking system with Crystalline modules. An annual irradiation of 2,060 kWh/m² was calculated for a location in GBA. As the project focuses on the penetration of the GBA electricity generation grid by equivalent PV-technology, three different penetration scenarios were defined: No PV-Penetration, 7 MW PV Penetration and 5% PV-Penetration.

An economic analysis was carried out for all scenarios, including a sensitivity analysis with regard to Fuel Price and CAPEX. It was expected that increases of the LUC by integrating PV power plants, could be compensated somehow in the medium or long term, either due to fuel (oil) price increase, as it proportionally increases the LUC of the thermal generation system, or due to reduction of the investment costs for PV-options (as a result of the market development in the future), which may decrease the LUC of these options.

The calculations results showed that no PV-penetration would be economically feasible, assuming a fuel price of about USD 42.50 per barrel of HFO. There are two possible ways for PV power plants interconnected to the GBA grid to becoming an economical viable option: either the fuel price would increase about 4.5 times or the PV power plant investment costs would go down by the same ratio. Certainly, in the future, both developments could congregate at some middle point and presumably moving in parallel. Thus, the fuel price will increase while the production costs and the investment costs required for a PV power plant will decrease. It could be subject to further evaluation at which point both developments would result in a turning point for the integration of PV-systems in the NAWEC grid.

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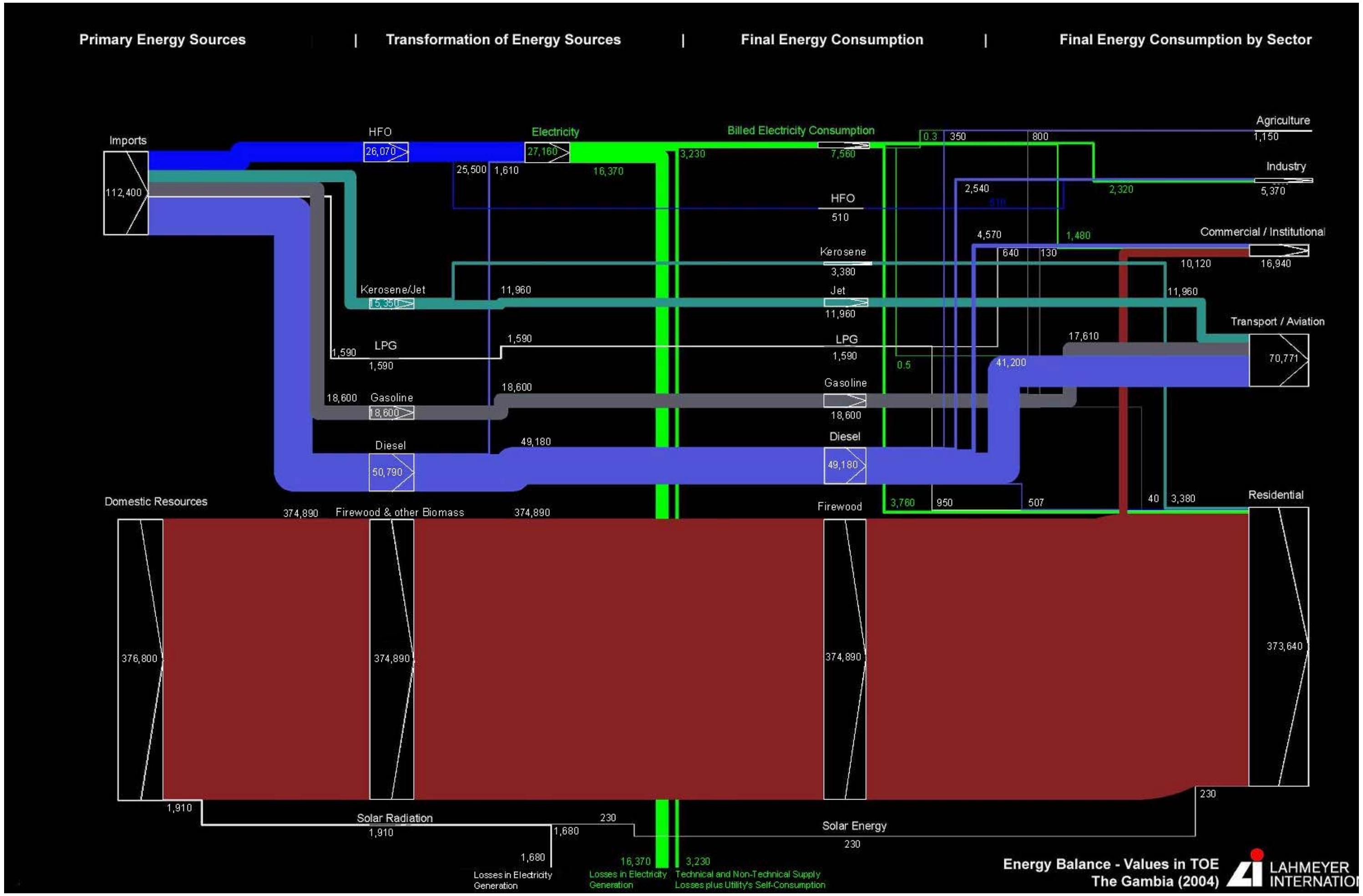
12 Annexes

Annex 1: Energy Demand Assessment and Projection

12.1 Energy Balance of The Gambia in TOE/a



12.2 Primary Energy Projections (Fuelwood, Diesel and HFO)

Entire Fuelwood Demand		Base >>	2010	2015	2020	2025
Total Annual Demand	**TOE/a**	**367,747**	**454,356**	**502,225**	**519,048**	**539,326**
GBA - GREATER BANJUL AREA	TOE/a	95,989	116,374	126,533	132,010	137,798
LGA OF BRIKAMA	TOE/a	104,494	152,374	185,483	195,374	207,555
LGA OF MANSAKONKO	TOE/a	19,655	21,147	21,149	20,914	20,699
LGA OF KEREWAN	TOE/a	46,854	50,258	50,110	48,549	47,038
LGA OF KUNTAUR	TOE/a	21,549	23,880	24,343	24,140	23,943
LGA OF JANJANBUREH	TOE/a	29,270	34,262	36,890	39,324	42,449
LGA OF BASSE	TOE/a	49,936	56,060	57,718	58,736	59,845

Entire Diesel Demand		Base >>	2010	2015	2020	2025
Total Annual Demand	TOE/a	**50,786**	**60,096**	**84,756**	**119,653**	**170,258**
GBA - Greater Banjul Area - Annual Demand	TOE/a	43,137	46,896	63,270	83,815	111,741
LGA OF BRIKAMA - Annual Demand	TOE/a	3,039	5,654	7,644	9,649	12,417
LGA OF MANSAKONKO - Annual Demand	TOE/a	546	578	729	903	1,123
LGA OF KEREWAN - Annual Demand	TOE/a	1,303	1,357	1,697	2,071	2,530
LGA OF KUNTAUR - Annual Demand	TOE/a	583	593	740	938	1,186
LGA OF JANJANBUREH - Annual Demand	TOE/a	803	889	1,182	1,593	2,177
LGA OF BASSE - Annual Demand	TOE/a	1,375	1,488	1,910	2,443	3,135

Entire HFO Demand		Base >>	2010	2015	2020	2025
Total Annual Demand	**TOE/a**	**26,580**	**78,305**	**87,040**	**87,593**	**88,366**
Total Electricity Demand at Sent-Out Level (including Suppressed Demand)	TOE/a	24,861	51,257	62,278	72,881	87,453
Electricity Demand to be covered by Primary Energy Transformation	TOE/a	10,786	31,047	34,511	34,730	35,036
HFO Demand of Energy Industry	TOE/a	26,070	76,801	85,369	85,911	86,669
HFO Demand of Other Industry	TOE/a	510	1,503	1,671	1,682	1,697

Annex 2: Solar Energy Resources

12.3 Ground Base Solar Data

Table 12-1 Average Daily Values for each month of collection in Wh/m².day

Station/Month	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06	Apr-06	May-06	Jun-06
Station01	4960	5264	5338	4965	5102	4476	4849	5563	6343	6939	6907	6247
Station02	4799	5146	5007	4963	5001	4367	4678	5306	6233	6611	6588	6072
Station03	4878	5185	5194	4971	4975	4456	4869	5532	6308	6776	6529	6082
Station04	4876	5175	5324	5039	4916	4325	4734	5562	6269	6803	6695	6082
Station05	4998	5041	5060	4918	4810	4453	4698	5497	5897	6528	6211	5990
Station06	5033	5341	5417	5386	5271	4682	4779	5708	6328	6923	6568	6305
Station07	4647	4983	5020	4773	4682	4184	4448	4927	5851	6649	6712	5960
Station08	4354	4669	4661	4579	4518	3938	4197	4866	5503	6052	6010	5350
Average value	**4818**	**5101**	**5128**	**4949**	**4909**	**4360**	**4656**	**5370**	**6092**	**6660**	**6528**	**6011**

