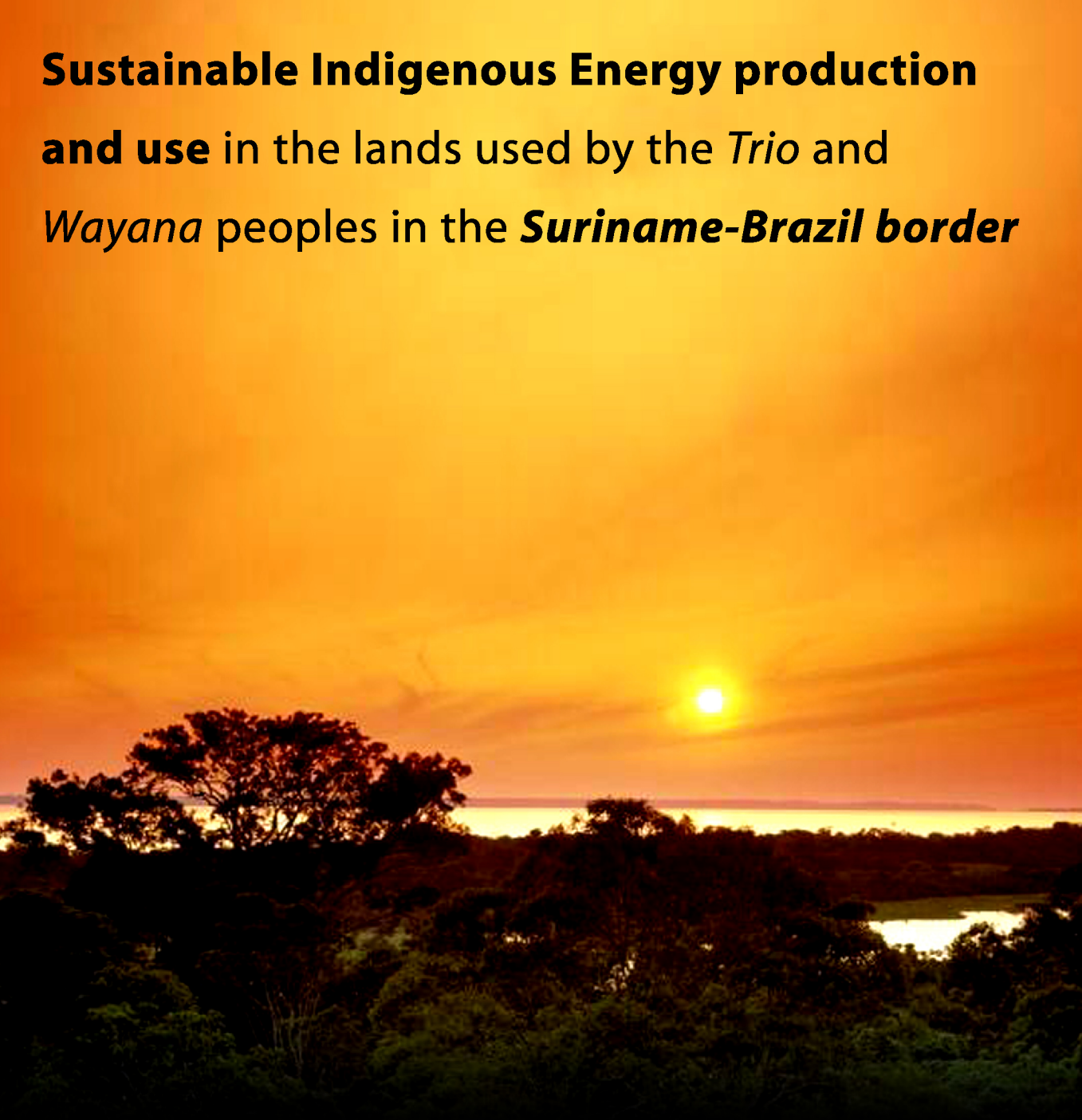




# **Sustainable Indigenous Energy production and use in the lands used by the *Trio* and *Wayana* peoples in the ***Suriname-Brazil border*****



***Renewable Energy component of the Sustainable Development and  
Bio-cultural Conservation in the Suriname-Brazil border program***



ing. Kevin H. De Cuba, MSc  
Department for Sustainable Development (DSD)  
The Organization of American States (OAS)

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# **Towards Sustainable Energy production and use in the lands inhabited by the Trio and Wayana peoples in the Suriname-Brazil border**

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Suriname-Brazil border program**

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July 2006

## Acknowledgements

This report is dedicated to the indigenous Trio and Wayana people in the Suriname-Brazil border region. Thanks to all the people that made this project possible. Special thanks to Granman Asongo and other village representatives for receiving the OAS team and for the interesting discussions held. Thanks to Ken (village captain) for accompanying me during the assessments made in Kwamalasamutu. The OAS Suriname office director, Mr. Bramble and also Ms. Bundle that arranged the meetings with several representatives in the energy sector of Suriname are greatly appreciated. And last but not least, Ms. Emanuels-Smith and other members of the Amazon Conservation Team (ACT) are thanked very much for making it possible to visit Kwamalasamutu and Alalapadu, the accommodation, guidance and feedback provided during the visit.

## List of Acronyms

ACT	Amazon Conservation Team
BOS	Balance of System
CI	Conservation International
DSD	Department of Sustainable Development
GWh	Giga Watt hour
MW	Megawatt
NIMOS	Nationaal Instituut voor Milieu en Ontwikkeling Suriname
OAS	Organization of American States
PV	Photo Voltaic
SUR\$	Suriname Dollars (1 US\$ = 2.75 SRD)
SRD	Suriname Dollars
Wp	Rated Wattage

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# Executive summary

## Background

The southern part of the province of Sipaliwini in Suriname forms part of the Suriname-Brazil border region, a relatively isolated area mainly inhabited by the Trio (Tirio or Tareno) and Wayana indigenous people. Infrastructure development in this region, including that related to energy, has been very limited and deals with many restrictions, due to limited access and high costs of transportation to and from the region. In many villages of this region the electricity need is considered to be urgent, for example, electricity needs for public lighting, radio communication for external contact, electrical devices for the village clinics (as refrigerators, freezers or electric microscope), and electrical pumps for fresh water supply. Isolation, thus high prices bounded to the import of materials, fuel, or other requirements, make the operation and management of any energy system a challenge, as it is to achieve a sustainable energy development for this region.

## Objective

The main objective of this study is to describe the current state of the energy production, use and need in the Trio and Wayana areas (Brazil-Suriname border region), and to perform a qualitative techno-economic analysis to indicate possible required investment and operation costs of renewable electricity production systems, using Kwamalasamutu, the largest agglomeration in the area, as a case study. Kwamalasamutu was also chosen as the residence of the Granman, leader of the Trio people, and representative of the Trio and Wayana people in all external communication matters. In his official role, the Granman can facilitate the co-operation between NGO's, International Organizations as the OAS and the local people for future energy development activities.

## Methodology and Results

A visit was paid to Kwamalasamutu (Suriname) and a literature review was performed where all available energy related documentations or reports about the Suriname-Brazil border region were collected and used for describing past renewable energy projects as well as the current energy production and use. Based on this review, a qualitative energy resource assessment and a techno-economic analysis, recommendations are made on how to implement a sustainable energy development strategy.

### *Energy analysis*

Demographic data of Kwamalasamutu was collected and an attempt was made to create an inventory of the amount of households, public buildings, and infrastructure and currently used electrical production systems. Additionally, an inventory was made of the electrical appliances and their specific energy requirements that are used in each building. The current electricity production was analyzed and energy demand projections were made based on two scenarios:

- Scenario K1 entails the electricity demand (164 Wh/day) to cover the basic needs, which would include lighting and limited use of appliances, in a typical household in Kwamalasamutu.
- Scenario K2 describes the energy demand (680 Wh/day) to cover premium needs; this means, next to basic needs it would also include the use of TV, radio and/or refrigeration in a household.

The electricity demand in year 20 is about 18.7 MWh/year for scenario K1 and 71.6 MWh/year for scenario K2. See table A-1 for an overview of the electricity demand projection per scenario for Kwamalasamutu.

**Table A-1 Arithmetic means of electricity demand for each scenario for Kwamalasamutu**

Year	Unit	K1 scenario	K2 scenario
0	MWh/year	15.7	59.0
5	MWh/year	16.4	61.9
10	MWh/year	17.1	65.0
15	MWh/year	17.9	68.2
20	MWh/year	18.7	71.6

*Energy resource assessment*

A qualitative energy resource assessment was performed to identify renewable energy technologies (RET's) that could be introduced into the alternatives for electricity production in the village. The alternatives are considered based on the energy resource assessment and their technical performance or, in other words, their electricity production potential. The RET's under consideration were solar PV, micro hydro power, and anaerobic bio digestion systems; see table A-2 for a general overview of the electricity production potential of each system.

**Table A-2 General overview of electricity production potential of pre-selected RETs**

Pre-selected Renewable Energy Technologies			
Solar PV systems			
Parameter	Unit	Scenario K1	Scenario K2
Energy demand (year 20)	MWh/year	18.7	71.6
Energy demand per household	Wh/day	164	680
Required PV arrays capacity (period 0-20 yrs)	kW	16.4 kW <sup>1</sup>	62.7 kW <sup>2</sup>
Micro Hydro Power systems			
Location	Installed capacity (kW) <sup>3</sup>		Electricity production (MWh/year)
Bush Papaja	21 – 28		147 – 196
Sir. W. Raleigh	177 – 235		1240 – 1647
Karina Ituru	39 – 52		273 – 364
Anaerobic Digestion systems			
Size of unit	Installed capacity (kW/year)		Electricity production (MWh/year)
Village size	1.02 – 1.51		8.9 – 13.2
Primary school	0.3		0.25

<sup>1</sup> Estimate based on 298 PV panels with a rated capacity of 0.055 kWp

<sup>2</sup> Estimate based on 285 PV panels with a rated capacity of 0.220 kWp

<sup>3</sup> 1 kW means that 1 kWh is produced over 1 hour, this is in other words the electricity output of a system assuming that it will produce its maximal electricity output during any given timeframe. In general a 10 MW capacity system means it can produce 10 MWh \* 87,600 h over a period of 1 year which is 876,000 MWh per year or 876 GWh/year.

Because the solar PV systems are available in modular sizes and depend on non local bounded solar radiation availability, it is possible to dimension the PV systems across the village to increasingly comply with the electricity demand. Table A-2 shows two scenarios on how the PV systems could be dimensioned and the total production capacity required per scenario after a 20 years project lifetime. As an example, in scenario K1, about 298x0.055 kWp PV arrays are needed to comply with the energy demand of 18.7 MWh/year. In the case of the micro hydro power and anaerobic digestion options, their electricity production potential depends to a higher extent on location-bounded average available water speeds and available biomass respectively, that are more prone to fluctuations; this is the reason for projecting ranges of electricity production capacities.

#### *Economical analysis*

The economical analysis is performed on two levels, on the first level, which is the household level; a diesel system is compared to a solar home PV system. In the second analysis, the technical pre-selected alternatives, a bio-digester, micro hydro power, and solar PV system, are compared to diesel systems based on the predetermined energy production potential. The reason for this approach is that the RET's vary in available energy resources and their energy production potential, thus there is variation in unit capacity. To perform an objective comparative economical analysis, one requirement is that the unit capacities are in the same range. Only in case of PV systems, because of their modular character, they can be dimensioned on the household as on the village levels. The main performance indicators used in the economical analysis are the initial capital investment (US\$), the levelized cost of electricity production<sup>4</sup> (US\$/kWh), the CO2 mitigation value (US\$ / project lifetime) and the energy supply fraction to the village demand (%).

#### Household level

Table A-3 shows the summary of the results of the economical analysis performed at the household level. In this analysis, instead of looking at the electricity supply fraction as a performance indicator, a focus is set on the value loss due to loss of excess electricity. In the case of the diesel system, since the smallest available capacity is 1000 W, there is always excess electricity produced and this represents loss in monetary value. By dimensioning the PV system adequately this loss of excess electricity value can be limited.

**Table A-3 Summary of results of the economical analysis at household level in Kwamalasamutu**

Parameter	Unit	Value (Scenario K1)		Value (Scenario K2)	
		PV system	Diesel system	PV system	Diesel system
Electrical demand	kWh/year	59.7		248.2	
Installed capacity	Wp	55	1000	220	1000
<b>Investment</b>	<b>US\$</b>	<b>381</b>	<b>770</b>	<b>1499</b>	<b>770</b>
O&M costs <sup>5</sup>	US\$/year	9	30.8	39	30.8
Fuel costs	US\$/year	-	1213.9	-	1213.9
<b>Levelized cost of electricity</b>	<b>US\$/kWh</b>	<b>1.14</b>	<b>1.07</b>	<b>1.12</b>	<b>1.07</b>
<b>Electricity supply fraction</b>	<b>%</b>	<b>&gt;100</b>	<b>&gt;100</b>	<b>&gt;100</b>	<b>&gt;100</b>
Excess electricity	kWh	31.3	11922	1650	10317
Loss value <sup>6</sup>	US\$	27.5	10491	1452	9079

<sup>4</sup> The levelized electricity production cost (COE) is the average cost for electricity production for a single or an integration of electricity production systems, including renewable energy production systems. In this cost calculation the main parameters are the generation capital investment costs, the generation operation and maintenance costs, the replacement costs and/or the fuel costs.

<sup>5</sup> 4% of total investment cost of system

<sup>6</sup> multiplying by the LLC if diesel is run at 24h/day (0.88 US\$/kWh)

The levelized cost of electricity production (COE) of the PV systems ranges 1.12 – 1.14 US\$/kWh, while the electricity production cost of diesel systems is 1.07 US\$/kWh. The main reason for the high electricity cost of the PV systems is the high capital investment cost per nominal capacity, this is 6.93 US\$/Wp compared to 0.77 US\$/W for diesel.

#### Village / medium size level (grid connected)

Table A-4 shows the summary of the results of the economical analysis at the village level. PV system 1 is the PV system that is dimensioned to cover the scenario K1 energy demand. PV system 2 is the PV system dimensioned to cover the energy demand of scenario K2. Bio system entails the anaerobic digestion system dimensioned based on a 2.9 kW gas engine capacity. Hydro system 1, 2 and 3 represent the hydro power potential at the locations, Bush Papaja, Sir W. Raleigh and Karina Ituru respectively.

**Table A-4 Summary of results of economical analysis at village/medium size level**

Parameter	Unit	PV 1	PV 2	Bio	Hydro 1	Hydro 2	Hydro 3
Installed capacity	kW	16.3	62.1	2.9	24.5	206.0	45.5
Investment	US\$	64,913	217,477	24,734	128,248	891,740	300,744
Levelized cost of electricity	US\$/kWh	0.56	0.49	0.19	0.12	0.10	0.15
Electricity supply fraction		1	1	0.05 – 0.18	0.4 – 1.5	3.3 - 13	0.7 - 2.8
Carbon mitigation value	US\$	2,142	8,231	2,036	17,258	145,087	32,037

The hydro system 2 (Sir. W. Raleigh) has the lowest electricity production cost of 0.10 US\$/kWh. One main reason is its large electricity production capacity than can supply at least 3 times the energy demand in Kwamalasamutu. See section 5.3.2 for more explanation.

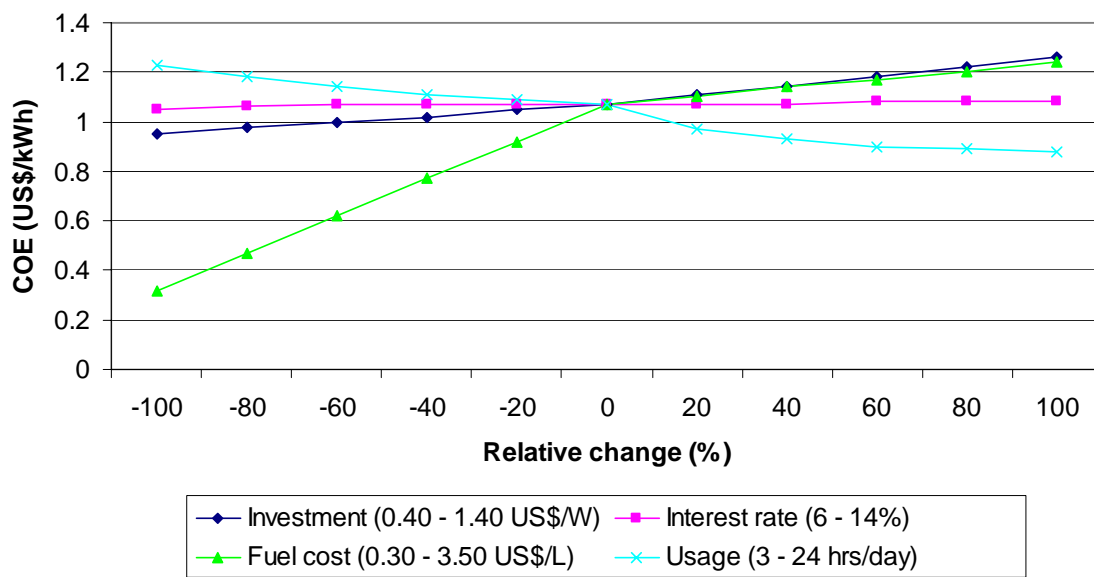
#### *Sensitivity analysis*

A sensitivity analysis was performed to identify the parameters that have the largest impact on the cost of electricity production (COE) for each electricity production system. This output is an important performance parameter to facilitate the comparative evaluation of the systems. Also, this analysis can identify the maximum range of COE and the input parameters that require further analysis to reduce the overall uncertainty in the end results.

#### Household level

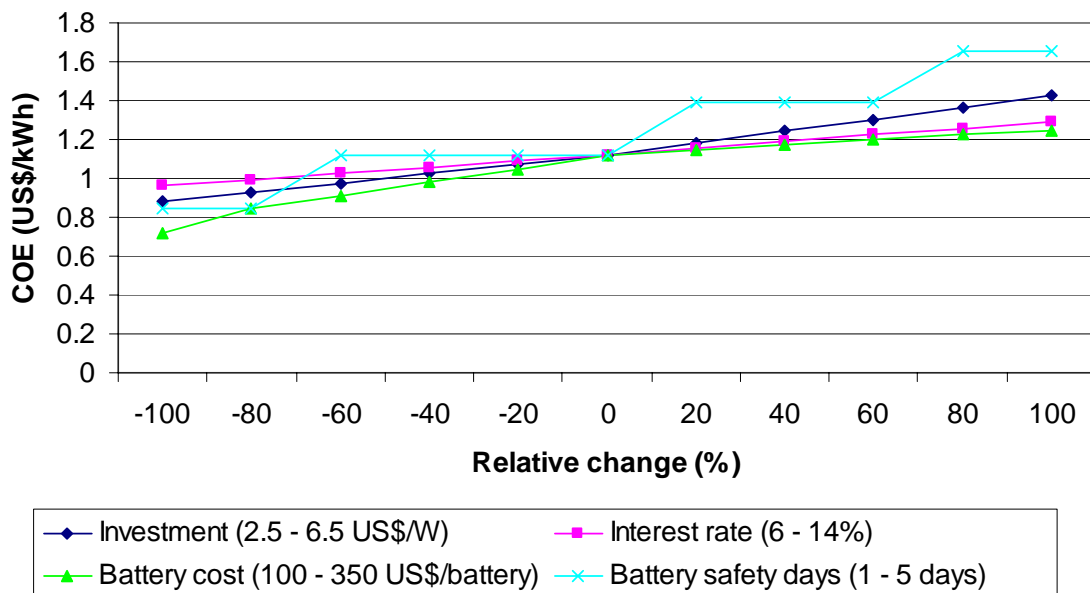
From sensitivity analysis it is found that in case of the portable diesel system the fuel cost has the highest influence on the cost of electricity production (COE). This means that the logistics of transporting the fuel should be optimized to lower the fuel costs in order to become an attractive option. See as example figure A-1 where a 1kW portable diesel generator is analyzed.





**Figure A-1 Results of sensitivity analysis for the 1 kW portable diesel system (scenario K2)**

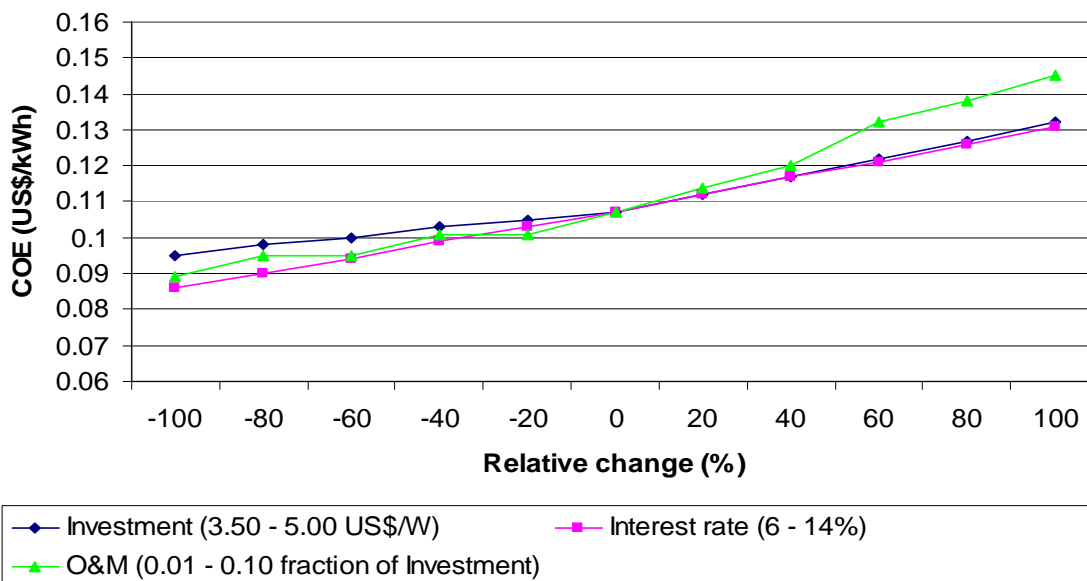
In case of the Solar Home PV system, the battery safety days can have a large influence on the COE. The cost of a battery normally fluctuates with its capacity. As one can see in figure A-2, the COE can range between 0.722 – 1.659 US\$/kWh depending on the design chosen and its dimensioned battery sizes and their costs.



**Figure A-2 Results of sensitivity analysis for the Solar Home PV System (scenario K2)**

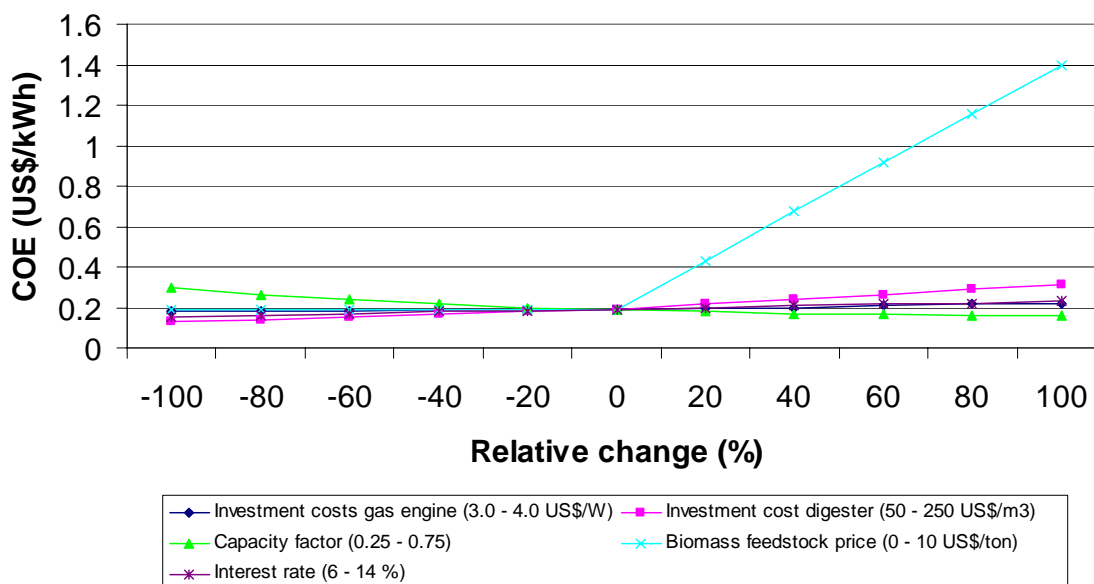
#### Village / medium size level (grid connected)

In the case of a grid connected PV system there is no significant difference in COE output between the input factors. Only in the case that the O&M costs reach higher levels (10% of total investments), this may increase the COE from 0.107 to 0.145 US\$/kWh. On the overall, one can say that the COE for this system ranges between 0.086 – 0.145 US\$/kWh, see figure A-3.



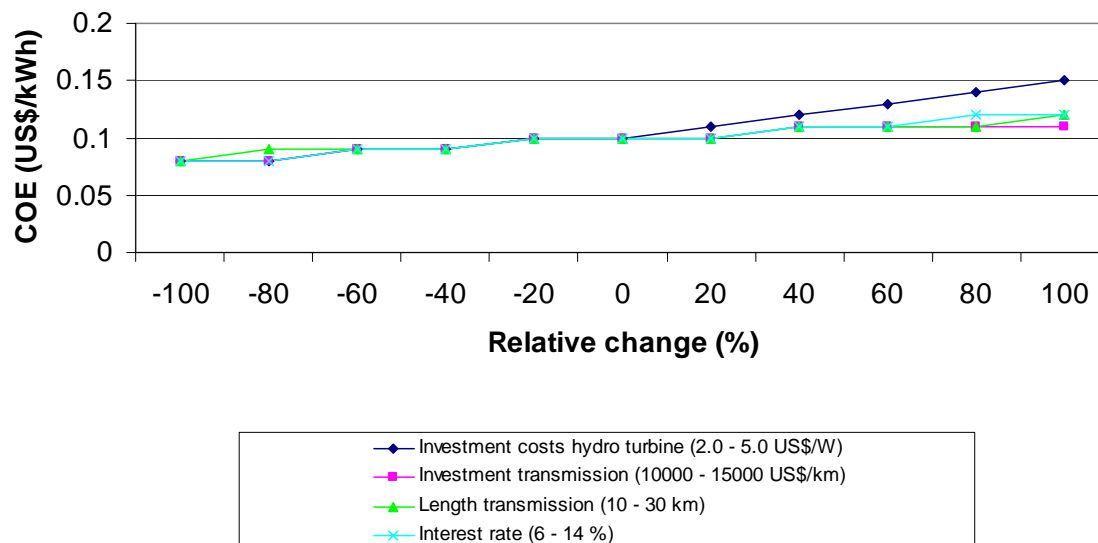
**Figure A-3 Results of sensitivity analysis grid connected PV system (scenario K1)**

The COE of the bio system was calculated to be 0.19 US\$/kWh. This value is based on the assumption that the biomass feedstock is 0, but when one wants to include agricultural waste or other sources next to human waste, there are costs bounded to the collection and transportation of this feedstock. It results that the biomass feedstock price has a large impact on the COE, and that this should be looked at in more detail when considering this option for Kwamalasamutu. See figure A-4 for more detail.



**Figure A-4 Sensitivity results for the grid connected 2.9 kW bio digestion system**

Figure A-5 shows the sensitivity results for the micro hydro-power option with the largest production potential. In this case the investment cost and lower ends of the interest rate have the largest impact on the COE. This indicates that the COE may range between 0.08 – 0.15 US\$/kWh.



**Figure A-5 Sensitivity results of the 206 kW micro hydropower system**

## Conclusions and Recommendations

### Energy cost comparison: Household level

The levelized cost of electricity (COE) for the solar home PV systems in scenario K1 is 1.14 US\$/kWh and for scenario K2, 1.12 US\$/kWh over a project lifetime of 20 years. The COE for scenario K2 can range between 0.722 – 1.659 US\$/kWh depending on the design chosen and its dimensioned battery sizes and their costs. These costs of electricity production are on average higher than the electricity production costs of the diesel system. Note that there are many factors that are uncertain in this analysis that may lead to this result.

Important factors to take in consideration are:

1. the investment cost of the PV array + inverter; note that this is 5.5x higher than the diesel system, and that the chosen investment cost is estimated, thus more detailed analysis is required to find the real investment costs of the PV arrays + inverter by taking in account logistical factors that are location dependant and play an important role in the case of Kwamalasamutu.
2. The diesel fuel price, which can be higher or lower and has to be analyzed into more detail to find the real local price of diesel.
3. Battery type and size; in this analysis sealed batteries are used, while deep cycle batteries in general perform better; also, the dimensioning of the battery is important since costs largely vary between battery capacities (100 – 200 Ah).
4. The interest rate is set on 10%, this factor in general also has large impact on the cost of electricity, thus the future financing mechanism should be scrutinized.

### Energy cost comparison: Village / medium size level

Based on the analysis and input parameters used we can indicate that the micro hydro power systems generate lower electricity production costs than the other alternatives. The costs range from 0.10 – 0.15 US\$/kWh for the hydro power systems compared to 0.49 – 0.56 US\$/kWh for

the PV and 0.19 US\$/kWh for the Bio system. On the other hand, the hydro power systems require on average much higher initial capital investment compared to other renewable alternatives and diesel based systems. The hydro micro systems have the benefit that they have high electricity production potential, they can generate considerable carbon credit values, and this can be deducted from the initial capital investment to make this alternative financially more attractive.

The PV systems on average generate the highest electricity production costs (0.49 and 0.56 US\$/kWh). But there is much potential to reduce the costs, the investment cost per nominal capacity can be reduced due to economies of scale, the installment is relatively easier than the other alternatives and due to its modular character, the PV capacity can be dimensioned according to energy demand, and if a solution is found for increasing the frequency and lowering of transport to and from Kwamalasamutu to optimize the replacement of batteries, this alternative may become financially more attractive.

The COE for the bio digestion system is 0.19 US\$/kWh and is in the range of the hydro power systems. In the case of the bio digestion alternative in this analysis, it is more challenging to draw conclusions. First of all, no costs are accounted for the biomass feedstock, also the biogas produced has a certain value but is considered 0 in this analysis. The total energy production capacity is not enough to cover the energy demand in Kwamalasamutu when considering only human waste as biomass feedstock source. Under these conditions the system can only be considered as part of an electricity production mix. A positive point is that the initial capital investment cost for this system is the lowest among the alternatives. Additionally, one can use the produced biogas directly in gas lamps for public lighting and/or cooking. From the sensitivity analysis one can conclude that the biomass feedstock cost will have a large impact on the COE. When including other sources in the biomass feedstock, there will be a cost related to the harvesting and/or collection and transportation of this feedstock. This will cause the COE to increase rapidly. Therefore a detailed economic analysis is required to find the optimal balance between feedstock costs and final electricity production costs.

### Recommendations

- In order to make good estimations of material needs and to plan installation or reparation activities in the village it is recommended to create a map of existing buildings and infrastructure prior to the initiation of these projects.
- The possible electricity demand of Kwamalasamutu depends very much on the energy demand package required per each household. The population size and growth, number of habited houses, the specific energy requirement of the appliances used and use profile; all are factors influencing the energy demand in the village. More detail analysis is required on these matters.
- Financial scheme is important, to be integrated into other economical and income generating activities. These activities may provide some basic financial conditions for survival of a new energy supply system.
- The government could subsidize the flights to and from Kwamalasamutu and other isolated villages in the South of Suriname in order to give them a chance to export their cultivated or crafted products and gradually become self sustaining. The greatest limitation for development of economical activities in the isolated regions is that the supply and export of materials, goods or services are too costly and not frequent enough to make economical activities feasible.
- There are studies done that show that diesel-PV hybrid systems may operate better than single type systems and that the costs may result to be lower. To be able to perform a

hybrid system study more financial and technical data is required, also in many occasions energy models are used to dimension the optimal hybrid system, which was not at disposal in this study.

- In later stages of this project one has to design a fee structure. To create this fee structure issues as defining an affordable basic rate has to be tackled. Also the scaled rate for premium needs. Determine who pays for community power needs and how do local business pay for electricity service.
- The composition of management and office personnel to coordinate and monitor the electricity services has to be determined. One should think of choosing a method of selection of personnel. The people will need training in administrative and financial matters to know how the money has to be handled.
- Maintenance personnel will also need to be capacitated. They will have to receive technical training and a system of compensation is needed. Maintenance schedules are important to coordinate the maintenance activities.



# 1. Introduction

## 1.1 Background and problem description

The southern part of the province of Sipaliwini in Suriname is the most isolated region in the country and is mainly inhabited by the Trio (Tirio or Tareno) and Wayana indigenous people. Since the lands the Trios and Wayanas use cut across the existing country borders, this region is named in this project as the Suriname-Brazil border region.

The energy development in this Suriname-Brazil border region has been very limited and deals with many restrictions. For many decades there have been sporadic attempts of the Government of Suriname and other NGO's to supply systems to produce electricity in these remote areas. Several diesel generators have been installed and distribution systems created but unfortunately without long term perspective or feasibility. Many of the diesel units are either never used or out of order, and the remaining operating units cope with logistical problems as high costs for fuel, low frequency of supply from Paramaribo, and lack of maintenance.

In the case of renewable energy projects, there have been a few studies to assess the potential use of renewable alternatives in the region. Studies indicate that solar PV and micro hydro power alternatives have the highest energy production potential among the available renewable alternatives<sup>7, 8</sup>. But as the result of the same logistical and financial problems related to the operation and maintenance of the diesel generators, a limited capacity of Solar PV and micro hydropower alternatives has been installed during the last decades up to now.

Energy is an important driving force for (economical) development and tool to supply basic needs. Based on previous communications with the indigenous people from Kwamalasamutu (Trio area), energy shortage results to be a structural problem for development of economic and health care activities<sup>9, 10</sup>. Especially at the village level the availability of electricity is considered to be urgent. One can take in mind public lighting, radio communication for external contact, electrical devices for the village clinics (as refrigerators, freezers or electric microscope) and electrical pumps for fresh water supply. Isolation, and thus high prices bounded to the import of materials, fuel or other requirements make the operation and management of any energy system a challenge to come to a sustainable energy development for this region.