12.4 Ground Base Solar Data Plots

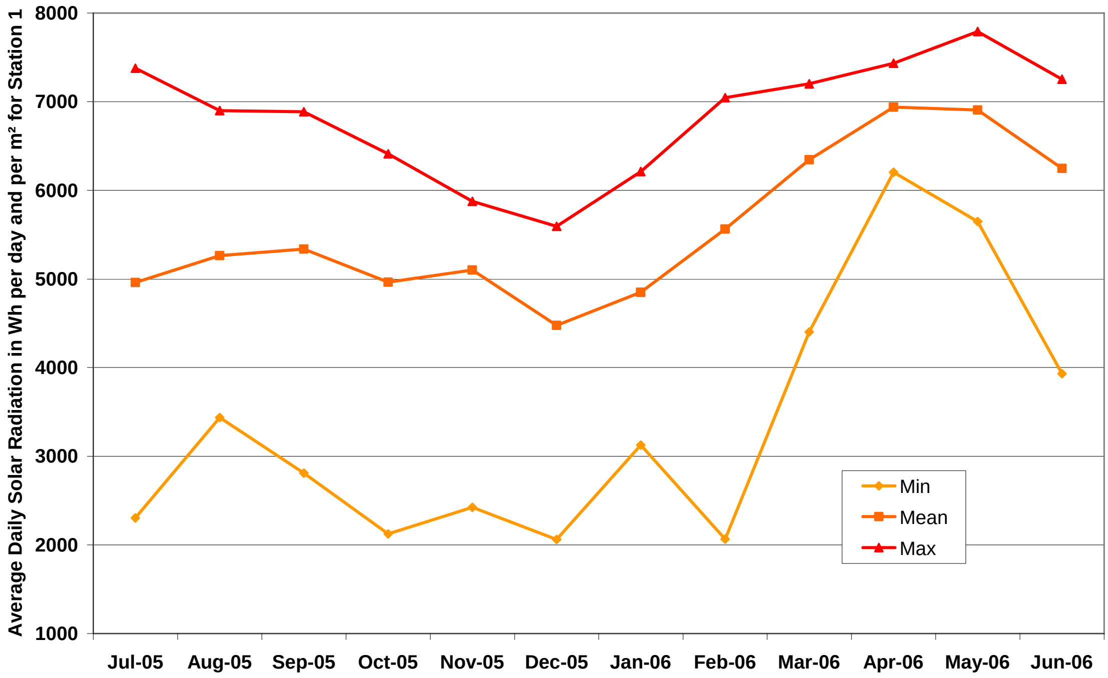


Figure 12-1: Average daily solar radiation for station 1, in Wh/m² per day

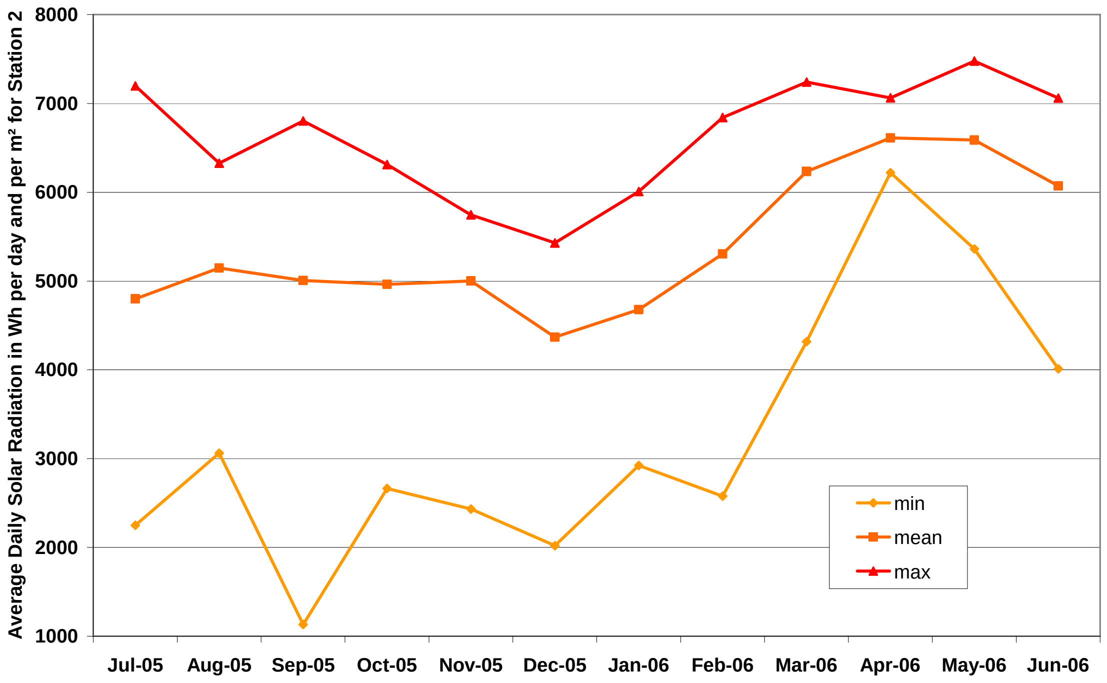


Figure 12-2: Average daily solar radiation for station 2, in Wh/m² per day

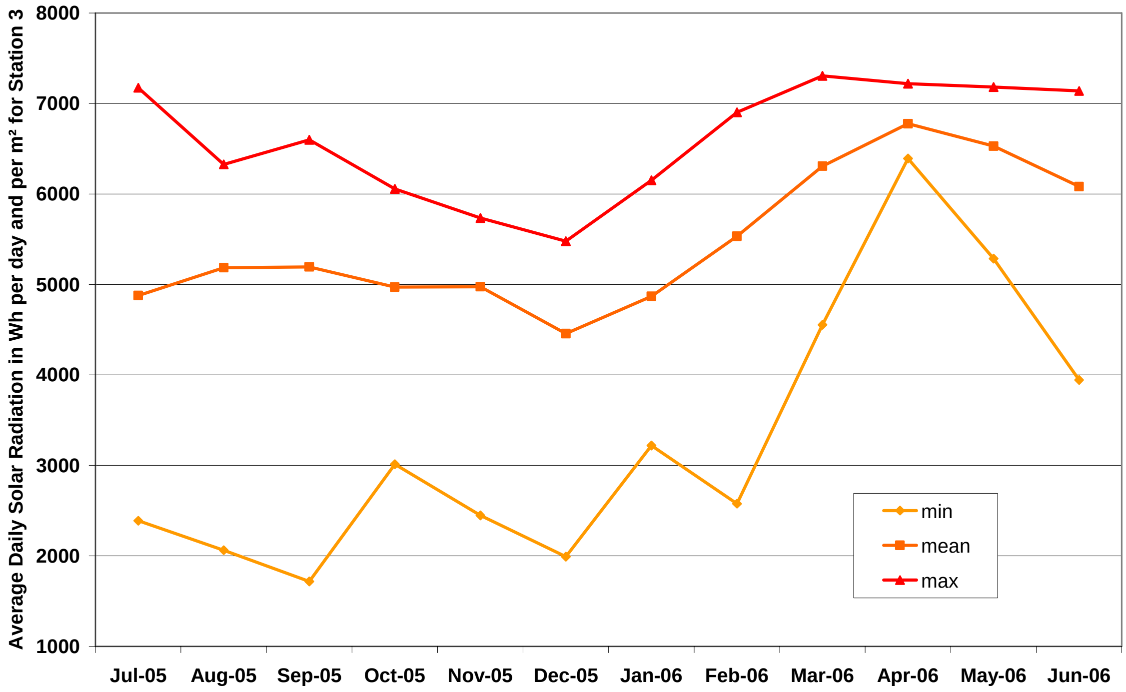


Figure 12-3: Average daily solar radiation for station 3, in Wh/m² per day

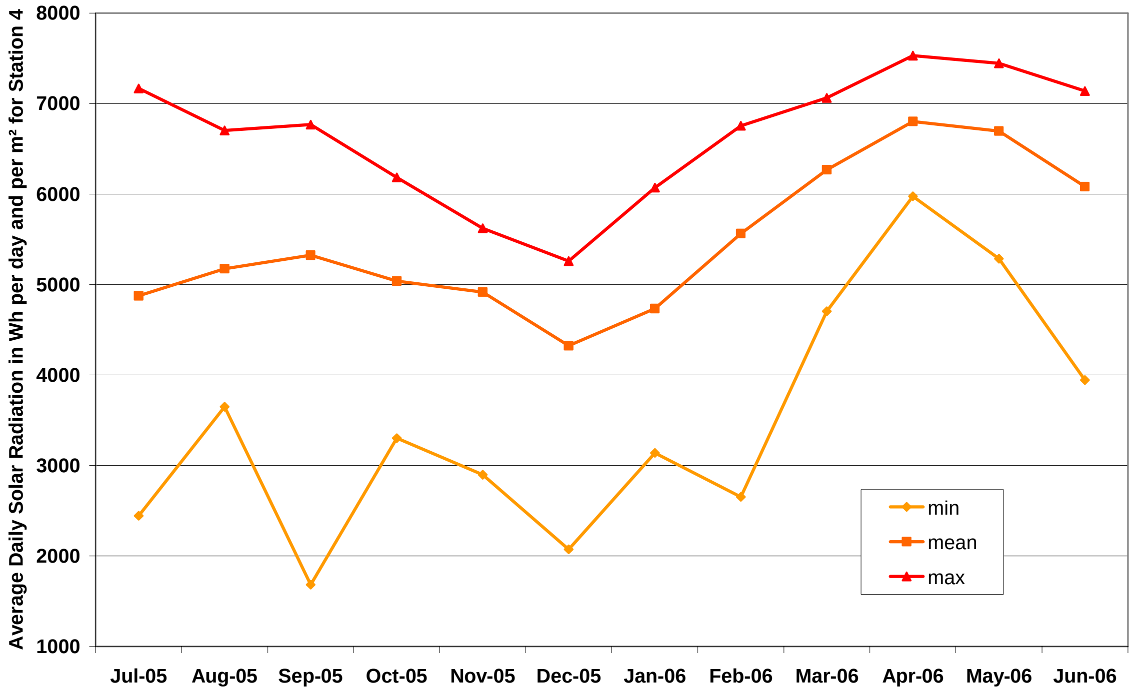


Figure 12-4: Average daily solar radiation for station 4, in Wh/m² per day