## 1.2 Main objective and scope

In this subsection, first the general objective of the renewable energy component (component 11) of the Sustainable Development and Bio-cultural Conservation in the Suriname-Brazil Border Project is explained. Secondly, the specific objective of this baseline study is described.

### General objective of renewable energy component (component 11)

The general objective of the renewable energy development project (component 11 of the Sustainable Development and Bio-cultural Conservation in the Suriname-Brazil border program) is to collaborate with the indigenous peoples of the Brazil-Suriname border region, the Trio and

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<sup>7</sup> Suriname Master Energy Plan study, 2000

<sup>8</sup> De Castro, J.F.M. and Jansen, J.C., "Alternative elektriciteitsvoorziening in het binnenland van Suriname", ECN and CCE, 1993

<sup>9</sup> Vermeieren, J., Comments and Notes from Jan Vermeieren based on the field mission to Suriname, OSDE/OAS, March 2004

<sup>10</sup> de Cuba, K.H., Travel report "Sustainable Indigenous Energy production and use", as part of the "Sustainable Development and Bio-cultural Conservation in the Suriname-Brazil border" program, DSD/OAS, April 2006

Wayana people in Suriname and the Tiriyo/Katxuyana and Wayana/Apalai in Brazil to identify appropriate energy production systems that are in balance with the sustainable management of the natural resources and energy needs of the indigenous peoples.

Thereby focusing on the following issues:

1. Examine the energy needs of the indigenous people in the region
2. Examine the current energy production and use in the communities
3. Identify success/failures of previous attempts at renewable energy in the region
4. Conduct a review of successful use of renewable energy under same conditions
5. Provide recommendations on energy production and use in the region
6. Perform feasibility studies for renewable energy projects in the region
7. Coordination, finance and management of the renewable energy implementation projects

### **Main objective of this baseline study and demarcation**

The first step of this study was to project the current state of the energy production, use and need in the Trio and Wayana areas (Brazil-Suriname border region), to be able to make future energy demand estimations and to analyze the feasibility of renewable energy. Due to time and resource limitations it is decided to select Kwamalasamutu as a case study, as the largest agglomeration of the Trio people in the southeastern part of Suriname, and encounters more complex energy problems than smaller villages, at the other hand it is still representative for other growing isolated villages in the region. Kwamalasamutu is only accessible by plane and makes the operation of any energy system a challenge, since there are high prices bounded to the import of materials, fuel or other requirements.

Once the baseline study is completed, the second objective is to give recommendations that include methods how to collect and monitor energy related data for further detailed renewable energy assessment and analysis that could be extrapolated to other villages in the Trio and Wayana lands. Energy related information about other parts of this region will be provided to the extent possible, based on available information.

The focus is set on the following issues:

1. Make an inventory of the finalized and ongoing renewable energy projects or initiatives in this region
2. Provide an overview of the current energy legislation that has influence on this region
3. Perform a qualitative energy use and demand analysis
4. Perform a qualitative energy resource assessment
5. Identify possible renewable energy alternatives and perform general costs analysis
6. Make general assumptions and recommendations for further assessment

## **1.3 Methodology**

### **Collection of energy and other relevant data**

A visit is paid to Suriname to identify and meet the relevant stakeholders to this sustainable energy project. In the first meeting round, several key persons related to the energy sector and government of Suriname were interviewed to get an idea of the current energy policy, production and distribution in the South-Eastern (SE) region of Suriname. After this round of meetings the SE region was visited in order to communicate and interview the local people (village representatives) to gather their views on what their energy needs are and what their opinion is on renewable energy. Also a survey was set up to make an inventory of the present used electrical



equipments, machines and lighting in Kwamalasamutu. The times and number of hours these machines or equipments are used were collected. By collecting these data estimation can be made of the energy use (load curves) in Kwamalasamutu. This type of data is important to be able to make future energy demand estimations and to analyze the feasibility of renewable energy. A brief report of the current (2006) energy production and use in Kwamalasamutu and Alalapadu were described in a travel report (see appendix A for the travel report to Suriname). All this information is important to know, to identify possible bottlenecks for future sustainable energy development projects. Additionally, the methodology created can function as a guideline for future energy analysis in other villages in the region.

After the visit to Suriname a desk study was performed where all possible energy related documentations or reports about the Suriname-Brazil border region were collected and used for describing past renewable projects, the current energy production and use and how to achieve sustainable energy use. The collected data from the meetings with the several stakeholders and desk study are described in this report and assumptions are made for missing data in order to perform a qualitative energy analysis of Kwamalasamutu and the Suriname-Brazil border region. Recommendations are made for further energy resource assessments, socio-cultural impacts, implementation and management.

## **Processing of collected data**

### Energy analysis

#### **1) Inventory of buildings / infrastructure / electrical appliances**

An inventory of each building was performed, including the composition of electrical appliances and an estimate of their energy consumption. In this way the current energy demand per household or at the village level can be verified.

- Households in Kwamalasamutu
  - Basic needs: lighting (limited use of TV, radio, etc.)
- Public buildings/infrastructure in Kwamalasamutu
  - Public lighting
  - Pumping water
  - Community buildings: Primary school, community building (Krutu Oso), Festivity hall, Granman office + loudspeaker and church
- Clinics/Other
  - ACT Building
  - ACT clinic
  - CI Building
  - MZ Clinic
  - Existing shops
  - Future new businesses

## **2) Electricity production**

The future electricity demand can be estimated using two scenarios, scenario 1 (cover basic needs) and scenario 2 (cover premium needs).

- Existing electricity production systems
  - Count number of panels and batteries
    - Analyze condition of panels, batteries, poles, and wiring
  - Count number of small portable diesel generators
    - Analyze condition of diesel generation sets and fuel consumption
- Future electricity demand
  - Analyze power needed for each household
  - Analyze power needed for public buildings / infrastructure
  - Analyze power needed for clinics / other buildings
  - Analyze power needed for the village
  - Set up demand scenarios to comply with:
    - basic needs: lighting
    - premium needs: refrigeration, TV, radio or DVDs

## **3) Electricity production alternatives**

- Energy resource assessment
  - Identify and quantify energy resources available
  - Pre-select electricity production systems based on available energy sources
- Design/feasibility of electricity production system based on data collected
  - decentralized electricity production (household level)
  - central electricity production + grid (village level)

## **4) Electricity cost assessment**

- What is the initial investment needed per system
  - To build electricity production system: Turn key investment costs per system
- Operation & Maintenance costs per system
  - Fuel/feedstock costs per system
  - Labour/training costs per system
- Match power production capacity with future demand growth
  - household level
  - village level
- Cost and Revenue
  - Determine levelized costs of electricity production
  - Determine CO2 mitigation and revenue per system

## 1.4 Structure of report

*Chapter 2* deals with a brief description of the geography, demography, and other background information that help to describe the Trio and Wayana areas (Surinam-Brazil border region). Also the energy development in the Trio and Wayana's lands is briefly described and a brief summary is given of the past and ongoing renewable energy projects or initiatives.

In *chapter 3* the village of Kwamalasamutu (the largest agglomeration in the area) is scrutinized and considered as a case study, where the current energy production, use and demand is described in more detail and where it is possible to make better assessments of future energy needs and management options.

*Chapter 4* analyzes and describes the natural energy resources in and around Kwamalasamutu and in the Suriname-Brazil border area. The collection of the data is based on the available literature, a theoretical energy production assessment and pre-feasibility assessment. The focus is on the common renewable energy sources, as wind, hydro, solar and biomass sources. Also a pre-selection of renewable alternatives is made based on their technical performance.

In *Chapter 5*, based on the gathered data in the previous chapters, pre-selected alternative energy production systems are economically analyzed to assess the costs related to each system. As main outputs, estimates of the initial capital investment, the levelized cost of electricity production and the CO<sub>2</sub> mitigation value are produced.

In *chapter 6* general conclusions and recommendations are made for further assessments for developing renewable energy projects in the Suriname-Brazil border region.



## 2. General background information

In this chapter a brief description is given of the geography, demography, and other background information that help to describe the Trio and Wayana areas (Surinam-Brazil border region).

### 2.1 Geo-demographical and physical environment info

Suriname is located in the north of South America surrounded by Guyana (on the left), French Guyana (on the right) and Brazil (down south). Suriname is located 2-6° on the northern hemisphere 54-58° western length and is subjected to N-E to S-E winds. Suriname has a humid tropical climate, with an average annual rainfall ranging from 2000 to 2500 mm, an average maximum temperature of 31°C, while the average minimum temperature centres on 23°C. The relative humidity is very high: 70-90 percent. As a result of crossing the Inter-Tropical Convergence Zone<sup>11</sup> (ITC-zone) over Suriname two times a year, four seasons can be distinguished in the coastal region, i.e. a long rainy season from April to the middle of August, a long dry season from the middle of August to the end of November, a short rainy season during December and January and a short dry season during February and March. Extremely dry seasons rarely occur<sup>12</sup>.

The Suriname-Brazil border region (part of the Northern Amazon Basin) is located in the southern part of Suriname and Northern part of Brazil and it covers an area of roughly estimated about 40,043 km<sup>2</sup><sup>13</sup> and forms the living area of a variety of indigenous tribes, mainly occupied by the Trio (Tiriyo or Tareno) and Wayana people<sup>14</sup>. The average temperature is about 26.8 °C and in contrast to the coastal region, the interior has two seasons, the raining and the dry season. The rain season starts in the end of January and continues till the month of July, whereas the rest of the year it is the dry season<sup>15</sup>.

As can be seen on figure 2.1, the approximated Trio and Wayana usufruct area demarcations do not correlate with the existing country borders. The area inhabited and used by the Trio people is concentrated in the south of the Sipaliwini province of Suriname and the northern parts of Brazil, also there is a sub area that reaches into Guyana. In the case of the Wayana people their usufruct area entails the southeastern part of the Sipaliwini province of Suriname and parts of the south western part of French Guyana.

Next to being inhabited by indigenous people, this region consists mainly of primary tropical rain forests with high levels of biodiversity and contains natural minerals as gold, copper and bauxite. Also it includes major parts of the largest river systems and fresh water aquifers in the South American continent. See figure 2.1 to have an impression of the project area.

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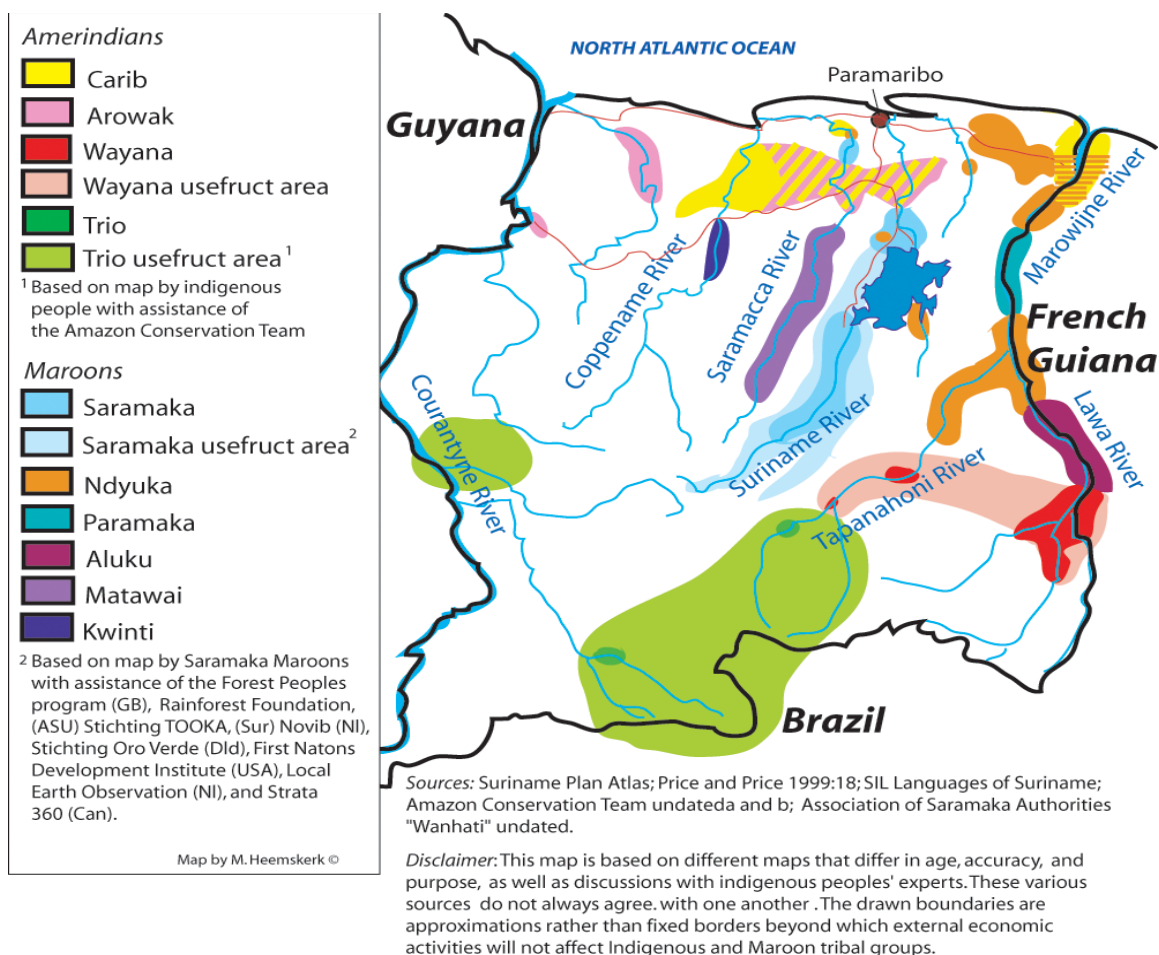
<sup>11</sup> Nurmohamed, R.J. and Naipal, S., Variability of rainfall in Suriname and the relation with ENSO-SST and TA-SST, University of Suriname, Paramaribo, January 2006

<sup>12</sup> Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 143

<sup>13</sup> Calculated based on two sources, de Vries, B. et al., An analysis of Governance, Resource Management and Development Issues, 2003, section 2.2 and Estratégia de Participação das Populações Indígenas, Remanescentes de Quilombos, Mulheres e Jovens Pobres, May 2003, page 34.

<sup>14</sup> de Vries, B. et al., An analysis of Governance, Resource Management and Development Issues, 2003, section 2.2

<sup>15</sup> Anton de Kom University of Suriname, "Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken", Community Development Fund Suriname (CDFS), 2003



**Figure 2.1 Map of lands habited or used by indigenous peoples in Suriname<sup>16</sup>**

Until the 60s the Trios lived dispersed in at least more than 13 independent groups or clans. In this period they were contacted by missionaries from both border sides, that categorized the several ethnic groups into the Trio people (Suriname) or the Tiriyo people (Brazil).

On the Suriname side, the Trio people are mainly concentrated in Kwamalasamutu located on the Sipaliwini river and Pelele Tepu on the Tapanahoni river. The Wayana people are concentrated in the villages Apetina (on the Tapanahoni river) and Kawemhakam on the Marowini / Lawa river. On the Brazilian side, the Tiriyo's live in a now called "Parque Indigena de Tumucumaque" reserve. There are agglomerations at the Paru de Oeste/Cuxare river and the Paru de Leste river that crosses through this area. On the Paru de Oeste/Cuxare river the Tiriyo's share their lands with other tribes as the Kaxuyana, Ewarhuyana, Tsikuyana, some members of the Akuriyo, Waiwai and Waiapi. On the Paru de Leste river the Tiriyo's live predominantly in the northern part of the river while there are also some Wayana's and Apalai living in the area.

In the 70s a process of centralization started, where a few agglomerations were created as Kwamalasamutu in Suriname, and Missao Tiriyo in Brazil. In this period about 60% of the Trio population in Brazil (about 460 persons) lived in and around Missao Tiriyo, the remaining (about 350 persons) lived distibuted among several small villages along the Paru de Oeste river and in the village called Igarape Cuxare.

<sup>16</sup> Source: Amazone Conservation Team (ACT)

In the 90s during the Interior War of Suriname, Trios that have migrated to Suriname returned to Brazil and settled down in Igarape Mataware along the Paru de Leste river. A part of this group moved to more southern locations and lived among the Wayana and Apalai, in the village Posto Indigena Apalai<sup>17</sup>.

## 2.2 Demographic data

From a literature review and communications it results to be difficult to project the current population in these areas because the indigenous people have a nomadic lifestyle, moving in and out of the villages and sometimes crossing the borders with the surrounding countries. Based on a 2005 survey executed by the primary health care organization “Medische Zending Suriname” the current Trio and Wayana population at the Suriname part of the region is estimated to be about 1766 and 630 respectively. On the Brazilian side there are about 811 people with Tiriyo, Kaxuyana, Ewarhuyana or Tsikuyana ethnicity (all fall under the Tiriyo people categorization) living in Paru de Oeste/Cuxare. And about 74 Tiriyo people that live on the Paru de Leste river. This means a total Tiriyo population of about 885<sup>18</sup> (1200<sup>19</sup>) people on the Brazilian side of the Suriname-Brazil border region.

Table 2.1 shows an overview of the population counts per each village in the Trio and Wayana lands. Note that the demographic information for Suriname is meant for indicative reasons and that the limitation of this data is that it only includes villages where a clinic is located and where there is a registry of the inhabitants. There are more Trio villages on the Surinamese side of the region, namely Coeroeni, Wanapan and Amatopo<sup>20</sup>, but unfortunately there is no data available on the population’s sizes in these villages. On the Brazilian side there are ongoing survey’s to count the population sizes in each village within the Tumucumaque reserve. From general estimates there are two major villages, Missao Trio and Cuxare. See table 2.1 for more detail.

**Table 2.1 Demographic data of the Suriname-Brazil border region<sup>21</sup>**

Village	Population
Trio	
Kwamalasamutu	1042
Alalapadu	32
Sipaliwini	109
Pelele Tepu	469
Coeroeni	n.a.
Wanapan	n.a.
Amatopo	n.a.
Missao Tiriyo	600
Cuxare	100
Trio/Wayana	
Palumeu	228
Wayana	
Apetina (Puleowime)	325
Kawemhakam	191
<b>Total</b>	<b>3096</b>

<sup>17</sup> Source: [http://www.amapabusca.com.br/edgar/indios\\_primeiros\\_contatos.htm](http://www.amapabusca.com.br/edgar/indios_primeiros_contatos.htm)

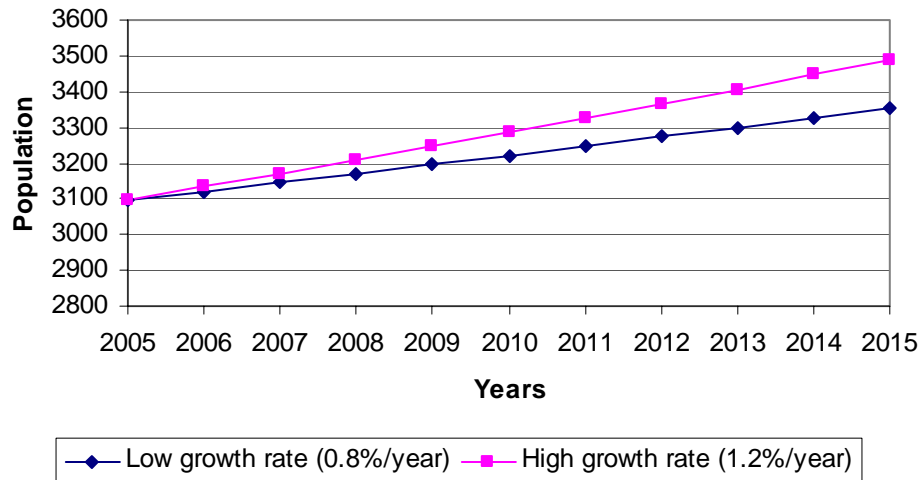
<sup>18</sup> Source: [http://www.amapabusca.com.br/edgar/indios\\_primeiros\\_contatos.htm](http://www.amapabusca.com.br/edgar/indios_primeiros_contatos.htm)

<sup>19</sup> From communications with Mr. van Roosmalen, ACT Brazil, May 2006

<sup>20</sup> From communications with the Amazone Conservation Team (ACT)

<sup>21</sup> Source: Population survey per poli, Medische Zending Suriname, November 2005

The population size within the Suriname-Brazil border region is between 3096 – 3600 people, with a population density between 0.08 – 0.09 pers./km<sup>2</sup> <sup>22</sup>. The population growth rate in the Suriname-Brazil border region is not monitored, but on Suriname national level the population growth is set between 0.8-1.2%<sup>23</sup>. If this growth rate is applied to the population of the Suriname-Brazil border region the population will grow to between 3353 - 3488 people in the year 2015, see figure 2.2.



**Figure 2.2 Growth projection of the people from the Suriname-Brazil border region (2005-2015)**

Note that the projections made in figure 2.2 are based on the national data of Suriname, for a better assessment the population size and growth rate levels of each individual village in the Suriname-Brazil border region need to be collected.

### 2.3 Economical conditions

In the Trio and Wayana lands there is hardly a monetized economy. The majority of the people live from hunting, fishing and limited agricultural activities for own consumption. Due to the high concentration of people in Kwamalasamutu, the surrounding nature seems to have reached its carrying capacity since the Trios need to go farther away to hunt or fish for food supply. The main income source is from the social security of the government and limited sales of handcrafts (limited eco-tourism).

The conditions for developing economical activities are constrained by the limited accessibility, where the only means of transportation to reach the villages in this region is by small airplanes, or very slowly by river. Along with this, the large distances to the coastal parts of the country (that could form as an export market for local produced products) and high prevailing fuel prices make that the costs of importing or exporting goods increase drastically.

Within the Suriname-Brazil region there are a few organized economical activities on village level. As is the case of the village of Alalapadu, where a Brazil-nut production project was started as part of the project this exercise forms a part of and has been having positive financial

<sup>22</sup> This number is calculated based on the total estimated population of 2396 divided by the roughly estimated land surface of 40,000 km<sup>2</sup> (see section 2.1)

<sup>23</sup> Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 143



outcomes. The village people go into the forest and collect the Brazil nuts and sort, treat and package the nuts to be transported by the occasionally arriving planes to Paramaribo to be sold. On the Brazilian side of the Trio lands the major sources of income consist of selling handcrafts and into lesser extent also wild honey production.

## **2.4 Background energy development**

In this section a brief chronological overview is given on energy related programs, initiatives or policies that have an impact on the Trio and Wayana lands. This overview can help avoid new energy projects to be repetitive and give better background information of what is done and what is required in the future.

### Energy production and distribution

At the national level, the state-owned electricity company, Elektriciteit Bedrijven Suriname (EBS) supplies electricity in the northern urban areas of Suriname and is responsible for the generation, transmission and distribution of the energy. The company operates generating plants at Paramaribo and Nickerie, which supply 15% of its capacity. The remaining power comes from the 189 MW hydroelectric power station of Suriname Aluminum Company (Suralco) situated at the Brokopondo lake. A new 161 KV transmission line, with finance from China, is soon to be finished, which will reduce the loss of power on the connection to Paramaribo<sup>24</sup>. Currently large parts of the Sipaliwini province (thus also the Suriname-Brazil border region) are not connected to the national grid or are being served by this company.

Specifically in the Trio and Wayana lands (the Suriname-Brazil border region), there have been limited initiatives in the past to bring electrification of these isolated areas.

### Alternative Energy Supply in the interior of Suriname (1992/93)

In 1992/93 a joint initiative of the Government of Suriname and the Dutch Government was created where the focus was on the identification of social and economical responsible application possibilities for alternative energy in village communities in the interior of Suriname. This resulted in a report created by the Energy Centre of the Netherlands (ECN) and Castro Consulting Engineers (CCE)<sup>25</sup>. This report concluded that wind energy development is unlikely to be possible in the interior, based on wind speed assessments and other practical limitations. In relation to micro hydropower options, the technology was considered to be capital intensive and inflexible to changes in demand patterns. But it was also highlighted that not all sights are analyzed and that under specific conditions, as in the case of the prevailing high fuel prices, micro hydropower may become feasible. The solar PV option was indicated to be a possibility in the case of Kwamalasamutu, since it is difficult to dimension a diesel system that can reach to an optimal load factor because of the unpredictable demand patterns and also because of high costs for fuel supply. The report also noted that the environmental benefits of using solar PV options were not taken in mind and should be included in future comparative economical analysis.

### Solar PV project Kwamalasamutu (1994/95)

A year later in 1994 an initiative was started by the Government of Suriname in co-operation with the Dutch Government to install solar PV systems in Kwamalasamutu with the primary focus on the electrification for lighting purposes. The results are reported by Consulting Partners N.V. and Efacon N.V.<sup>26</sup>. This project included the installation of 85-100 Wp solar PV systems (including

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<sup>24</sup> Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 153

<sup>25</sup> Jansen, J. and de Castro, J.F.M., "Alternatieve Elektriciteitsvoorziening in het binnenland van Suriname", ECN and CCE, 1993

<sup>26</sup> Van Kampen, M.A. and dos Ramos, O.A., "Zonne-energie Kwamalasamutu, verslag van uitvoering", October 1994

lighting and outlets) on 140 positions in Kwamalasamutu that supplied 245 houses, a recreational building/ work place, 2 visitors cabins, and 4 houses of personnel of the medical clinic with electricity (see appendix B for more details). This project will be further discussed in chapter 3.

#### Suriname Master Energy Plan (2000)

In the Suriname Master Energy Plan prepared by the Belgium Consultancy Tractebel and finalized in 2000, a chapter was dedicated to the economical analysis of energy supply in the interior<sup>27</sup>. Here four general options are analyzed: independent diesel units, interconnection to the grid, solar PV, and micro hydro electricity. In the case of interconnection to the grid, the conclusion was made that under their assumptions a 12kV connection to the grid intended to supply a load with 15 kW peak value is always profitable if its length is not greater than 1 km. Lines longer than 2 km are always more expensive than the option of installing a 15 kW diesel generator. In relation to the solar alternative the conclusion was that the PV solar option will be economically attractive only in remote areas where the cost of diesel generation is high due to the distance and due to difficult transport of fuel and it will be limited to strict residential usage. A major obstacle is the lack of concern and the lack of training of the local population for this new technology. The micro hydro power alternative is considered capital intensive (2000 to 5000 \$/kW) and not flexible versus changes in load location. The power capacity of such equipment is generally in the range of 10-35 kW. This solution is limited to small villages located very close to waterfalls or to rivers offering the technical conditions for operation and far from the electrical grid.

Table 2.2 shows the installed diesel generator capacities in the Suriname part of the Suriname-Brazil border region last monitored in the year 2000 by the Ministry of Natural Resources.

**Table 2.2 Diesel power generators operated by the Ministry of Natural Resources (2000)**<sup>28</sup>

Power plant	Capacity (kW)
Kawenhaken	15
Pelele Tepu	30
Apetina	15
<b>Total</b>	<b>60</b>

The total installed diesel capacity in the Trio and Wayana lands (Suriname side) in 2000 was 60 kW. No information was found about the current state of these generators and additional diesel generators on the Brazilian side of the Suriname-Brazil border region.

#### Micro hydro power assessment Kwamalasamutu and surroundings (2003)

In 2003 a team of the Anton de Kom University of Suriname made a visit to Kwamalasamutu to assess the micro hydropower potential on four spots in the surrounding rivers<sup>29</sup>. Hydrological and topographic data was collected and the general conclusion was that of the four analyzed spots, the Sir Walter Raleigh Falls had the highest hydro power potential. One limitation of this spot is that it is located far from Kwamalasamutu, which requires a distribution net. But the production potential is higher, and thus in case, if a cost analysis is performed on a basis of costs incurred per installed capacity, this option may result to be a feasible option.

#### Environmental Assessment Guidelines for Power Generation and Transmission Projects (2005)

<sup>27</sup> Ministry of Natural Resources, Suriname Master Energy Plan, chapter 8, Paramaribo, 2000

<sup>28</sup> Ministry of Natural Resources, Suriname Master Energy Plan study (2000)

<sup>29</sup> Anton de Kom University of Suriname, "Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken", Community Development Fund Suriname (CDFS), 2003

In March 2005 the National Institute for the Environment and Development in Suriname (NIMOS) finalized an Environmental Assessment Guidelines for Power Generation and Transmission Projects<sup>30</sup>. In this report the environmental impact assessment and procedure to evaluate renewable energy projects is proposed and discussed. This environmental impact assessment activity forms a part of the Government of Suriname's Environmental Management Program. It means that future renewable energy projects should take in mind the socio-environmental impacts that can be caused by each renewable energy option as described in this document in order to be given license or be supported by the Ministry of Natural Resources and/or by the Ministry of Labour, Technological Development, and Environment.

#### Micro hydro power project Palumeu (2006)

From communications with several stakeholders in the Suriname Energy sector there are indications that currently there is an ongoing 20 kWp micro hydro project in Palumeu being assessed and managed by the Anton de Kom University of Suriname. No further details were available at the time this report was being developed.

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<sup>30</sup> Office of Environmental and Social Assessment, NIMOS, Environmental Assessment Guidelines Volume V: Power Generation and Transmission Projects, March 2005



### 3. Energy production, use and demand (Case study)

The village of Kwamalasamutu (the largest agglomeration in the Suriname-Brazil border region) is scrutinized and considered as a case study, where the current energy production, use and demand is described in more detail and where it is possible to make better assessments of future energy needs and management options.

#### 3.1 Past conditions

Kwamalasamutu is the largest Trio agglomeration in the southern part of Sipaliwini, located downstream of the Sipaliwini River, and was established in the mid 70s by several tribes of the Trio community<sup>31</sup>. Since 1977 there is an airstrip. Back in that time there was a 7.5 kW Lister Diesel generator installed, and later in '85 another 23 kW Diesel was installed (see figure 3.1). The population was about 1,200 people with about 200 houses. Each house had a 40 W lamp without a switch to turn the lights on or off. Next to lighting, use was made of radio/cassette players running on batteries that lasted for two weeks.



**Figure 3.1 A 23 kVA Hawker Siddeley Diesel installed in '85, Kwamalasamutu**

As mentioned before, in 1994/95 the solar PV project was started, on 140 locations in the village 2x30 Wp Solar Home PV systems were installed. Next to these, separate PV systems were installed for the meeting building “Krutu Oso”, the church, the school, and the MZ clinic. The total installed Solar PV capacity was about 11.5 kW<sup>32</sup>. Until the years '98-'99 most of the PV systems were still in operation<sup>33</sup>. But since an average battery lasts for 4-5 years, these had to be replaced, and it is after this period that the problems started, were many batteries started to fail

<sup>31</sup> Gunther, N., Report/Proceedings on the Workshop on Sustainable Development of Indigenous Communities of South Suriname, OSDE/OAS, Paramaribo, April 2005, page 8

<sup>32</sup> Assuming an overall PV system efficiency of 0.7 and a minimal monthly averaged daily radiation of 4.77 kwh/m<sup>2</sup>/day (Castro and Jansen, 1993) and a set minimal PV system output of 190 Wh/day, system existing of two arrays, see for more detail, Consulting Partners N.V., “Kwamalasamoetoe project dossier”, page 15

<sup>33</sup> Communication with Mr. Dos Ramos (Consulting Partners N.V.), April 2006

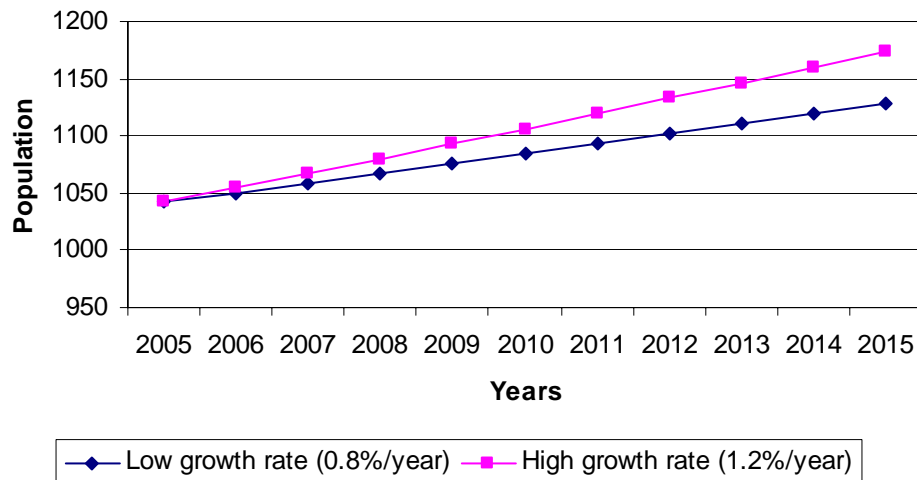
and there was need for money to replace the batteries. The reasons for the lack of maintenance and supervision of the financial scheme are not known, but it does call attention upon the need for designing into development programs strategies for follow-up and maintenance.

### 3.2 Current conditions

As part of the Suriname-Brazil Border Region project, a visit was paid to Kwamalasamutu in April 2006, during which an inventory was made of the energy production and use.

#### Demography

A survey done by the Primary Health Service Suriname in November 2005 indicated that the population of Kwamalasamutu was about 1,042 people. The average household has been decreasing from 5-6 people to 4-5 people per household<sup>34</sup>. Roughly estimated there are currently about 210 – 250 houses in Kwamalasamutu. When we use the Suriname national population annual growth rate of between 0.8-1.2%<sup>35</sup>, we can make some generic projections of the possible population growth in Kwamalasamutu. See figure 3.2 for more detail.



**Figure 3.2 Population growth projection for Kwamalasamutu for the period 2005 to 2015**

Using the national growth rate ratios we can estimate that the population of Kwamalasamutu may grow to between 1128 – 1174 people in the year 2015. Because of the nomadic lifestyle of the Trio people these numbers in figure 3.2 can only be considered as indicative. As mentioned before, to make better demographic assessment a detailed survey has to be performed and the migration routes of the Trios and Wayana's identified.