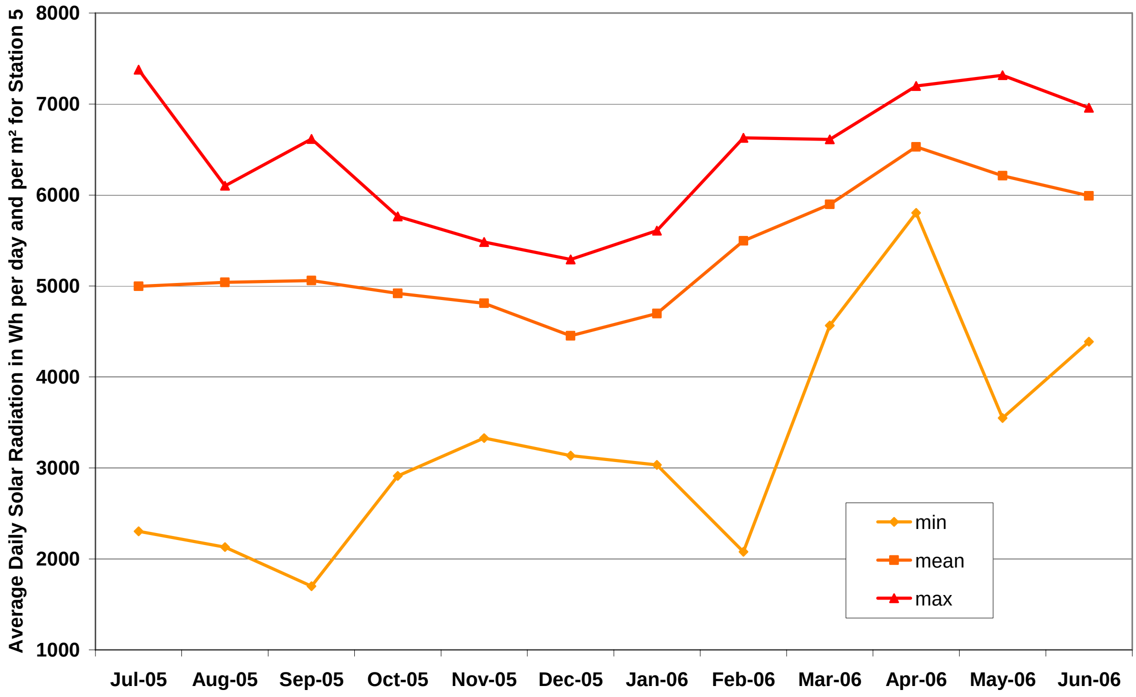


Figure 12-5: Average daily solar radiation for station 5, in Wh/m² per day

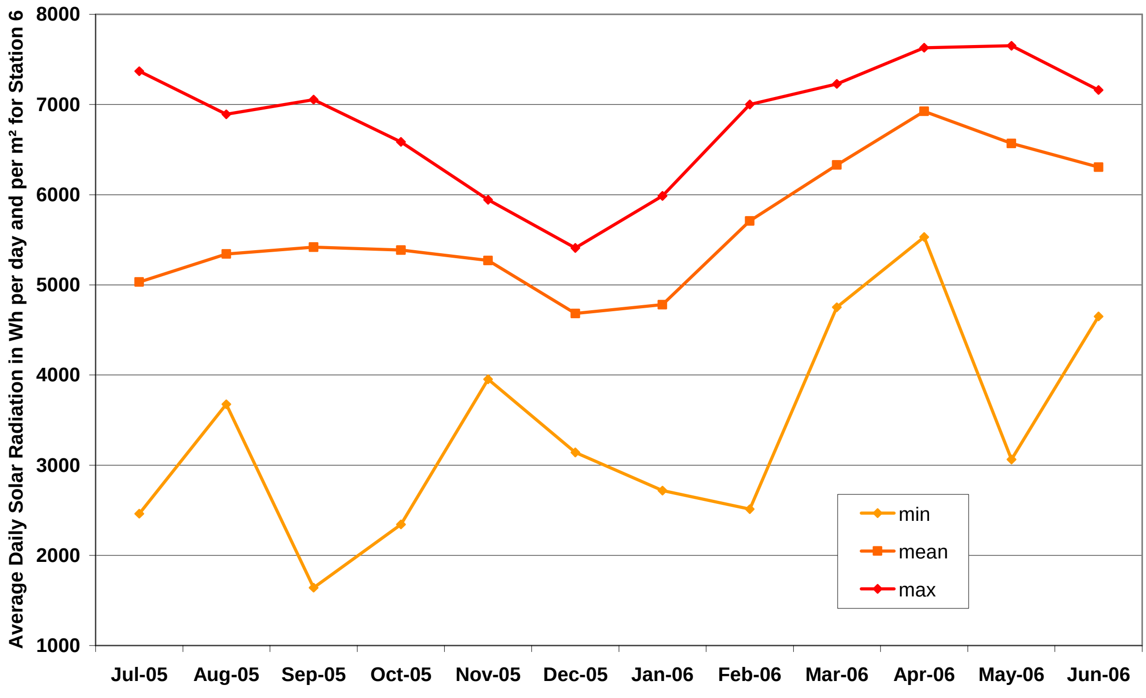


Figure 12-6: Average daily solar radiation for station 6, in Wh/m² day

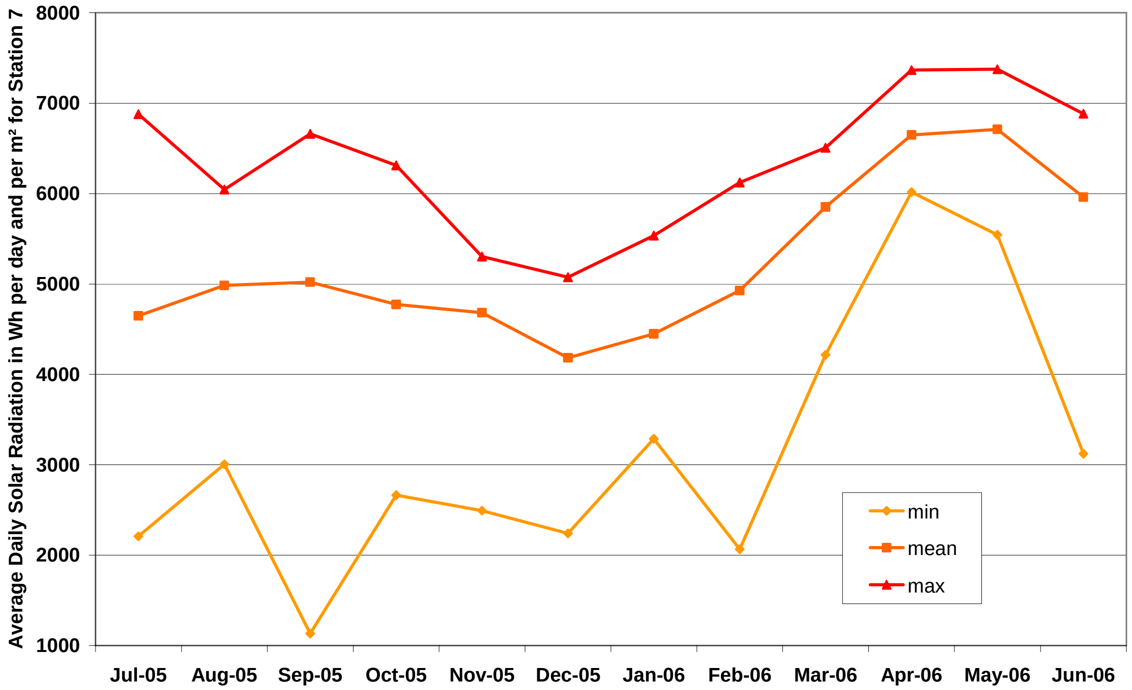


Figure 12-7: Average daily solar radiation for station 7, in Wh/m² per day

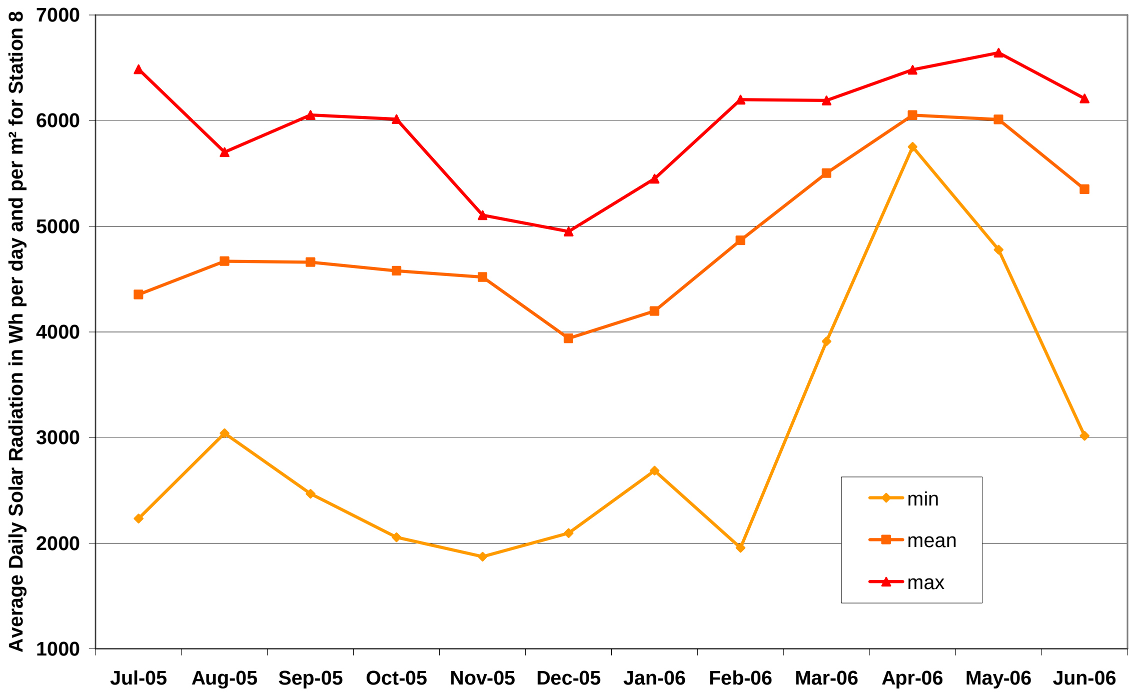


Figure 12-8: Average daily solar radiation for station 8, in Wh/m² per day

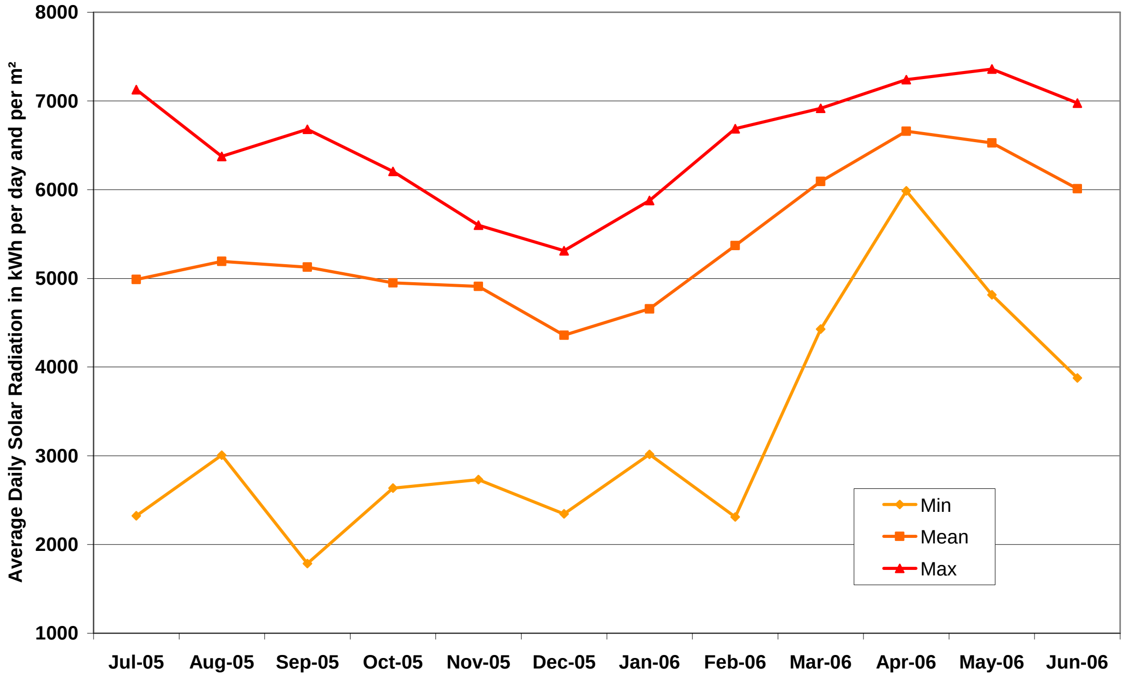


Figure 12-9: Average daily solar radiation for the Gambia, in Wh/m² per day

12.5 Solar Map based on Ground-Based Data

Figure 12-10: Colour Scale

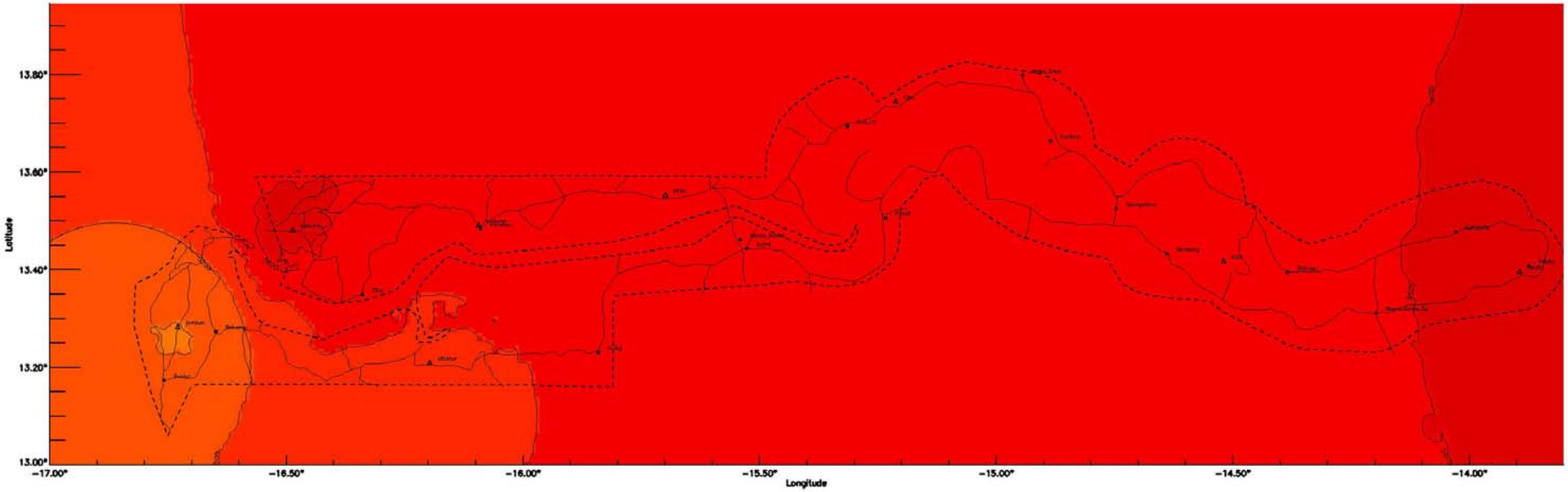


Figure 12-11: Average daily solar radiation over measurement period (July 2005 to June 2006), in Wh/m² per day

Annex 3: Supply options (installed capacity) per LGA

Product	Year	LGA OF BANJUL	LGA OF KANIFING	LGA OF BRIKAMA	TOTAL GAMBIA PV_1
PV_1	Base			-	-
	2010			-	-
	2015			1,000.0	1,000.0
	2020			2,000.0	2,000.0
	2025			3,000.0	3,000.0