#### Infrastructure

The village of Kwamalasamutu currently is comprised of about 210 - 250 houses and several facilities as a church, a primary school, two clinics, an air strip, a meeting or recreation place also called "Krutu Oso", a round festivity hall, electrical production infrastructure in the form of solar PV systems, a fresh water well, and buildings of NGOs such as the Amazon Conservation Team (ACT) and Conservation International (CI).

<sup>34</sup> Consulting Partners N.V., "Kwamalasamoetoe project dossier", page 7

<sup>35</sup> Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 143

The round festivity hall (see figure 3.2) is only used during the last months of the year for cultural activities. In relation to electrical installation in this building, there are 9x18W TL lamps installed and connected to 3 switches. The lighting installation is supplied by 3x2x30Wp PV arrays<sup>36</sup>. Since the building is not frequently used there has been little or no maintenance and these electrical installations are currently not functioning.



**Figure 3.2 Image of the round festivity building in the centre of Kwamalasamutu**

The primary school has 9 class rooms and about 230 students. The classrooms are equipped with each a 2x18W lamps that are supplied by 2x30 Wp PV systems that have not been working for the last 8 years<sup>37</sup>. This is considered to be a problem since this limits the hours of schooling received by children, and many children do need to make homework and have no electricity at home and thus no lighting. The school teacher proposed to have light available at the school to give the children that do not have light at home the opportunity to come to school to make homework in the evening hours, plus the school can be used for extra schooling of the parents in the evenings or for other social meetings in the village.

The local fresh water well (with dimensions of 7x3x3m<sup>38</sup>) is equipped with a 15hp diesel pump that pumps the water to a higher located central water collection tank from which the water is distributed to water tap points in the village. See figure 3.2 for an impression of the water well. Due to high diesel fuel prices and lack of maintenance this diesel pump is currently not used causing a shortage of fresh water supply to the village.

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<sup>36</sup> Van Kampen, M.A. and dos Ramos, O.A., “Zonne-energie Kwamalasamutu verslag van uitvoering”, 1994

<sup>37</sup> From communication with Mrs. Suzan Macnack (head of primary school Kwamalasamutu), April 2006

<sup>38</sup> Anton de Kom University of Suriname, “Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken”, Community Development Fund Suriname (CDFS), 2003





**Figure 3.2 Picture of the Fresh Water well located in Kwamalasamutu<sup>38</sup>**

Another problem is that during rainfall surface water runoff enters the well and contaminates the water; to resolve this problem, drainage goats are dogged up and there are plans to raise the wall surrounding the well.

Nearby the air strip there is one building with a solar PV system to supply a communication radio with electricity for air traffic. Also buildings belonging to the international organizations such as Amazon Conservation Team (ACT) and Conservation International (CI) are located nearby. These buildings either have an individual PV system installed or the electricity is supplied by portable generators that are brought along when there are people of the organizations visiting.

From a stakeholder meeting in April 2005<sup>39</sup> it was reported that a limited amount of electricity is being produced in Kwamalasamutu. From the recent visit it can be concluded that many of the solar PV systems installed in 94/95 are not in operation. To note is that in general the PV arrays are still in good state but due to inadequate or complete lack of maintenance of the batteries and wiring, many systems are out of order. See figure 3.3 to get an impression of the PV systems.

On the left side in figure 3.3 one can see a PV array of which the power output cable of 2x4mm<sup>2</sup> is cut. One can also see that there is shading over this array that causes the efficiency of the array to drop. The PV array on the right up corner is one of the few still operating PV systems. This is a new installed 120 Wp Astro Power PV array (Model AP-120 / 12V DC) and supplies the local ACT clinic energy for lighting and a communication radio. On the bottom right one can see that some arrays are used for other purposes. As one can see the PV arrays are installed with an angle of 15° on a support frame attached to wooden poles. The arrays are installed in this way to have enough slope to drain rainwater, wash away dust and prevent algae growth, they are positioned towards the southern direction, since Kwamalasamutu is located on the Northern Hemisphere.

<sup>39</sup> Trio and Wayana Stakeholder Consultation, Naks Volkshoge School, Lelydorp, Suriname, April 5 and 6, 2005





**Figure 3.3 Images of solar PV arrays installed in Kwamalasamutu (2006)**

Next to PV systems there are also about 5-10 households that have portable electric generators. Unfortunately due to time limitation no information was collected on the specific brands and capacities used by these households. Also it is not known what the composition of electrical appliances is that are connected to these generators. From general communications with local people it was indicated that the current local price for diesel is between SUR\$ 6-10 per liter. This price is very high when compared to the diesel price of SUR\$ 2.85 per liter (2005)<sup>40</sup> in Paramaribo.

### **3.3 Energy analysis**

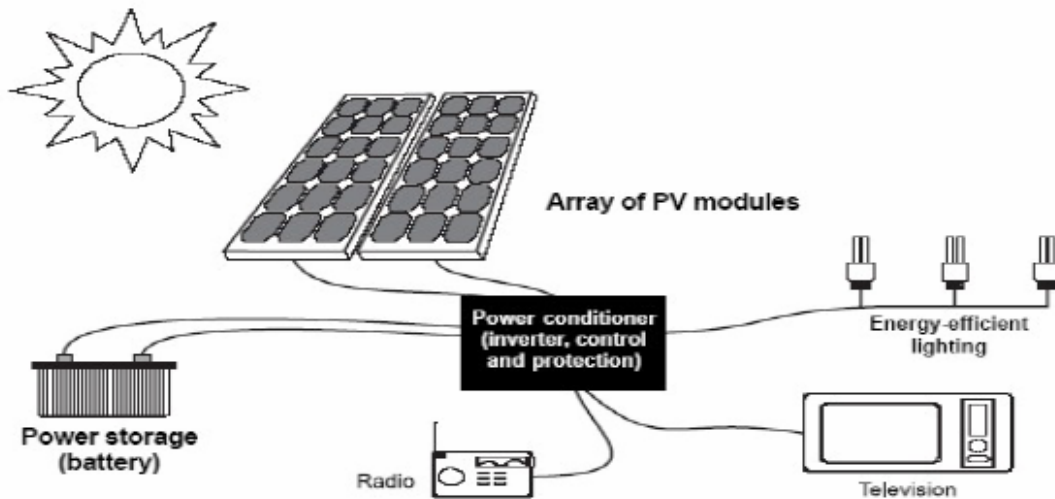
In this section an overview is given of the energy production in Kwamalasamutu. As described before, the electrical infrastructure exists of decentralized PV systems and portable electric generators. Other uses of energy are in the form of firewood for cooking, a limited amount of kerosene lamps for lighting, and gasoline that is imported for use in the boat motors for transport over the river. In this section the focus will be mainly on the solar PV systems, since this currently forms the largest contribution to the energy production mix in Kwamalasamutu. In addition no technical information is available on the portable electric generators and the gasoline or firewood consumption patterns for transport and cooking.

<sup>40</sup> Source: Caribbean Net News website: <http://www.caribbeannetnews.com/2005/09/14/price.shtml>

### 3.3.1 Household level

#### Solar Home PV systems

From a quick inspection and communication with local people it was inferred that 140 Solar PV systems were installed in 1994/95<sup>41</sup>, 112 Solar PV systems are systems that supply two households, while 28 houses have an individual Solar Home PV system. In 2006, of the 140 solar Home PV systems about 15-20 (with 2 or single connected houses) home systems are still in operation. See figure 3.4 for a schematic view of the Home PV systems.



**Figure 3.4 Schematic view of a stand alone Home PV system<sup>42</sup>**

In general the Solar Home systems consists of PV arrays with a Balance of System equipment (BOS) that includes mounting material and wiring systems used to connect the solar modules to the charge controller, batteries and electrical appliances used. The charge controller/conditioner has the specific task to stabilize the voltage provided by the PV arrays to feed the batteries and control the battery charge conditions. It contains a security function to prevent overloading or over discharging of the batteries and thus preventing battery damage. For PV systems, gel-based batteries are more adequate to use because they have a longer lifetime and require no maintenance. But alternatively conventional car-batteries can be used, but one needs to frequently add battery water to prevent battery damage.

From field observations it is difficult to point out which type of solar PV arrays were initially installed as part of the Solar Home PV systems. There are a series of different PV arrays installed with varying capacities ranging up to 120 Wp (see appendix C for description of the PV arrays). Therefore an energy analysis is performed based on available information about the PV project of 1995.

#### Solar PV project Kwamalasamutu (1995)

A Solar Home PV system in Kwamalasamutu supplies in general two houses with the main purpose for lighting. From the installation reports, we find that the power capacity of the installed solar PV systems of the standard home systems (existing of 2 PV arrays) are based on the

<sup>41</sup> See report: Van Kampen, M.A. and dos Ramos, O.A., "Zonne-energie Kwamalasamutu, verslag van uitvoering", October 1994

<sup>42</sup> Energy Unit, Energy and Water Department, The World Bank, Technical and Economic Assessment: Off grid, Mini-grid and Grid Electrification Technologies, Summary Report, 2005, page 27

assumption that there must be a minimal energy output of 190 Wh/day<sup>43</sup> (12V / 6A) to supply two 8W TL lamps and/or connected appliances for 3 hours a day distributed over two houses<sup>44</sup>.

#### *PV array capacity*

Based on the above mentioned assumptions we can perform a basic energy analysis of a Home PV system. From the available information the energy demand is:

$$2 * 8 \text{ W} * 3 \text{ h} + 3 \text{ h} * X \text{ W} = 190 \text{ Wh/day}$$

This means that  $X = 47.3 \text{ W}$  is available distributed over two connected households to connect 20 W appliances that could function for 3 hours.

To be able to verify the installed PV capacity we use equation 3.1.

$$C_p = \frac{E_{PVMIN}}{(MSR_{MIN} * \eta_{TOT})} \quad (3.1)$$

Where

$E_{PVMIN}$  = Minimal generation/demand capacity of the PV system (Wh/day)

$C_p$  = Rated or Nominal capacity (Wp)<sup>45</sup>

$MSR_{MIN}$  = Minimal available nominal solar radiation (4.77 kWh/m<sup>2</sup>/day)<sup>46</sup>

$\eta_{TOT}$  = Overall PV system efficiency (0.65 – 0.75)<sup>47</sup>

$$C_p = \frac{190}{(4.77 * 0.7)}$$

$$C_p = 57 \text{ Wp}$$

Since the Solar Home PV system consists of two PV arrays, each PV array should have at least a nominal capacity of 30 Wp.

#### *Battery capacity*

The battery is dimensioned based on the independence days (cloudy days without optimal supply from the PV arrays). From the project dossier<sup>43</sup> 2 x 100 Ah/12 V batteries were installed per Home PV system. We assume that deep cycle batteries are used; each battery can be discharged up to 40% of its total capacity without damaging the battery.

To calculate the amount of days the battery can be discharged without being damaged the modified form of equation 3.2 is used.

<sup>43</sup> Consulting Partners N.V., Kwamalasamoetoe project dossier

<sup>44</sup> Van Kampen, M.A. and dos Ramos, O.A., “Zonne-energie Kwamalasamutu, verslag van uitvoering”, October 1994

<sup>45</sup> Rated capacity (Watt-peak), that is the maximal power output measured at 1 kW/m<sup>2</sup> radiation at 25°C.

<sup>46</sup> Value used in Jansen, J. and de Castro, J.F.M., “Alternatieve Elektriciteitsvoorziening in het binnenland van Suriname”, ECN and CCE, 1993

<sup>47</sup> California Energy Commission, A guide to photovoltaic (PV) system design and installation, 2001

$$Cb = \frac{E_{MIN} * n(days)}{\eta_B * Vb} \quad (3.2)$$

Where

$E_{MIN}$  = Total minimal energy demand (Wh/day)  
 $Cb$  = Battery capacity (Ah)  
 $n(days)$  = Amount of cloudy days  
 $\eta_B$  = Battery discharge capacity (0.2 - 0.4)  
 $Vb$  = System voltage (V)

$$n(days) = \frac{Cb * Vb * \eta_B}{E_{MIN}}$$

$$n(days) = \frac{2 * 100 * 12 * 0.4}{190} = 5.1 \text{ days}$$

Thus the 2 x 100 Ah installed batteries can supply a demand of 190 Wh/day (12 V DC / 6A) over 5 days.

#### *Current Electricity demand*

The 15 – 20 PV systems that are still in operation are in general the individual systems and are owned by villagers that have the means to travel to Paramaribo and/or buy new batteries to replace the dried batteries. A typical household with a functioning PV system generally includes a Radio (20 - 30W) and lighting (8-15W). Since there was limited time to perform a detailed analysis (including all the households in Kwamalasamutu), five households with an operating solar PV systems, located randomly in the village, were visited to confirm this. It results that the TVs (55-120W) and DVDs (20-30W), although present, are rarely used. See table 3.1 for more detail on the energy requirement of an average household in Kwamalasamutu with a functioning PV system.

**Table 3.1 Appliances used in an average household in Kwamalasamutu (2006)<sup>48</sup>**

Household	Amount	Wattage (rated)		Usage (Hrs/day)		Power requirement (Wh/day)	
Appliance		MIN	MAX	MIN	MAX	MIN	MAX
Radio	1	20	30	3	5	60	150
Lighting	2	8	15	3	5	48	150
Total						<b>108</b>	<b>300</b>

From table 3.1 an average household in Kwamalasamutu with functioning PV system requires between 108-300 Wh/day. These calculations are based on the assumption that there is no control or monitoring of the type and brand of appliances bought by the local people. Thus the specific power requirement of a radio depends on the available brands and sizes on the Suriname market, which can deviate considerably in power requirement. Note that the surveyed houses included

<sup>48</sup> Partly used source: Typical wattages of devices: <http://www.kgelectric.co.za/appliance%20power.htm> and <http://www.ext.vt.edu/pubs/disaster/490-303/490-303.html>

appliances on the lowest end of the given power requirement margins. Thus one can say that the average household in Kwamalasamutu requires about **108 Wh/day**.

If we compare the energy production with the energy demand, we see that the production of 190 Wh/day covers the minimum case, being 108 Wh/day. But one can see that if people buy appliances >20W the energy demand can surpass the supply capacity of the Home PV system, limiting the hours it can be used. The system has its flexibility in the sense that one can choose to light for more hours while not using the radio or visa versa. The maximal amount of hours both a 20 W radio and 2x8W lighting can be used is 5 hours a day ( $190 \text{ Wh/day} / (20\text{W} + 2 \times 8\text{W}) = 5.2 \text{ h}$ ).

Thus in Kwamalasamutu having now (2006) about 15-20 houses with a functioning Solar Home PV system there is a total electricity demand between 1.6 – 6.0 kWh/day this is equal to 584 – 2190 kWh/year.

#### Total energy production and consumption of Home PV systems in Kwamalasamutu

Based on the previous information we can estimate that a total of 8.4 kWp (140 Home PV System \* 2x30 Wp PV arrays) was initially installed in 1995. In the meanwhile only about 15 – 20 houses still have a functioning Home PV system, this means that the current installed capacity is between 0.9 – 1.2 kWp. See table 3.2 for an overview of the current PV related energy production in Kwamalasamutu.

**Table 3.2 General performance data of Home PV Systems in Kwamalasamutu**

Home PV systems	Installed capacity (kW)	Electricity production (MWh/year)	Electricity demand (MWh/year) <sup>49</sup>	Capacity factor <sup>50</sup>
140	8.4	9.71	5.52	13 %
20	1.2	1.39	0.79	
15	0.9	1.04	0.59	

From table 3.1 one can see that the only 11 – 14% of the original installed PV capacity (1995) is still in operation in 2006. Based on the assumption that all the households in Kwamalasamutu have an energy demand of 108 Wh/day, we see that the Home PV systems produce enough energy to comply with the demand per household.

Next to the Solar Home PV systems there are other buildings in Kwamalasamutu that currently (2006) use a different PV system. This is the case with the MZ Clinic, the ACT clinic and a researcher's guest house.