Product	Year	LGA OF BRIKAMA	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_2 SL
PV_2 SL	Base	0.05	0.02	0.05	0.06	0.05	0.01	0.2
	2010	0.15	0.07	0.16	0.18	0.16	0.03	0.7
	2015	0.66	0.31	0.68	0.77	0.70	0.13	3.2
	2020	1.63	0.71	1.56	1.72	1.62	0.30	7.5
	2025	1.86	0.86	1.86	2.16	1.97	0.37	9.1

Product	Year	LGA OF BRIKAMA	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_2 SHSp
PV_2 SHSp	Base	0.05	0.02	0.05	0.06	0.05	0.01	0.2
	2010	0.15	0.07	0.15	0.17	0.16	0.03	0.7
	2015	0.88	0.41	0.90	1.02	0.93	0.17	4.3
	2020	3.08	1.44	3.15	3.58	3.26	0.61	15.1
	2025	4.43	2.07	4.53	5.15	4.69	0.88	21.8

Product	Year	LGA OF BRIKAMA	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_2 SHSm
PV_2 SHSm	Base	0.24	0.11	0.25	0.28	0.26	0.05	1.2
	2010	0.73	0.34	0.75	0.85	0.78	0.15	3.6
	2015	5.6	2.6	5.8	6.5	6.0	1.1	27.6
	2020	13.0	6.0	13.3	15.1	13.7	2.6	63.6
	2025	14.8	6.9	15.1	17.2	15.7	2.9	72.6

Product	Year	LGA OF BRIKAMA	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_2 SHSs
PV_2 SHSs	Base	0.61	0.28	0.63	0.71	0.65	0.12	3.0
	2010	1.83	0.85	1.88	2.13	1.94	0.36	9.0
	2015	14.1	6.6	14.4	16.3	14.9	2.8	69.0
	2020	26.3	12.3	26.9	30.5	27.8	5.2	129.0
	2025	27.9	13.0	28.5	32.4	29.5	5.5	136.8

Product	Year	LGA OF BRIKAMA	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_2 SHSl
PV_2 SHSl	Base	0.98	0.46	1.00	1.14	1.04	0.19	4.8
	2010	2.94	1.37	3.00	3.41	3.11	0.58	14.4
	2015	22.5	10.5	23.0	26.1	23.8	4.5	110.4
	2020	42.1	19.6	43.0	48.9	44.5	8.4	206.4
	2025	44.6	20.8	45.6	51.8	47.2	8.9	218.9

Product	Year	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_3_10%
PV_3_10%	Base		-	-	-	-	-
	2010		405.0	37.0	130.0	310.0	882.0
	2015		405.0	37.0	130.0	310.0	882.0
	2020		810.0	74.0	260.0	620.0	1,764.0
	2025		810.0	74.0	260.0	620.0	1,764.0

Product	Year	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_3_15%
PV_3_15%	Base		-	-	-	-	-
	2010		605.0	55.0	190.0	470.0	1,320.0
	2015		605.0	55.0	190.0	470.0	1,320.0
	2020		1,210.0	110.0	380.0	940.0	2,640.0
	2025		1,210.0	110.0	380.0	940.0	2,640.0

Product	Year	LGA OF MANSAKONKO	LGA OF KEREWAN	LGA OF KUNTAUR	LGA OF JANJANBUREH	LGA OF BASSE	TOTAL GAMBIA PV_3_20%
PV_3_20%	Base		-	-	-	-	-
	2010		825.0	75.0	260.0	650.0	1,810.0
	2015		825.0	75.0	260.0	650.0	1,810.0
	2020		1,650.0	150.0	520.0	1,300.0	3,620.0
	2025		1,650.0	150.0	520.0	1,300.0	3,620.0

Product	Year	LGA OF BANJUL	LGA OF KANIFING	LGA OF BRIKAMA	TOTAL GAMBIA BM_1
BM_1	Base		-		-
	2010		600.0		600.0
	2015		600.0		600.0
	2020		600.0		600.0
	2025		600.0		600.0

Product	Year	LGA OF BANJUL	LGA OF BRIKAMA	LGA OF KANIFING	TOTAL GAMBIA SWP_1a&b
SWP_1a&b	Base		3,960.0		3,960.0
	2010		5,940.0		5,940.0
	2015		7,920.0		7,920.0
	2020		7,920.0		7,920.0
	2025		7,920.0		7,920.0

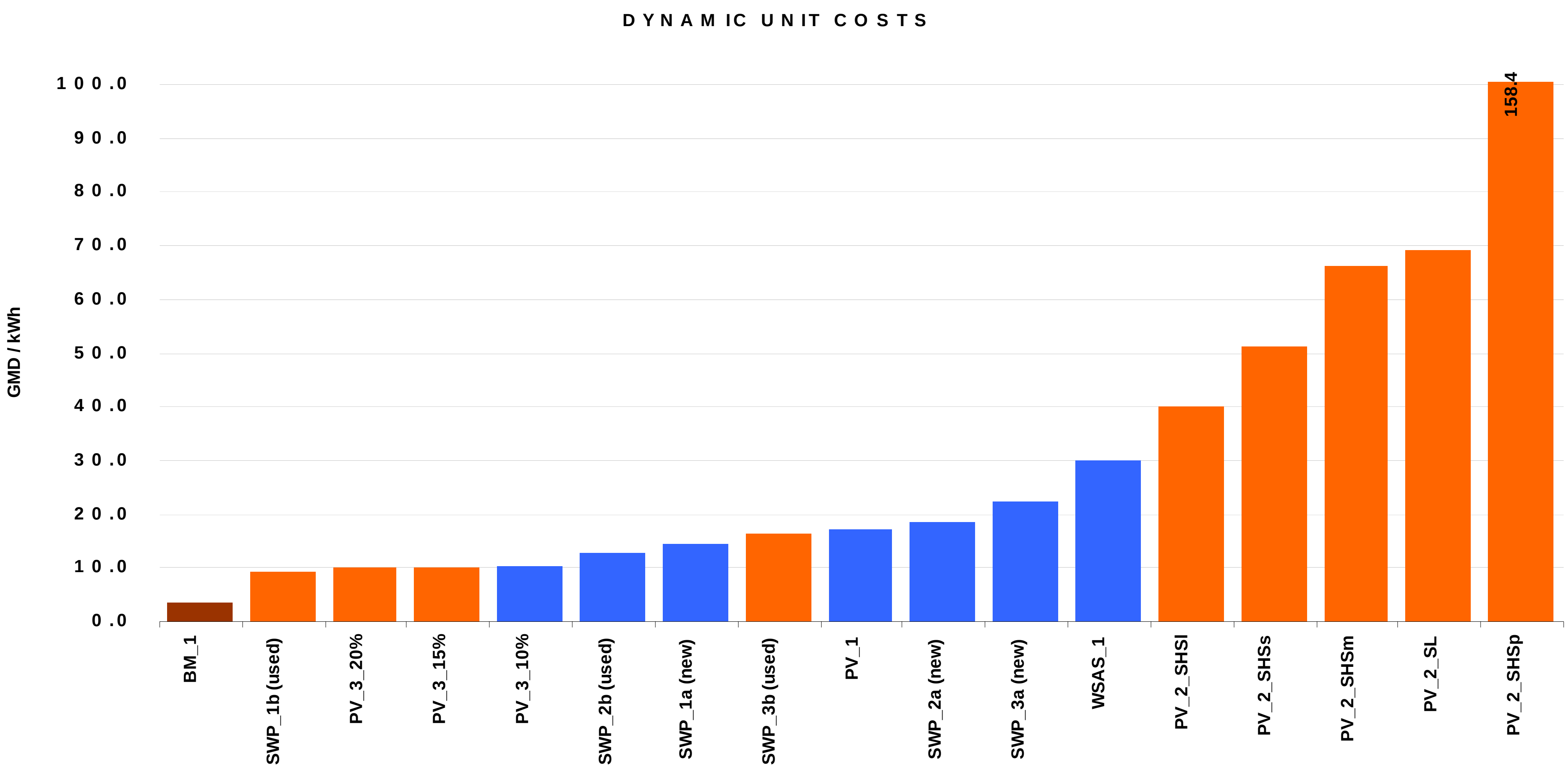
Product	Year	LGA OF BANJUL	LGA OF BRIKAMA	LGA OF KANIFING	TOTAL GAMBIA SWP_2a&b
SWP_2a&b	Base		1,500.0		1,500.0
	2010		2,250.0		2,250.0
	2015		3,000.0		3,000.0
	2020		3,000.0		3,000.0
	2025		3,000.0		3,000.0

Product	Year	LGA OF MANSAKONKO	LGA OF KEREWAN	TOTAL GAMBIA SWP_3a&b
SWP_3a&b	Base		60.0	60.0
	2010		60.0	60.0
	2015		90.0	90.0
	2020		90.0	90.0
	2025		90.0	90.0

Product	Year	LGA OF KEREWAN	TOTAL GAMBIA WSAS_1
WSAS_1	2006	105.0	105.0
	2010	105.0	105.0
	2015	105.0	105.0
	2020	105.0	105.0
	2025	105.0	105.0

The installed capacity considers 30 kW Diesel Generator and 70 kW Wind Power Generator.

Annex 4: Dynamic Unit Costs – Comparison of all Products


DYNAMIC UNIT COSTS
GMD / kWh
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
158.4
BM_1
SWP_1b (used)
PV_3_20%
PV_3_15%
PV_3_10%
SWP_2b (used)
SWP_1a (new)
SWP_3b (used)
PV_1
SWP_2a (new)
SWP_3a (new)
WSAS_1
PV_2_SHSl
PV_2_SHSs
PV_2_SHSm
PV_2_SL
PV_2_SHSp

Annex 5: Economic Analysis of Biomass Energy Products

BM_1

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Operational Year			1	2	3	4	5	6	7	8	9	10
Construction period		1	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10
Generation	kWh	0	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000
CAPEX	TGMD	105,818	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	2,305	2,305	2,305	2,305	2,305	2,305	2,305	2,305	2,305	2,305
Total Costs		**105,818**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**
Fuel savings	litres	0	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27
Fuel savings	TGMD	0	36,577	37,400	38,242	39,102	39,982	40,882	41,801	42,742	43,704	44,687
Total Benefits		**0**	**36,577**	**37,400**	**38,242**	**39,102**	**39,982**	**40,882**	**41,801**	**42,742**	**43,704**	**44,687**
Net Benefits	**TGMD**	**-105,818**	**34,272**	**35,095**	**35,937**	**36,797**	**37,677**	**38,577**	**39,496**	**40,437**	**41,399**	**42,382**

Year		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year		11	12	13	14	15	16	17	18	19	20
Construction period		0	0	0	0	0	0	0	0	0	0
Operational period		11	12	13	14	15	16	17	18	19	20
Generation	kWh	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000	4,200,000
CAPEX	TGMD	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	2,305	2,305	2,305	2,305	2,305	2,305	2,305	2,305	2,305	2,305
Total Costs		**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**	**2,305**
Fuel savings	litres	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000	1,630,000
Fuel price	GMD / ltr	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	45,692	46,720	47,772	48,847	49,946	51,069	52,218	53,393	54,595	55,823
Total Benefits		**45,692**	**46,720**	**47,772**	**48,847**	**49,946**	**51,069**	**52,218**	**53,393**	**54,595**	**55,823**
Net Benefits	**TGMD**	**43,387**	**44,415**	**45,467**	**46,542**	**47,641**	**48,764**	**49,913**	**51,088**	**52,290**	**53,518**

NPV, Generation	kWh	35,756,968
NPV, Costs	TGMD	125,449
NPV, Benefits	TGMD	362,487
ENPV	TGMD	237,045
EIRR	%	34.6%
Benefit / Cost Ratio		2.9
DUC - BM_1	GMD / kWh	3.51

Annex 6: Economic Analysis of Wind Energy Products

SWP_1a

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000
CAPEX	TGMD	189,915	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	2,949	2,949	4,719	4,719	4,719	4,719	4,719	4,719	4,719	4,719	7,078	7,078	7,078	7,078	7,078	7,078	7,078	7,078	7,078	7,078
Total Costs		**189,915**	**2,949**	**2,949**	**4,719**	**4,719**	**4,719**	**4,719**	**4,719**	**4,719**	**4,719**	**4,719**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**
Fuel savings	litres	0	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	14,047	14,364	14,687	15,017	15,355	15,701	16,054	16,415	16,784	17,162	17,548	17,943	18,347	18,759	19,182	19,613	20,054	20,506	20,967	21,439
Total Benefits		**0**	**14,047**	**14,364**	**14,687**	**15,017**	**15,355**	**15,701**	**16,054**	**16,415**	**16,784**	**17,162**	**17,548**	**17,943**	**18,347**	**18,759**	**19,182**	**19,613**	**20,054**	**20,506**	**20,967**	**21,439**
Net Benefits	**TGMD**	**-189,915**	**11,098**	**11,414**	**9,968**	**10,298**	**10,636**	**10,982**	**11,335**	**11,696**	**12,065**	**12,443**	**10,470**	**10,865**	**11,268**	**11,681**	**12,103**	**12,535**	**12,976**	**13,427**	**13,889**	**14,361**

NPV, Generation	kWh	15,988,473
NPV, Costs	TGMD	232,607
NPV, Benefits	TGMD	139,213
ENPV	TGMD	-93,394
EIRR	%	2.0%
Benefit / Cost Ratio		0.598
DUC - SWP_1a	GMD / kWh	14.55

SWP_1b

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000	1,878,000
CAPEX	TGMD	81,596	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	7,078	7,078	7,078	7,078	7,078	7,078	7,078	7,078	7,078	7,078	9,438	9,438	9,438	9,438	9,438	9,438	9,438	9,438	9,438	9,438
Total Costs		**81,596**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**7,078**	**9,438**	**9,438**	**9,438**	**9,438**	**9,438**	**9,438**	**9,438**	**9,438**	**9,438**	**9,438**
Fuel savings	litres	0	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000	626,000
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	14,047	14,364	14,687	15,017	15,355	15,701	16,054	16,415	16,784	17,162	17,548	17,943	18,347	18,759	19,182	19,613	20,054	20,506	20,967	21,439
Total Benefits		**0**	**14,047**	**14,364**	**14,687**	**15,017**	**15,355**	**15,701**	**16,054**	**16,415**	**16,784**	**17,162**	**17,548**	**17,943**	**18,347**	**18,759**	**19,182**	**19,613**	**20,054**	**20,506**	**20,967**	**21,439**
Net Benefits	**TGMD**	**-81,596**	**6,969**	**7,285**	**7,608**	**7,939**	**8,277**	**8,622**	**8,976**	**9,337**	**9,706**	**10,084**	**8,110**	**8,505**	**8,909**	**9,322**	**9,744**	**10,175**	**10,617**	**11,068**	**11,529**	**12,001**

NPV, Generation	kWh	15,988,473
NPV, Costs	TGMD	147,447
NPV, Benefits	TGMD	139,213
NPV	TGMD	-8,234
EIRR	%	8.6%
Benefit / Cost Ratio		0.944
DUC - SWP_1b	GMD / kWh	9.22

SWP_2a

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782
CAPEX	TGMD	86,778	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	1,503	1,503	2,404	2,404	2,404	2,404	2,404	2,404	2,404	2,404	3,606	3,606	3,606	3,606	3,606	3,606	3,606	3,606	3,606	3,606
Total Costs		**86,778**	**1,503**	**1,503**	**2,404**	**2,404**	**2,404**	**2,404**	**2,404**	**2,404**	**2,404**	**2,404**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**
Fuel savings	litres	0	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	5,152	5,268	5,387	5,508	5,632	5,758	5,888	6,020	6,156	6,294	6,436	6,581	6,729	6,880	7,035	7,193	7,355	7,521	7,690	7,863
Total Benefits		**0**	**5,152**	**5,268**	**5,387**	**5,508**	**5,632**	**5,758**	**5,888**	**6,020**	**6,156**	**6,294**	**6,436**	**6,581**	**6,729**	**6,880**	**7,035**	**7,193**	**7,355**	**7,521**	**7,690**	**7,863**
Net Benefits	**TGMD**	**-86,778**	**3,650**	**3,765**	**2,982**	**3,104**	**3,228**	**3,354**	**3,484**	**3,616**	**3,752**	**3,890**	**2,830**	**2,975**	**3,123**	**3,274**	**3,429**	**3,587**	**3,749**	**3,915**	**4,084**	**4,257**

NPV, Generation	kWh	5,863,989
NPV, Costs	TGMD	108,528
NPV, Benefits	TGMD	51,058
NPV	TGMD	-57,470
EIRR	%	n.a.
Benefit / Cost Ratio		0.470
DUC - SWP_2a	GMD / kWh	18.51

SWP_2b

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782	688,782
CAPEX	TGMD	42,315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	3,606	3,606	3,606	3,606	3,606	3,606	3,606	3,606	3,606	3,606	4,808	4,808	4,808	4,808	4,808	4,808	4,808	4,808	4,808	4,808
Total Costs		**42,315**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**3,606**	**4,808**	**4,808**	**4,808**	**4,808**	**4,808**	**4,808**	**4,808**	**4,808**	**4,808**	**4,808**
Fuel savings	litres	0	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594	229,594
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	5,152	5,268	5,387	5,508	5,632	5,758	5,888	6,020	6,156	6,294	6,436	6,581	6,729	6,880	7,035	7,193	7,355	7,521	7,690	7,863
Total Benefits		**0**	**5,152**	**5,268**	**5,387**	**5,508**	**5,632**	**5,758**	**5,888**	**6,020**	**6,156**	**6,294**	**6,436**	**6,581**	**6,729**	**6,880**	**7,035**	**7,193**	**7,355**	**7,521**	**7,690**	**7,863**
Net Benefits	**TGMD**	**-42,315**	**1,546**	**1,662**	**1,780**	**1,902**	**2,026**	**2,152**	**2,282**	**2,414**	**2,550**	**2,688**	**1,628**	**1,773**	**1,921**	**2,072**	**2,227**	**2,385**	**2,547**	**2,713**	**2,882**	**3,055**