#### **Portable Electric Generators**

From communication with local villagers, 5 to 10 houses have a portable generator. Due to lack of time these houses were not visited. Thus there is no idea of what capacities and brands of portable electric generators are used and how the composition is of the appliances used in these specific households. From general internet sources one can conclude that the capacity ranges of the smallest portable electric generators are between 1000 - 3000 W<sup>51</sup>. This means that if 5 – 10 households make use of 1600 W portable generators (see example in figure 3.7) and use it for 5

<sup>49</sup> (140 PV systems \* 0.108 kWh/day \* 365 days) / 1000 kWh/Mwh = 5.52 MWh/year

<sup>50</sup> Capacity factor = (9.71\*1000 kWh) / (8.4 kW \* (365 \*24 h)) = 0.13

<sup>51</sup> See following sources : <http://www.yamahagenerators.com/default.htm?cart=1147556627317896>, <http://www.colemanpowermate.com/generators/>, <http://www.tylertool.com/generators.html> and [http://www.dieselgenerators.com/honda\\_eu.htm](http://www.dieselgenerators.com/honda_eu.htm)



hours a day, the electricity production will be about 7.5 kWh/day. Via a very simple calculation the fuel consumption can be estimated (see figure 3.7 for values used in the calculations):

$$\text{Fuel consumption} = \frac{4.1L}{1.6kW * 10.5h} = 0.24 \text{ L/kWh}$$

Thus the fuel consumed per day:

$$7.5 \text{ kWh/day} * 0.24 \text{ L/kWh} = 1.8 \text{ L/day}$$

At a cost of 6 – 10 SRD/L<sup>52</sup>, the operation costs will sum around:

$$1.8 \text{ L/day} * 365 \text{ day/year} * 8 \text{ SRD/L (2.91 US\$/L)} = 5256 \pm 1314 \text{ SRD/year (1912 US\$/year)}$$

The LHV of diesel fuel is 36 MJ/L<sup>53</sup>. This means that the annual primary energy use per household is:

$$(1.8 \text{ L/day} * 365 \text{ day/year} * 36 \text{ MJ/L}) / 1000 \text{ MJ/GJ} = 23.7 \text{ GJp/year per household. Thus for 5 – 10 houses the total primary energy consumption is between 0.12 – 0.24 TJp.}$$



Max HP	2.5
Sound Level (DB)	52
Output (kw): Rated	1.6
Max	2.0
Output Voltage (V)	230
Continuous Operating Hours	10.5
Without Refuelling at Rated Load	
Dimensions (mm)	L: 510, W: 290, H: 425
Dry Weight (kg)	21
FuelType	Petrol
DC Output	12V, 8A
Current (A)	7
Frequency (Hz)	50
Tank Capacity (litres)	4.1

**Figure 3.7 An EU20i electric generator<sup>54</sup>**

The fuel costs of a diesel/gasoline fueled electrical generator form in general the largest share in the operation costs. In this case the electricity production cost is 1920 SRD/MWh.

Later in chapter 5 a comparative techno-economic analysis is performed that will indicate the costs ranges for installing and operating a diesel generator.

<sup>52</sup> Local diesel price in Kwamalasamutu (2006)

<sup>53</sup> Blok, K. and Van Egmond, S., Energy Analysis, Copernicus Institute, Utrecht University, 2005

<sup>54</sup> Source: [http://www.dieselgenerators.com/honda\\_eu.htm](http://www.dieselgenerators.com/honda_eu.htm)

### 3.3.2 Public buildings / infrastructure

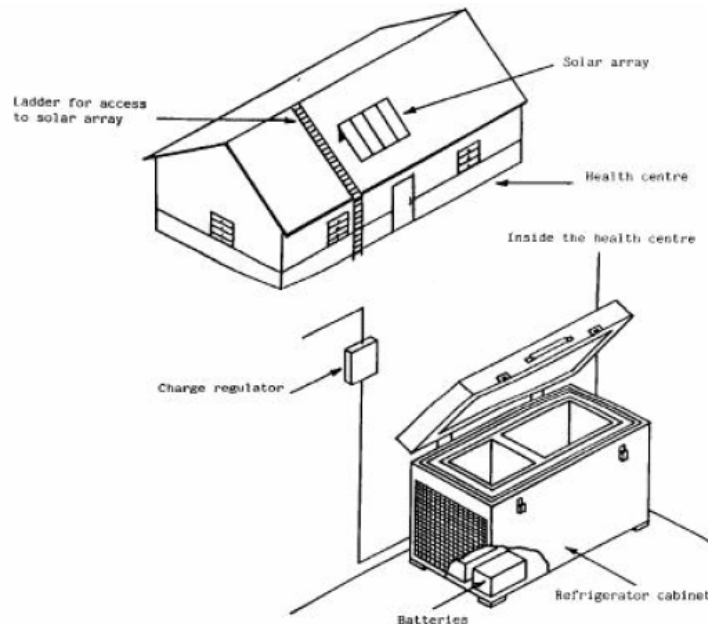
At the moment (April 2006) none of the public buildings have a functional electricity production system. The water pump is not being used because the 15hp pump is not functioning. Also there is no public lighting.

### 3.3.3 Clinics / others

#### MZ Clinic

At the “Medische Zending” Clinic two PV systems are installed. One system consisting of 4x125Wp Conergy PV arrays that supply two 159 Ah VARTA (Vb 6159)<sup>55</sup> batteries with energy that are interconnected with a recently installed Prostar Refrigerator (XL6000 model, 85 kg), a LEICA CME microscope (20W) and lighting (3x18W). The second PV system consists of 4x85Wp Solar Shell PV arrays connected to a 120 Ah KOBE battery and supplies energy for lighting (1x18W + 4x8W) and the communication radio (25W).

The PV system installed at the MZ Clinic for the solar powered fridge can be seen in schematic manner in figure 3.4.



**Figure 3.4 A typical solar powered refrigerator layout<sup>56</sup>**

For the batteries a capacity to run the refrigerator for five days without sun is generally recommended. The charge regulator maintains the power supply within the current and voltage range tolerated by the refrigerator and prevents overcharge of the battery. Some models include an audible alarm or warning light to signal when battery voltage becomes low. Lightning surge protection must be provided for tropical areas. The solar array can be for roof or ground mounting. The typical PV array requirement is 150 - 200 Wp of photovoltaic modules<sup>56</sup>.

<sup>55</sup> See for more detail: <http://www.batteryelectric.com/be-products08-stats2.htm>

<sup>56</sup> Source : [www.itdg.org/docs/technical\\_information\\_service/solar\\_refrigeration\\_vaccines.pdf](http://www.itdg.org/docs/technical_information_service/solar_refrigeration_vaccines.pdf)

### Energy production at the MZ clinic

Using equation 3.1, the energy productions of the installed PV arrays are:

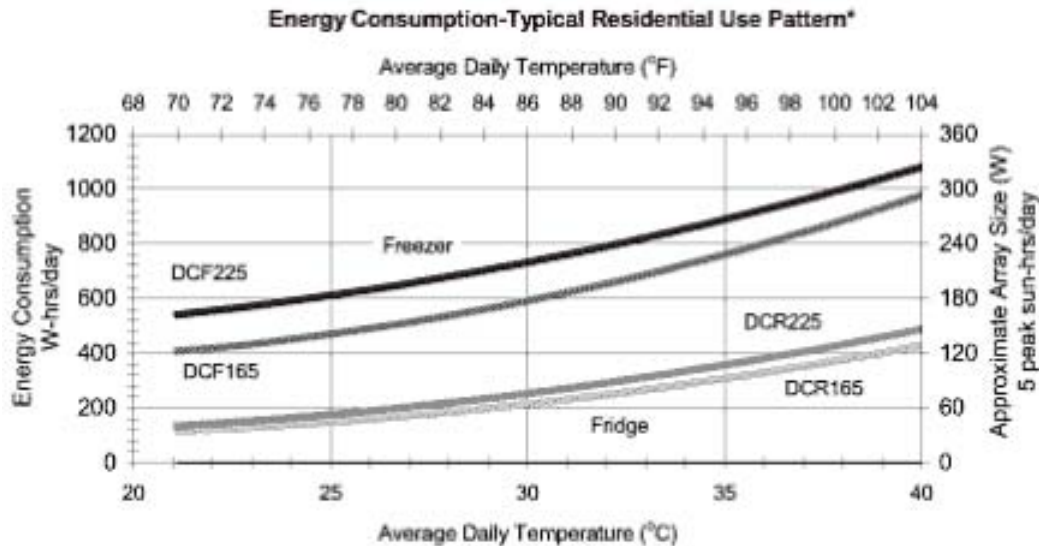
$$4 * 125 \text{ Wp} * 4.77 \text{ kWh/m}^2/\text{day} * 0.7 = 1670 \text{ Wh/day}$$

$$4 * 85 \text{ Wp} * 4.77 \text{ kWh/m}^2/\text{day} * 0.7 = 1135 \text{ Wh/day}$$

The total electricity production per year is  $(1.670 + 1.135 \text{ kWh/day}) * 365 \text{ days} = 1.02 \text{ MWh/year}$ .

### Energy demand at the MZ Clinic

The average energy consumption in the MZ Clinic is calculated to verify the supply-demand match. In the case of solar powered refrigerator/freezers the energy consumption is not as straightforward as other appliances used in a household. The energy consumption depends on the average daily temperature and the size of the fridge/freezer. See figure 3.4 to find an example of energy consumption of 4 different types of fridge/freezers.



**Figure 3.4 Energy consumption patterns of solar powered fridge/freezers based on average daily temperature<sup>57</sup>**

Since it was not possible to trace back the specific energy consumption of the Prostar XL6000 model, a comparison was made with the DCR225 model (160 lbs) that has a storage capacity in the similar range as the ProStar (see figure 3.4). The average daily temperature at Kwamalasamutu is about 28°C, thus the energy consumption of the fridge can be in the range of 225 – 250 Wh/day.

The composition of appliances used at this clinic and their energy consumption is shown in table 3.3.

<sup>57</sup> Source: <http://www.cetsolar.com/sundanzer.htm>



**Table 3.3 Appliances used at the MZ clinic in Kwamalasamutu (2006)**

MZ Clinic	Amount	Wattage (rated)		Hrs/day		Wh/day	
Appliance		MIN	MAX	MIN	MAX	MIN	MAX
PV system 1							
Fridge	1					225	250
Microscope	1	20		0	1	0	20
Lighting	3	18		3	5	162	270
Total						<b>387</b>	<b>540</b>
PV system 2							
Com. Radio <sup>58</sup>	1	25		9	11	225	275
Lighting	1	18		3	5	54	90
Lighting	4	8		3	5	96	160
Total						<b>375</b>	<b>525</b>
Total MZ Clinic						<b>762</b>	<b>1065</b>

The power requirement of the MZ clinic is between 762 - 1065 Wh/day. Note that these are averages and that this is a qualitative analysis.

A specific issue to mention is that even if there is a large PV array capacity installed, the battery discharge capacity has a large influence on the current supplied to the appliance. Most car batteries can only be discharged up to 20% but there are deep cycle batteries (build for PV systems) that can be discharged up to 40%. If we analyze the PV system 2, the total average appliance energy demand was 450 Wh/day (12V DC and 7A current) and all connected to a 120 Ah deep cycle battery.

$$120 \text{ Ah} * 12 \text{ V} * 0.4 = 576 \text{ Wh}$$

$$576 \text{ Wh} / 450 \text{ Wh/day} = 1.3 \text{ days}$$

This is a very short energy supply security period (in case there is not enough sunlight). This means also that the battery will pass more frequently through its discharging / charging cycle, that decreases its lifetime. A typical battery has a lifetime around 4-5 years, but the more frequently the cycle, this lifetime can decrease to 2-3 years.

### ACT clinic

There are two PV systems installed at the ACT clinic. One system consists of a 120 Wp Astro Power PV array that supplies an Electrolux Fridge (C165 model). The other PV systems consists of a 110 Wp Shell Solar PV array that supplies energy for lighting (4x8W + 2x18W) and a communication radio (25W). See table 3.3 for an overview of the appliances used in this clinic.

#### *Energy production at the ACT clinic*

The energy productions of the PV systems are:

$$120 \text{ Wp} * 4.77 \text{ kWh/m}^2/\text{day} * 0.70 = 401 \text{ Wh/day}$$

$$110 \text{ Wp} * 4.77 \text{ kWh/m}^2/\text{day} * 0.70 = 367 \text{ Wh/day}$$

The electricity production per year is  $(0.401+0.367 \text{ kWh/day}) * 365 \text{ days} = 0.28 \text{ MWh/year}$ .

<sup>58</sup> Source: <http://www.kgelectric.co.za/appliance%20power.htm>

### *Energy demand at the ACT Clinic*

As in the case of the MZ clinic it was not possible to trace back the specific energy use of the Electrolux Fridge. And thus the same assumptions are made as in the MZ clinic situation. See table 3.4 for the composition of appliances used at this clinic and their energy consumption.

**Table 3.4 Appliances used at the ACT clinic in Kwamalasamutu (2006)**

ACT clinic	Amount	Wattage (rated)		Hrs/day		Wh/day	
Appliance		MIN	MAX	MIN	MAX	MIN	MAX
PV system 1							
Fridge	1					225	250
PV system 2							
Lighting	4	8		3	5	96	160
Com. Radio	1	25 (5W stand-by)		9	12	225	300
Total						321	460
Total ACT Clinic						546	710

The power requirement of the ACT clinic is between 546 - 710 Wh/day. Note that these are rough estimations, for instance in the case of the communication radio the calculations are based on 25W, while this only counts during transmission and in the remaining time the stand-by consumption is 5W.

### **Research visitor building**

There is a building for visiting researchers with relatively new PV system installed. The PV system consists of a 125 Wp Conergy PV module and an 85 Wp Solar Shell PV module connected to a 225 W inverter and 2 x AC Deep Cycle Delco Batteries to supply a Phocos 12V DC fridge and two light points (2x8W).

### *Energy production at the Researchers guest house*

The energy production is:

$$(125 \text{ Wp} + 85 \text{ Wp}) * 4.77 \text{ kWh/m}^2/\text{day} * 0.7 = 701 \text{ Wh/day}$$

The electricity production per year is  $0.701 \text{ kWh/day} * 365 \text{ days} = 0.256 \text{ MWh/year}$ .

### *Energy demand at the Researchers guest house*

In table 3.5 one can see the energy demand at the researchers building.

**Table 3.5 Appliances used at the Visiting Researchers Building in Kwamalasamutu (2006)**

Research B. Appliance	Amount	Wattage (rated)		Hrs/day		Wh/day	
		MIN	MAX	MIN	MAX	MIN	MAX
Fridge <sup>59</sup>	1					500	
Lighting	2	8		3	5	48	80
Total						548	580

<sup>59</sup> This fridge is of the brand Phocos SF50, technical data found: <http://www.aetsolion.gr/enversion/pdf/Phocos%20FR%20165-225.pdf>

In the case of the guest house the refrigerator energy demand was traced back, this resulted to be 500 Wh/day. In table 3.5 one can see that the energy demand at the researcher's guesthouse is between 548 – 580 Wh/day. The annual consumption is between 0.20 – 0.21 MWh/year.

#### *Battery capacity*

$$2 * 220 \text{ Ah} * 12 \text{ V} * 0.4 = 2112 \text{ Wh}$$

$$2112 \text{ Wh} / 596 \text{ Wh/day} = 3.5 \text{ days}$$

If we compare the installed capacity with the energy demand there is a security supply margin of:  
 $1 - (596 \text{ Wh/day} / 701 \text{ Wh/day}) * 100\% = 15\%$

### **3.3.4 Fuel consumption for cooking/lighting**

From the literature a rural household uses about 1.2 kg/person-day of firewood<sup>60</sup> for cooking or lighting, and has a calorific value of about 19 – 20 MJ/kg<sup>61</sup>. In case of a household with 4 people the firewood consumption will be:

$$4 \text{ people} * 1.2 \text{ kg/person-day} * 365 \text{ days} = 1752 \text{ kg of firewood per year}$$

$$1752 \text{ kg} * 19.5 \text{ MJ/kg} = 34.2 \text{ GJ primary energy per year}$$

Having about 210 – 250 houses in Kwamalasamutu, the total firewood consumption could range between 368 – 438 ton of firewood per year for cooking. This is equal to a primary energy content of 7.2 – 8.5 TJp.

Since the fuel usage for cooking or lighting is not analyzed for Kwamalasamutu this section is only used to illustrate that fuel consumption in the form of firewood or kerosene can be large and that this needs to be analyzed to identify future alternatives for cooking/lighting.

### **3.3.5 Total energy production and consumption in Kwamalasamutu**

To summarize the previous sections, see table 3.6 for a general overview of the current installed PV capacity, the energy production and consumption in Kwamalasamutu.

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<sup>60</sup> Source: <http://www.ashdenawards.org/winners/bsp>

<sup>61</sup> Source: [http://www.grahamandrews.com/burning\\_firewood.htm](http://www.grahamandrews.com/burning_firewood.htm)

**Table 3.6 General overview of installed PV capacity and energy production in Kwamalasamutu (2006)**

	Description	Installed PV capacity (kW)	PV Electricity production (MWh/year)	Electricity demand (MWh/year)	Fuel consumption (TJp/year)
PV installations	15 to 20 Home PV systems (2x30Wp)	1.8 – 2.4	1.0 – 1.4	0.59 – 2.19	
	MZ clinic	0.84	1.02	0.28 – 0.39	
	ACT clinic	0.23	0.28	0.20 – 0.26	
	Guest House (Researchers)	0.21	0.26	0.20 – 0.21	
	<b>Total</b>	<b>3.1 – 3.7</b>	<b>2.6 – 3.0</b>	<b>1.3 – 3.1</b>	
Electric generators	5 to 10 houses (1600W)	8 - 16	21.9 – 43.8	<i>n.a.</i>	0.12 – 0.24
Cooking	210 to 250 houses	-	-	-	7.2 – 8.5
Total		<b>11.1 – 19.7</b>	<b>24.5 – 46.8</b>	<b>1.3 – 3.1</b>	<b>7.3 – 8.7</b>

From table 3.6 one can see that there are several uncertainty factors influencing the results. But if one takes the average values, one can conclude for Kwamalasamutu that the current electricity demand is on average 2.2 MWh/year. With a total installed PV capacity of 3.4 kW that produces around 2.8 MWh/years. The overall PV capacity factor is 9.4%<sup>62</sup>, this makes that a relatively large PV capacity is needed to supply the electricity required in Kwamalasamutu. The *italic* values are fictive, but are shown here to identify the need to monitor these values.

### 3.4 Energy demand projections

To describe the required conditions and to be able to project future demand, we have to note that in the initial solar PV project design of 1995, 140 Home PV systems were installed to supply a total of 252 houses (112 \* 2 houses + 28 \* 1 house). From current (2006) communication with the local people an estimated amount of 210 – 250 houses are inhabited. This decrease in houses may be due to the fact that an average household decreased from 5-6 people to 4-5 people per household, perhaps due to people having migrated to other villages in the Trio area.

#### 3.4.1 Scenarios

To be able to make projections, assumptions have to be made on the required and/or future composition of appliances used in a household. The combined energy demand of all the appliances and growth in households will indicate the future energy demand in Kwamalasamutu. As the required conditions two scenarios, scenario K1 and K2 are created.

##### Scenario K1 (Basic needs)

The first scenario (K1-scenario) is based on the assumption that in year 0 (start of operation) the existing electrical infrastructure at each household can be repaired and that each household minimally should be able to use 2x8W light points for 4 hours and have 100 Wh/day available to connect an appliance, this is enough to run a 20 W radio for 5 hours. The total energy demand per household will be 164 Wh/day (59.7 kWh/year). Also the energy demand from other public buildings as the “Krutu Oso” (1600 Wh/day), the church (648 Wh/day), the school (2400 Wh/day) and recreation hall (648 Wh/day) are included in this scenario. See appendix H for more

<sup>62</sup> Capacity factor = (2.8\*1000 kWh/year)/(3.4kW \* (365\*24h)) = 0.094

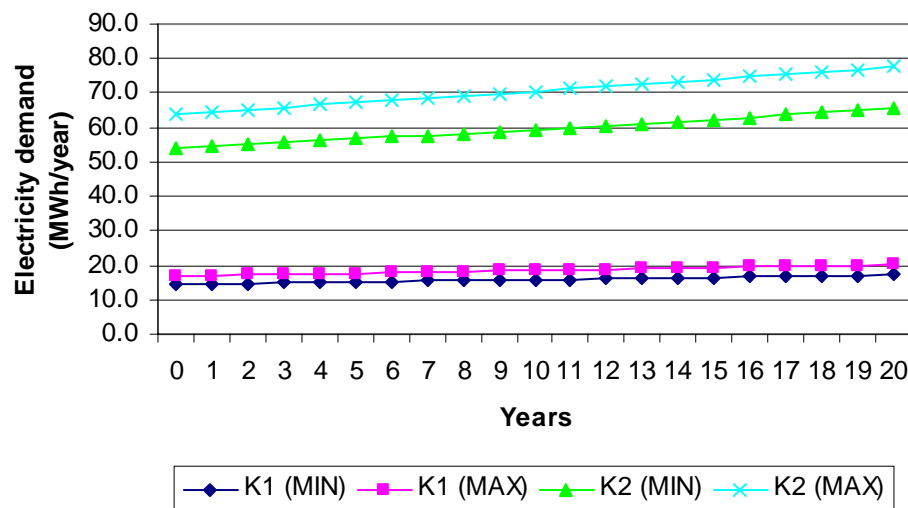
detail. This makes the total energy demand to be 5460 Wh/day. When taking in account 210 – 250 houses, the electricity demand in year 0 will be between 14.5 – 16.9<sup>63</sup> MWh/year.

#### Scenario K2 (Premium needs)

The second scenario (K2-scenario) is based on the assumption that in year 0 (start of implementation), each household should be able to use 2x18W light points for 5 hours and have 500 Wh/day available to connect several appliances as TV, DVD, or refrigerators. The total energy demand of each household is then 680 Wh/day (248.2 kWh/year). Along with the public buildings, as described in scenario K1, the total energy demand sums up to 5976 Wh/day. The total electricity demand for the starting year will be between 52.1 – 62.1 MWh/year.

### 3.4.2 Energy demand curve

To calculate the future demand the average population growth of 1.0% per year (0.8 – 1.2 % per year) is taken in mind. This is multiplied to the energy demand of the households and then added to the energy demand of the public buildings. See figure 3.8 for the electricity demand projections per scenario for Kwamalasamutu.



**Figure 3.8 Electricity demand projection per scenario for Kwamalasamutu for a period of 20 years.**

As one can see in figure 3.8, the electricity demand for scenario K1 (MIN) and K1 (MAX) increase up to 17.3 MWh/year and 20.2 MWh/year respectively. This is because the energy requirement per household was very low, around 164 Wh/day. In the case of scenarios K2 (MIN) and K2 (MAX) the increase can reach up to 65.5 – 77.7 MWh/year.

**Table 3.7 Arithmetic means of electricity demand for each scenario for Kwamalasamutu**

Year	K1 scenario	K2 scenario	Unit
0	15.7	59.0	MWh/year
5	16.4	61.9	MWh/year
10	17.1	65.0	MWh/year
15	17.9	68.2	MWh/year
20	18.7	71.6	MWh/year

<sup>63</sup> ((X mount houses \* 0.164kWh/day) + sum (public buildings = 5.296 kWh/day) \* 365 days)/1000 = X MWh/year

To facilitate in further calculations, the values in table 3.7 are used. These are the arithmetic means of the electricity demand ranges as shown in figure 3.8. Note that table 3.7 shows the required electricity demand in the village over a period of 20 years. Scenarios 1 and 2 are based on the possible current minimal required demand on household level and extrapolated to the possible future energy demand growth on village level, but this does not per definition mean that the electricity demand should be supplied by PV systems. This is because the purpose of this study is to also look at other renewable energy sources and technologies to comply with the demand, we have to quantify the required installed capacity of each RET based on their capacity factor.

The possible electricity demand of Kwamalasamutu depends very much on the energy demand package required per each household. The population size and growth, number of habited houses, the specific energy requirement of the appliances used and use profile, all are factors influencing the energy demand in the village. Due to lack of time and sources an intensive energy analysis could not be performed and as a recommendation all the above named factors should be updated or monitored to be able to make better assessment of the energy needs in Kwamalasamutu.

## 4. Energy resource assessment and alternatives

In this chapter the natural energy resources in the Suriname-Brazil border area are analyzed. The collection of the data is based on the available literature, a theoretical energy production assessment, and a pre-feasibility assessment using the HOMER<sup>64</sup> micro-optimization model. This model will help identifying the theoretical potential of renewable energy technologies. The renewable energy sources, as wind, hydro, solar, and biomass sources are selected based on previous energy assessment reports performed in Suriname and field observations.

### 4.1 Solar energy

There are two main categories of solar energy conversion processes, solar thermal systems, and photovoltaic (PV) systems. Thermal solar systems use various mirror configurations to concentrate the sunlight and then convert the sun's energy into high-temperature heat that can be used directly or converted to electricity. In the case of rural isolated regions one can think of small solar ovens or solar water heaters that are based on this same principal. Photovoltaic systems convert radiant light energy (photo) to electricity (voltaic). PV cells are the basic building blocks of this energy technology. These cells are made of semiconductor materials, most typically silicon. The amount of electricity a PV cell produces depends on its size, its conversion efficiency, and the intensity of the light source. Sunlight is the most common source of the energy used by PV cells to produce an electric current.

#### 4.1.1 PV potential in Kwamalasamutu

When analyzing the solar energy resource potential, the best indicator is the insulation level (daily solar radiation in kWh/m<sup>2</sup>/day) available at Greenwich Mean Time<sup>65</sup>. To gather this data, the HOMER model was used. As input data the geographical location of the village is required and in which time zone it is located. The model is linked with several satellite based solar data bases and downloads the most up to date solar radiation data for that location.

Here are the input data used to find the solar radiation data at Kwamalasamutu.

Location Kwamalasamutu = LAT 2 21' LONG 56 50'  
Time zone = (GMT – 03:00) Greenland, Eastern South-America

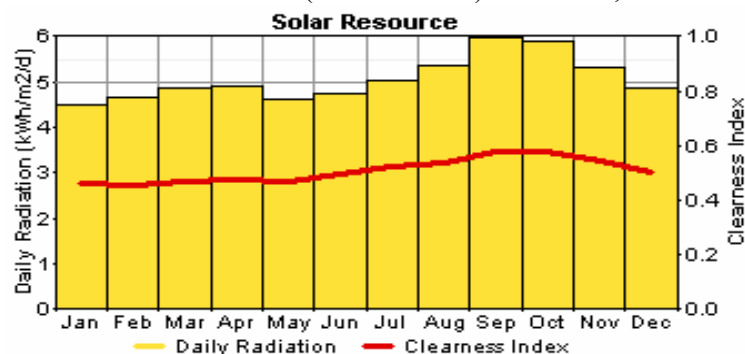


Figure 4.1 Solar monthly radiation levels for Kwamalasamutu<sup>66</sup>

<sup>64</sup> See Homer website: <http://www.nrel.gov/homer/>

<sup>65</sup> Greenwich is the place where all the time zones are measured and the GMT time marks the starting point of every time zone in the world.

<sup>66</sup> This is the output data from the HOMER micro optimization model for Kwamalasamutu

Figure 4.1 shows the result of the 10 year averaged daily radiation values for Kwamalasamutu. The minimal monthly averaged daily radiation level at Kwamalasamutu is about 4.510 kWh/m<sup>2</sup>/day in the month of January. The scaled annual average radiation is 5.07 kWh/m<sup>2</sup>/day.

To be able to dimension a PV system, the energy demand is required (Wh/day). In addition, the system efficiency (not the same as the energy conversion efficiency of the PV cells) should be taken in mind. This in general means that there are losses in the PV system, such as energy consumption by the regulator and the fact that the batteries cannot be discharged totally. The month with the lowest average radiation value should be used for the analysis to calculate the minimal required installed PV capacity needed to have security of supply.

For dimensioning the PV systems the scenarios 1 and 2 are used as starting point. We know from table 3.7 (section 3.5) that the electricity demand after 20 years can be about 18.7 MWh/year (scenario K1) and 71.6 MWh/year (scenario K2). The minimal required PV capacity is estimated for both scenarios to comply with the electricity demand. With other words, one should find out how much PV capacity should be installed to supply the energy demand in 20 years from year 0.

To be able to estimate the total required installed PV capacity to comply with the above named demands, first the rated capacity per household has to be identified for both scenarios. Using equation 3.1 we can find the rated capacities:

$$C_p = \frac{E_{PVMIN}}{MSR_{MIN} * \eta_{TOT}}$$

Where

- $E_{PVMIN}$  = Minimal generation capacity of the PV system (Wh/day)
- $C_p$  = Rated or Nominal capacity (Wp)<sup>67</sup>
- $MSR_{MIN}$  = Minimal available nominal solar energy (4.51 kWh/m<sup>2</sup>/day<sup>68</sup>)
- $\eta_{TOT}$  = Overall PV system efficiency (0.65 – 0.75)

For scenario K1 the total daily requirement is set on 164 Wh/day, thus the rated capacity is:

$$C_p = \frac{164Wh / day}{4.51kWh / m^2 / day * 0.7}$$

$$C_p = 51.9 Wp$$

A 55 Wp PV array will then be adequate to provide a stable energy supply to each household in scenario K1, with a capacity factor of 13%. Thus in the initial stage (year 0) when dealing with 210 – 250 houses the total installed PV capacity will be between 11.6 – 13.8 kWp. The installed PV capacity required to produce 18.7 MWh/year (after 20 years) is 16.4 kWp<sup>69</sup>. This makes that about 298 PV arrays of 55Wp are needed.

This same methodology is applied to scenario K2 to calculate the required installed PV capacity. See table 4.1 for an overview of the results.

<sup>67</sup> Rated capacity (Watt-peak), that is the maximal power output measured at 1 kW/m<sup>2</sup> radiation at 25°C.

<sup>68</sup> This data is based on the method used in chapter 4.1.1

<sup>69</sup> (18.7 MWh/year / 0.13 \* (365\*24h))\*1000 = 16.4 kWp



**Table 4.1 Required installed PV capacity over 20 years in Kwamalasamutu**

	K1 scenario		K2 scenario	
Energy demand per household	164	Wh/day	680	Wh/day
Rated capacity	55	Wp	220	Wp
Battery capacity	100	Ah	200	Ah
Year	Energy demand (MWh/year)	Needed installed capacity (kW)	Energy demand (MWh/year)	Needed installed capacity (kW)
0	15.7	13.8	59.0	51.8
5	16.4	14.4	61.9	54.4
10	17.1	15.1	65.0	57.1
15	17.9	15.7	68.2	59.9
20	18.7	16.5	71.6	62.8
Required PV arrays (period 0-20 yrs)	298 x 55Wp		285 x 220 Wp	

For the solar PV alternative a total of 16.5 kWp PV capacity (298 x 55 Wp) is required to cover the energy demand over 20 years for the case of scenario K1. In scenario K2 the required rated PV installed capacity is about 62.8 kWp (285 x 220 Wp).

#### 4.1.2 Thermal solar systems

As mentioned before, thermal solar systems use various mirror configurations to concentrate the sunlight and then convert the sun's energy into high-temperature heat that can be used directly or converted to electricity. Since Kwamalasamutu is isolated and this alternative requires complex equipments and high-tech knowledge, it is not further analyzed. There is also a lack of information on the actual fuel consumption for cooking or lighting in Kwamalasamutu. This means that no comparative analysis can be performed and that this option is just highlighted as an alternative for cooking, but requires several basic input data to make a good assessment. Also these solar cookers/ovens are not part of electricity production systems.

##### Solar cooker/ovens

As an alternative to firewood or kerosene use for cooking, one could also think about the use of solar cookers/ovens.

There are many models or designs available and each with specific energy performance. The main input data is the lowest average monthly solar radiation, for Kwamalasamutu this is 4.51 kWh/m<sup>2</sup>/day.



Examples of Solar Cooking Ovens

There are several benefits of using solar cookers/ovens. Most of the designs are made of light, portable and durable material. The design can be built on required size and shape.

As an alternative for public lighting, there are several solar lamps available on the market. They can be used to illuminate pathways at night and as in the case of Kwamalasamutu illuminate the village bridge and other public areas to prevent elder people to have accidents in the evenings.

**Solar lamps**

As an alternative for public lighting one could consider solar lamps. The lamps are available in 1 - 20 W types and can light for 8 - 12 hours. The prices range between 23 - 120 US\$/lamp.





Examples of solar lamps

The benefits are that in general the lamps require low or no maintenance and are easy to transport and install.

#### 4.1.3 Suriname-Brazil border region

The same method used in 4.1.1 is applied here to find the solar radiation data for other villages in the Suriname-Brazil border region. Table 4.2 gives an overview of the collected solar radiation data for each village within the Suriname-Brazil border region. Some village geographical coordinates could not be found, but since solar data information is available for coordinates located in the extremes of the Suriname-Brazil border region (see Brazil 1 and 2) one can say that their solar radiation values are between 4.99 – 5.07 kWh/m<sup>2</sup>/day.

**Table 4.2 Collected solar radiation data for each village in the Suriname-Brazil border region**

Village name	Location <sup>70</sup>	Scaled annual average radiation (kWh/m2/day) <sup>71</sup>	Monthly averaged Daily radiation (kWh/m2/day)		Annual averaged clearness index <sup>72</sup>	Monthly Clearness index	
			MIN.	MAX.		MIN	MAX
Alalapadu	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Amatopo	LA 3 27' LO -57 36'	4,99	4,52	5,78	0,500	0,467	0,559
Apetina (Puleuwine)	LA 3 30' LO -55 3'	5,04	4,26	6,00	0,505	0,440	0,580
Coeroeni	LA 3 24' LO -57 20'	4,99	4,52	5,78	0,500	0,466	0,559
Kawemhakam	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Kwamalasamutu	LA 2 21' LO -56 50'	5,07	4,51	5,97	0,507	0,457	0,577
Palumeu	LA 3 20' LO -55 28'	5,04	4,26	6,00	0,505	0,439	0,580
Pelele Tepu	LA 3 8' LO -55 43'	5,04	4,26	6,00	0,505	0,438	0,580
Sipaliwini	LA 2 1' LO -56 7'	5,07	4,51	5,97	0,507	0,456	0,577
Brazil (1)	LA 1 47' LO -55 33'	5,01	4,33	6,01	0,501	0,439	0,581
Brazil (2)	LA 1 48' LO -55 31'	5,01	4,33	6,01	0,501	0,439	0,581

From table 4.2 one can see that Kwamalasamutu and Sipaliwini have the highest average annual solar radiation value of 5.07 kWh/m2/day, with deviations in value from 4.51 – 5.97 kWh/m2/day. The average radiation values of the remaining villages deviate by maximal 1.6% lower than the highest values. The solar power potential depends on the area one takes into account to comply with the demand. It can change according to the situation and is dependant on many other factors.