NPV, Generation	kWh	5,863,989
NPV, Costs	TGMD	75,864
NPV, Benefits	TGMD	51,058
NPV	TGMD	-24,806
EIRR	%	0.4%
Benefit / Cost Ratio		0.673
DUC - SWP_2b	GMD / kWh	12.94

SWP_3a

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926
CAPEX	TGMD	8,532	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	142	142	226	226	226	226	226	226	226	226	340	340	340	340	340	340	340	340	340	340
Total Costs		**8,532**	**142**	**142**	**226**	**226**	**226**	**226**	**226**	**226**	**226**	**226**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**340**
Fuel savings	litres	0	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	418	428	437	447	457	468	478	489	500	511	523	534	546	559	571	584	597	611	624	638
Total Benefits		**0**	**418**	**428**	**437**	**447**	**457**	**468**	**478**	**489**	**500**	**511**	**523**	**534**	**546**	**559**	**571**	**584**	**597**	**611**	**624**	**638**
Net Benefits	**TGMD**	**-8,532**	**277**	**286**	**211**	**221**	**231**	**241**	**252**	**262**	**273**	**285**	**183**	**195**	**207**	**219**	**232**	**244**	**258**	**271**	**285**	**299**

NPV, Generation	kWh	476,130
NPV, Costs	TGMD	10,580
NPV, Benefits	TGMD	4,146
NPV	TGMD	-6,435
EIRR	%	n.a.
Benefit / Cost Ratio		0.392
DUC - SWP_3a	GMD / kWh	22.22

SWP_3b

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926	55,926
CAPEX	TGMD	4,570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	340	340	340	340	340	340	340	340	340	340	453	453	453	453	453	453	453	453	453	453
Total Costs		**4,570**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**340**	**453**	**453**	**453**	**453**	**453**	**453**	**453**	**453**	**453**	**453**
Fuel savings	litres	0	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642	18,642
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	418	428	437	447	457	468	478	489	500	511	523	534	546	559	571	584	597	611	624	638
Total Benefits		**0**	**418**	**428**	**437**	**447**	**457**	**468**	**478**	**489**	**500**	**511**	**523**	**534**	**546**	**559**	**571**	**584**	**597**	**611**	**624**	**638**
Net Benefits	**TGMD**	**-4,570**	**79**	**88**	**98**	**108**	**118**	**128**	**138**	**149**	**160**	**171**	**70**	**82**	**94**	**106**	**118**	**131**	**144**	**158**	**172**	**186**

NPV, Generation	kWh	476,130
NPV, Costs	TGMD	7,729
NPV, Benefits	TGMD	4,146
NPV	TGMD	-3,584
EIRR	%	n.a.
Benefit / Cost Ratio		0.536
DUC - SWP_3b	GMD / kWh	16.23

WSAS_1

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754	59,754
CAPEX	TGMD	13,033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	61	61	61	620	61	61	61	620	61	61	1,141	1,662	61	61	61	620	61	61	61	61
Total Costs		**13,033**	**61**	**61**	**61**	**620**	**61**	**61**	**61**	**620**	**61**	**61**	**1,141**	**1,662**	**61**	**61**	**61**	**620**	**61**	**61**	**61**	**61**
Fuel savings	litres	0	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918	19,918
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	447	457	467	478	489	500	511	522	534	546	558	571	584	597	610	624	638	652	667	682
Total Benefits		**0**	**447**	**457**	**467**	**478**	**489**	**500**	**511**	**522**	**534**	**546**	**558**	**571**	**584**	**597**	**610**	**624**	**638**	**652**	**667**	**682**
Net Benefits	**TGMD**	**-13,033**	**386**	**396**	**406**	**-142**	**427**	**438**	**450**	**-97**	**473**	**485**	**-583**	**-1,091**	**523**	**536**	**549**	**4**	**577**	**591**	**606**	**621**

NPV, Generation	kWh	508,719
NPV, Costs	TGMD	15,206
NPV, Benefits	TGMD	4,429
NPV	TGMD	-10,776
EIRR	%	n.a.
Benefit / Cost Ratio		0.291
DUC - WSAS_1	GMD / kWh	29.89

Annex 7: Economic Analysis of Solar Energy Products

PV_1

Year		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450	1,536,450
CAPEX	TGMD	188,331	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OPEX	TGMD	0	3,767	3,767	3,767	3,767	3,767	3,767	3,767	3,767	3,767	3,767	5,650	5,650	5,650	5,650	5,650	5,650	5,650	5,650	5,650	5,650
Total Costs		**188,331**	**3,767**	**3,767**	**3,767**	**3,767**	**3,767**	**3,767**	**3,767**	**3,767**	**3,767**	**3,767**	**5,650**	**5,650**	**5,650**	**5,650**	**5,650**	**5,650**	**5,650**	**5,650**	**5,650**	**5,650**
Fuel savings	litres	0	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150	512,150
Fuel price	GMD / ltr	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34	35	36	37	37
Fuel savings	TGMD	0	12,562	12,845	13,134	13,430	13,732	14,041	14,357	14,680	15,010	15,348	15,693	16,046	16,407	16,776	17,154	17,540	17,934	18,338	18,751	19,172
Total Benefits		**0**	**12,562**	**12,845**	**13,134**	**13,430**	**13,732**	**14,041**	**14,357**	**14,680**	**15,010**	**15,348**	**15,693**	**16,046**	**16,407**	**16,776**	**17,154**	**17,540**	**17,934**	**18,338**	**18,751**	**19,172**
Net Benefits	**TGMD**	**-188,331**	**8,796**	**9,078**	**9,367**	**9,663**	**9,965**	**10,274**	**10,590**	**10,913**	**11,243**	**11,581**	**10,043**	**10,396**	**10,757**	**11,126**	**11,504**	**11,890**	**12,284**	**12,688**	**13,101**	**13,522**

NPV, Generation	kWh	13,080,667
NPV, Costs	TGMD	224,867
NPV, Benefits	TGMD	124,496
ENPV	TGMD	-100,364
EIRR	%	1.4%
Benefit / Cost Ratio		0.554
DUC - PV_1	GMD / kWh	17.19

PV_2_SL

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57
CAPEX	TGMD	1.9	0	0	0	0	0	0	1.9	0	0	0	0	0	0	1.9	0	0	0	0	0	0
OPEX	TGMD	0	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total Costs		**2**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
Fuel savings	litres	0	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Benefits		**0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Net Benefits	**TGMD**	**-2**	**-0.01**	**-0.01**	**-0.01**	**-0.01**	**-0.01**	**-0.01**	**-1.89**	**-0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-1.88**	**0.00**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**

NPV, Generation	kWh	56
NPV, Costs	TGMD	4
NPV, Benefits	TGMD	0
ENPV	TGMD	-3
EIRR	%	n.a.
Benefit / Cost Ratio		0.126
DUC - PV_2_SL	GMD / kWh	69.27

PV_2_SHSp

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71	19.71
CAPEX	TGMD	14.7	0	0	4.1	0	0	4.1	0	0	4.1	0	0	4.1	0	0	4.1	0	0	4.1	0	0
OPEX	TGMD	0	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Total Costs		**15**	**0**	**0**	**4**	**0**	**0**	**4**	**0**	**0**	**4**	**0**	**0**	**4**	**0**	**0**	**4**	**0**	**0**	**4**	**0**	**0**
Fuel savings	litres	0	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Benefits		**0**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Net Benefits	**TGMD**	**-15**	**0**	**0**	**-4**	**0**	**0**	**-4**	**0**	**0**	**-4**	**0**	**0**	**-4**	**0**	**0**	**-4**	**0**	**0**	**-4**	**0**	**0**

NPV, Generation	kWh	168
NPV, Costs	TGMD	27
NPV, Benefits	TGMD	1
ENPV	TGMD	-25
EIRR	%	n.a.
Benefit / Cost Ratio		0.055
DUC - PV_2_SHSp	GMD / kWh	158.43

PV_2_SHSm

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70
CAPEX	TGMD	24.6	0	0	4.9	0	0	4.9	0	0	4.9	0	0	4.9	0	0	4.9	0	0	4.9	0	0
OPEX	TGMD	0	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Total Costs		**25**	**0**	**0**	**5**	**0**	**0**	**5**	**0**	**0**	**5**	**0**	**0**	**5**	**0**	**0**	**5**	**0**	**0**	**5**	**0**	**0**
Fuel savings	litres	0	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total Benefits		**0**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.8**
Net Benefits	**TGMD**	**-25**	**0**	**0**	**-4**	**0**	**0**	**-4**	**1**	**1**	**-4**	**1**	**1**	**-4**	**1**	**1**	**-4**	**1**	**1**	**-4**	**1**	**1**

NPV, Generation	kWh	559
NPV, Costs	TGMD	37
NPV, Benefits	TGMD	5
ENPV	TGMD	-32
EIRR	%	n.a.
Benefit / Cost Ratio		0.132
DUC - PV_2_SHSm	GMD / kWh	66.17

PV_2_SHSs

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20	123.20
CAPEX	TGMD	34.5	0	0	7.5	0	0	7.5	0	0	7.5	0	0	7.5	0	0	7.5	0	0	7.5	0	0
OPEX	TGMD	0	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total Costs		**34**	**0**	**0**	**8**	**0**	**0**	**8**	**0**	**0**	**8**	**0**	**0**	**8**	**0**	**0**	**8**	**0**	**0**	**8**	**0**	**0**
Fuel savings	litres	0	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06	41.06
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total Benefits		**0**	**0.9**	**0.9**	**1.0**	**1.0**	**1.0**	**1.0**	**1.1**	**1.1**	**1.1**	**1.1**	**1.2**	**1.2**	**1.2**	**1.2**	**1.3**	**1.3**	**1.3**	**1.3**	**1.4**	**1.4**
Net Benefits	**TGMD**	**-34**	**1**	**1**	**-7**	**1**	**1**	**-7**	**1**	**1**	**-6**	**1**	**1**	**-6**	**1**	**1**	**-6**	**1**	**1**	**-6**	**1**	**1**

NPV, Generation	kWh	1,049
NPV, Costs	TGMD	54
NPV, Benefits	TGMD	9
ENPV	TGMD	-44
EIRR	%	n.a.
Benefit / Cost Ratio		0.170
DUC - PV_2_SHSs	GMD / kWh	51.10

PV_2_SHSI

Year		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10	197.10
CAPEX	TGMD	44.1	0	0	9.0	0	0	9.0	0	0	9.0	0	0	9.0	0	0	9.0	0	0	9.0	0	0
OPEX	TGMD	0	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Total Costs		**44**	**0**	**0**	**9**	**0**	**0**	**9**	**0**	**0**	**9**	**0**	**0**	**9**	**0**	**0**	**9**	**0**	**0**	**9**	**0**	**0**
Fuel savings	litres	0	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70	65.70
Fuel price	GMD / ltr	22	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34
Fuel savings	TGMD	0	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Total Benefits		**0**	**1.5**	**1.5**	**1.5**	**1.6**	**1.6**	**1.6**	**1.7**	**1.7**	**1.8**	**1.8**	**1.8**	**1.9**	**1.9**	**2.0**	**2.0**	**2.1**	**2.1**	**2.2**	**2.2**	**2.3**
Net Benefits	**TGMD**	**-44**	**1**	**1**	**-8**	**2**	**2**	**-7**	**2**	**2**	**-7**	**2**	**2**	**-7**	**2**	**2**	**-7**	**2**	**2**	**-7**	**2**	**2**

NPV, Generation	kWh	1,678
NPV, Costs	TGMD	67
NPV, Benefits	TGMD	15
ENPV	TGMD	-53
EIRR	%	n.a.
Benefit / Cost Ratio		0.218
DUC - PV_2_SHSI	GMD / kWh	40.00

PV_3_10%

Year		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950	521,950
CAPEX	TGMD	39,775.8	0	0	0	0	0	1,693	0	0	0	0	0	1,693	0	0	4,231	0	0	1,693	0	0
OPEX	TGMD	0	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76	397.76
Total Costs		**39,776**	**398**	**398**	**398**	**398**	**398**	**2,090**	**398**	**398**	**398**	**398**	**398**	**2,090**	**398**	**398**	**4,629**	**398**	**398**	**2,090**	**398**	**398**
Fuel savings	litres	0	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00	173,983.00
Fuel price	GMD / ltr	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34	35
Fuel savings	TGMD	0	3,992	4,082	4,174	4,268	4,364	4,462	4,562	4,665	4,770	4,877	4,987	5,099	5,214	5,331	5,451	5,574	5,699	5,827	5,958	6,093
Total Benefits		**0**	**3,992.0**	**4,081.8**	**4,173.7**	**4,267.6**	**4,363.6**	**4,461.8**	**4,562.2**	**4,664.8**	**4,769.8**	**4,877.1**	**4,986.8**	**5,099.1**	**5,213.8**	**5,331.1**	**5,451.0**	**5,573.7**	**5,699.1**	**5,827.3**	**5,958.4**	**6,092.5**
Net Benefits	**TGMD**	**-39,776**	**3,594**	**3,684**	**3,776**	**3,870**	**3,966**	**2,371**	**4,164**	**4,267**	**4,372**	**4,479**	**4,589**	**3,009**	**4,816**	**4,933**	**822**	**5,176**	**5,301**	**3,737**	**5,561**	**5,695**

NPV, Generation	kWh	4,443,655
NPV, Costs	TGMD	45,974
NPV, Benefits	TGMD	39,562
ENPV	TGMD	-6,413
EIRR	%	7.7%
Benefit / Cost Ratio		0.861
DUC - PV_3_10%	GMD / kWh	10.35

PV_3_15%

Year		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420	792,420
CAPEX	TGMD	59,616.7	0	0	0	0	0	1,787	0	0	0	0	0	1,787	0	0	6,426	0	0	1,787	0	0
OPEX	TGMD	0	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17	596.17
Total Costs		**59,617**	**596**	**596**	**596**	**596**	**596**	**2,383**	**596**	**596**	**596**	**596**	**596**	**2,383**	**596**	**596**	**7,022**	**596**	**596**	**2,383**	**596**	**596**
Fuel savings	litres	0	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140	264,140
Fuel price	GMD / ltr	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34	35
Fuel savings	TGMD	0	6,061	6,197	6,336	6,479	6,625	6,774	6,926	7,082	7,241	7,404	7,571	7,741	7,916	8,094	8,276	8,462	8,652	8,847	9,046	9,250
Total Benefits		**0**	**6,060.7**	**6,197.0**	**6,336.5**	**6,479.0**	**6,624.8**	**6,773.9**	**6,926.3**	**7,082.1**	**7,241.5**	**7,404.4**	**7,571.0**	**7,741.4**	**7,915.5**	**8,093.6**	**8,275.7**	**8,461.9**	**8,652.3**	**8,847.0**	**9,046.1**	**9,249.6**
Net Benefits	**TGMD**	**-59,617**	**5,464**	**5,601**	**5,740**	**5,883**	**6,029**	**4,391**	**6,330**	**6,486**	**6,645**	**6,808**	**6,975**	**5,359**	**7,319**	**7,497**	**1,254**	**7,866**	**8,056**	**6,464**	**8,450**	**8,653**

NPV, Generation	kWh	6,746,318
NPV, Costs	TGMD	68,130
NPV, Benefits	TGMD	60,062
ENPV	TGMD	-8,067
EIRR	%	8.1%
Benefit / Cost Ratio		0.882
DUC - PV_3_15%	GMD / kWh	10.10

PV_3_20%

Year		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Operational Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Construction period		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operational period		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Generation	kWh	0	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880	1,062,880
CAPEX	TGMD	79,739.7	0	0	0	0	0	2,163	0	0	0	0	0	2,163	0	0	8,620	0	0	2,163	0	0
OPEX	TGMD	0	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40	797.40
Total Costs		**79,740**	**797**	**797**	**797**	**797**	**797**	**2,960**	**797**	**797**	**797**	**797**	**797**	**2,960**	**797**	**797**	**9,417**	**797**	**797**	**2,960**	**797**	**797**
Fuel savings	litres	0	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298	354,298
Fuel price	GMD / ltr	22	23	23	24	25	25	26	26	27	27	28	29	29	30	31	31	32	33	33	34	35
Fuel savings	TGMD	0	8,129	8,312	8,499	8,691	8,886	9,086	9,290	9,499	9,713	9,932	10,155	10,384	10,617	10,856	11,100	11,350	11,606	11,867	12,134	12,407
Total Benefits		**0**	**8,129.3**	**8,312.2**	**8,499.3**	**8,690.5**	**8,886.0**	**9,086.0**	**9,290.4**	**9,499.4**	**9,713.2**	**9,931.7**	**10,155.2**	**10,383.7**	**10,617.3**	**10,856.2**	**11,100.5**	**11,350.2**	**11,605.6**	**11,866.7**	**12,133.7**	**12,406.7**
Net Benefits	**TGMD**	**-79,740**	**7,332**	**7,515**	**7,702**	**7,893**	**8,089**	**6,126**	**8,493**	**8,702**	**8,916**	**9,134**	**9,358**	**7,424**	**9,820**	**10,059**	**1,683**	**10,553**	**10,808**	**8,907**	**11,336**	**11,609**

NPV, Generation	kWh	9,048,897
NPV, Costs	TGMD	90,891
NPV, Benefits	TGMD	80,563
ENPV	TGMD	-10,328
EIRR	%	8.2%
Benefit / Cost Ratio		0.886
DUC - PV_3_20%	GMD / kWh	10.04