## 4.2 Wind energy

Wind turbines can be used for pumping water or graining seeds, as done in many rural areas. Small scale wind turbines can also be used to charge batteries or be connected to micro grids for electricity production. In two previous energy reports<sup>73</sup> related to the interior concluded that wind energy was not a feasible energy production option. The current wind speed data is not provided by the Central Statistical Office of Suriname. To still be able to verify these conclusions, the choice is made to find the wind speed data from the NASA Surface Solar Energy Data Set, where a 10 year (1983-1993) average wind speeds at hub height (50m above earth surface) and on anemometer height (10m above earth surface) are provided. These data can be considered acceptable since climate changes, thus wind speeds and directions do not deviate significantly by decades.

<sup>70</sup> Location is expressed by degrees and minutes in Latitude (North or South) by degrees and minutes in Longitude (East or West), source: <http://www.maporama.com/share/>

<sup>71</sup> NASA's Surface Solar Energy Data Set, Source: [http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?kevinhenry\\_decuba@yahoo.co.uk](http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?kevinhenry_decuba@yahoo.co.uk)

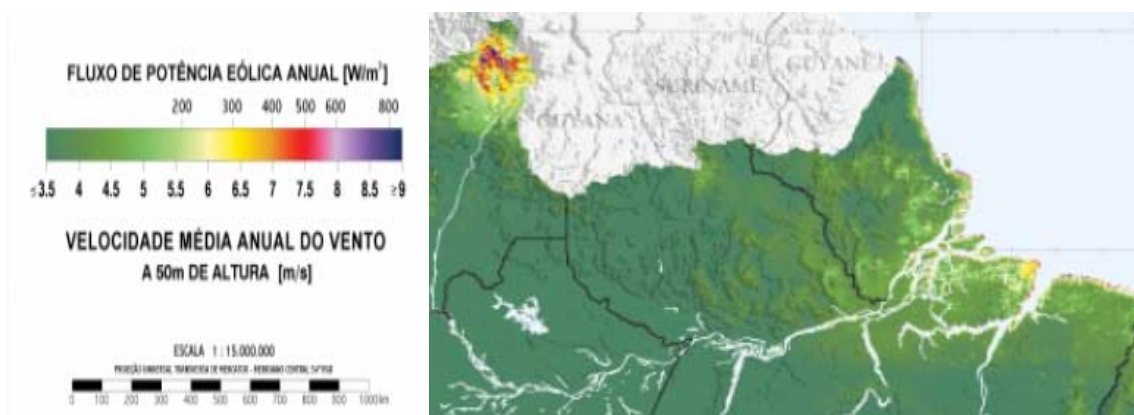
<sup>72</sup> The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions.

<sup>73</sup> See, Alternative Elektriciteitsvoorziening in het binnenland van Suriname (1993) and Suriname Master Energy Plan study (2000)

**Table 4.3 Wind speed data for villages located in the Suriname-Brazil border region**

Village name	Location	Average hub height wind speed (m/s) <sup>74</sup>	Annual minimum deviation (%)	Annual maximum deviation (%)	Average 10 m height wind speed (m/s) <sup>75</sup>
Alalapadu	n.a.	n.a.	n.a.	n.a.	n.a.
Amatopo	LA 3 27' LO -57 36'	2,39	-16	22	1,91
Apetina (Puleuwine)	LA 3 30' LO -55 3'	2,25	-17	20	1,80
Coeroeni	LA 3 24' LO -57 20'	2,39	-16	22	1,91
Kawemhakam	n.a.	n.a.	n.a.	n.a.	n.a.
Kwamalasamutu	LA 2 21' LO -56 50'	2,32	-18	22	1,86
Palumeu	LA 3 20' LO -55 28'	2,25	-17	22	1,80
Pelele Tepu	LA 3 8' LO -55 43'	2,25	-17	22	1,80
Sipaliwini	LA 2 1' LO -56 7'	2,32	-18	22	1,86

From the collected wind speed data (see table 4.3), we can see that the average annual wind speed on hub height is for all the villages on the Suriname side of the Suriname-Brazil border region between 2.25 – 2.39 m/s, with a deviation from -16 to 22% of the average wind speeds. On anemometer height the wind speed levels are between 1.80 – 1.91 m/s. If we look at the Brazilian side of the region, other sources, see figure 4.2, indicate that the wind speeds range between  $\leq 3.5$  – 4.5 m/s at hub height (50m above ground level).

**Figure 4.2 Wind speeds map of Brazil (modified)<sup>76</sup>**

Each wind turbine has its own wind power curve that indicates at what speed what amount of power could be produced. Also the cut in/out speed is a characteristic of a wind turbine, the cut in speed is the moment when there is enough wind to start the turbine to produce energy and the cut out speed is when the turbine turns off to prevent turbulence or material damage caused by high wind speeds. From a review of several turbine sizes, a general conclusion can be made that the average cut in speeds are between 3.0-4.0 m/s and the cut out speeds 20-25 m/s<sup>77</sup>. Based on this information a conclusion can be made that the average wind speeds are not high enough to

<sup>74</sup> Hub height = Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

<sup>75</sup> Difference Between The Average Wind Speed At 10 m Above The Surface Of The Earth And The Average Wind speed At 50 m Above The Surface Of The Earth (%), *Vegetation type* "Airport": flat rough grass (50cm)

<sup>76</sup> Source:

<sup>77</sup> Danish Wind Industry Association, See website: <http://www.windpower.org/en/tour/wres/pow/index.htm>

trespass the cut in speed of a large variety of wind turbines (15-2000 kW)<sup>77</sup>, in accordance with the conclusion reached by previous reports.

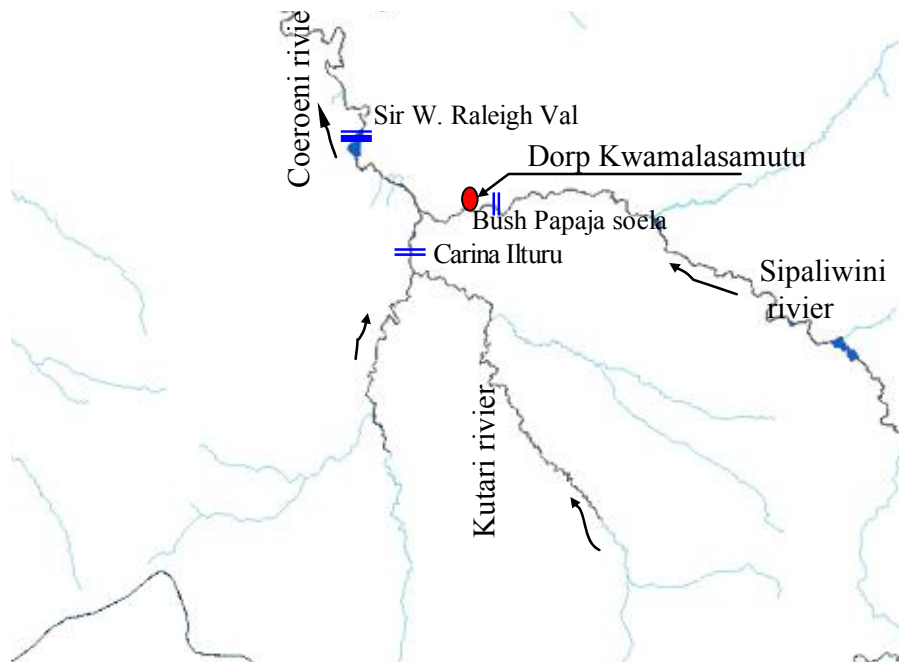
### 4.3 Micro hydro power

There are several types of micro hydro power turbines available as the variable speed turbines at low heads, induction generators and submersible turbo-generators. The use of each turbines type depends mainly on the pressure head and other the prevailing conditions where hydro power potential is identified.

The Suriname-Brazil border region has two seasons, the raining and the dry season. The rain season starts in the end of January and continues till the month of July, whereas the rest of the year it is dry. The hydrological regime principally depends on these events, where in the rain season extreme high water heads can be measured, and in the dry season low water heads can be estimated. The difference in average water heads between wet and dry season can be in the range of 8-10 m<sup>78</sup>.

#### 4.3.1 Micro hydro power in Kwamalasamutu

In 2003 field studies were done by the University of Suriname to assess the micro hydro power potential in the Trio lands, upstream of the Coeroeni, Kutarie and Sipaliwini Rivers (see figure 4.3 for the exact locations of measurements).



**Figure 4.3 Locations of hydrological measurements in the area of Kwamalasamutu<sup>78</sup>**

Hydrological and topographic measurements were made in Bush Papaja, which is about 20 minutes upstream from Kwamalasamutu. The second spot was at the Sir Walter Raleigh falls on the Coeroeni river, about 4 hours downstream by boat from Kwamala. The third spot was at the Karina falls on the Kutari river, about 2 hours downstream from Kwamala on the Sipaliwini river

<sup>78</sup> Anton de Kom University of Suriname, "Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken", Community Development Fund Suriname (CDFS), 2003

and then 20 minutes upstream the Kurani river. Table 4.4 gives the results of the micro hydro power assessment done in the Trio lands.

**Table 4.4 Micro hydro power assessments done in the Suriname-Brazil border region<sup>79</sup>**

Rapid/Fall name	Location	Head difference (m) in dry season <sup>80</sup>	Water debit (m3/s)	Power output <sup>81</sup> (kW)		Turbine type <sup>82</sup>	Electricity production (MWh/year) <sup>83</sup>	Required transmission length (km)
				0.6	0.8			
Bush Papaja	04 00.812'N 55 28.645'W	1.2	3	21	28	Kaplan	147 – 196	±4
Sir. W. Raleigh	02 24.794'N 056 55.507'W	5	6	177	235	Propeller	1240 – 1647	±20
Karina Ituru	02 19.581'N 056 52.430'W	2.2	3	39	52	Kaplan	273 – 364	±12

From table 4.4 one can conclude that the Sir. Walter Raleigh falls have the highest micro hydro power potential between 177 – 235 kW. But at the same time it requires a large transmission length. Thus a trade off should be searched between the costs for installing transmission lines and the total energy production potential of the micro-hydro power systems to evaluate their feasibility.

The power output is calculated based on equation 4.1.

$$P = \eta * \rho * g * H * Q \quad (4.1)$$

where:

- $\eta$  = efficiency (0.6 – 0.8)
- $\rho$  = water density (1000 kg/m<sup>3</sup>)
- $g$  = gravitational acceleration (9.81 m/s<sup>2</sup>)
- $H$  = difference in head (m)
- $Q$  = debit (m<sup>3</sup>/s)
- $P$  = power output (kW)

In the case of Sir. W. Raleigh rapid the electricity production delivered at Kwamalasamutu could be 992 – 1318 MWh/year (assuming grid losses of 10% per 10 km). This electricity production capacity is much larger than the 18.7 -71.6 MWh/year in 20 years from year 0 of each demand scenario. Even in the case of Bush Papaja, 141 – 188 MWh could be delivered to Kwamalasamutu. Energetically these options are at the first glance interesting for further analysis.

Economically and practically many issues have to be addressed, such as the creation of the electrical infrastructure/transmission lines in a rough and pristine area, the need for installing a mini-grid in Kwamalasamutu, the maintenance required, all adds up to the total investment cost and operation of the system. See figure 4.4 to get an impression of the Bush Papaja rapid and the Sir W. Raleigh falls.

<sup>79</sup> Info extracted from: Anton de Kom University of Suriname, “Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken”, Community Development Fund Suriname (CDFS), 2003

<sup>80</sup> This is the height difference between water level at the upper stream minus the water level downstream

<sup>81</sup> The values 0.6 and 0.8 stand for energy conversion efficiency of the turbines, the range of 0.6-0.8 is the general accepted efficiency range for micro hydro turbines

<sup>82</sup> All the selected turbines are reaction turbines, this means that the blades of the turbines are immersed in the water flow and that the angular and linear momentum of the water is converted to shaft power.

<sup>83</sup> The electricity production is calculated with a 0.8 capacity factor.





**Figure 4.4 (left) Bush Papaja soela (20 min upstream from Kwamalasamutu) (Picture taken in April 2006) and (right) Sir W. Raleigh falls (4 hours downstream by boat from Kwamalasamutu)<sup>84</sup>**

#### **4.3.2 Micro hydro power in Suriname-Brazil border region**

Next to Kwamalasamutu, the University of Suriname has also performed hydro power assessments in the area around Palumeu. In 2003 the NGO “Word and Music Ministries” received a US\$ 48,950 GEF small grant to make fundamental step towards generating and using of renewable energy for and in the village of Palumeu, creating thereby necessary conditions for improving the living standard of the village<sup>85</sup>. As part of this initiative a 5 – 20 kW micro hydro power system has been designed and is under construction by the technical faculty of the University of Suriname<sup>86</sup>. See figure 4.6 for an impression of the dam at Palumeu.



**Figure 4.6 Construction of the dam at Palumeu<sup>87</sup>**

<sup>84</sup> Anton de Kom University of Suriname, “Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken”, Community Development Fund Suriname (CDFS), 2003

<sup>85</sup> Source: UNDP GEF website:

<http://sgp.undp.org/index.cfm?module=Projects&page=SearchResults&CountryID=SUR&FocalAreaIDs=CC>

<sup>86</sup> Source: Dag blad van Suriname, [http://www.dbsuriname.com/archief/nat/2006/jan06/11-01-06/Nat\\_Oplevering%20eerste%20fase%20elektrificatieproject%20Palumeu.asp](http://www.dbsuriname.com/archief/nat/2006/jan06/11-01-06/Nat_Oplevering%20eerste%20fase%20elektrificatieproject%20Palumeu.asp)

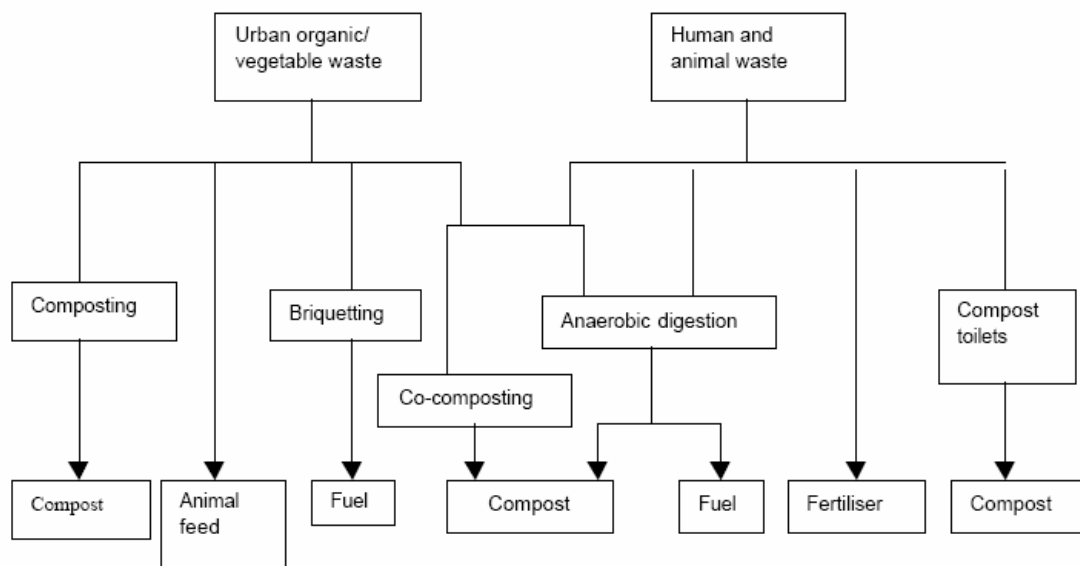
<sup>87</sup> Alvares, M., Field Study in Suriname, TU Delft

The local community contributed with collecting and delivering materials, as stone and sand were required for the construction of the 64 m long dam. There is no official final report available yet on the technical aspects of the turbines used and thus no concrete conclusions can be drawn on the electricity production.

#### 4.4 Bio-energy

The term biomass can include many forms of biodegradable products, as wood, agricultural waste, or animal waste. To prevent intensification of use of firewood or other forest products for cooking fuel or lighting, in this report the focus is on organic wastes that are produced by human habitation. These organic wastes generally include household biodegradable waste, agricultural waste and human and animal waste.

In the case of organic wastes, one can think of many biomass conversion routes to energy carriers or soil fertilizers. Conversion processes can be as complex as high technical thermal processes to conversions that occur via natural biochemical reactions. Since there is limited access to complex conversion technologies in the Suriname-Brazil border region, the focus is set on using common biochemical conversion routes. See figure 4.5 to have an impression of possible conversion routes.



**Figure 4.5 Potential energetic processes and products derived from organic wastes<sup>88</sup>**

The two main biochemical conversion processes are composting and anaerobic digestion. In the case of composting, organic materials are decomposed by naturally present microorganisms such as bacteria and fungi. This is a naturally-occurring process where the organic waste is converted to humus-type compost in a manner of weeks. Under controlled conditions this process can be speeded up. Anaerobic digestion entails a process whereby organic waste is broken down by microbiological activity and takes place under absence of air (anaerobic). This occurs naturally in the bottom of ponds or marches, where methane-rich gas (biogas) is produced. Under controlled conditions, biogas can be produced from human, animal or vegetable waste. The scale of biogas plants can vary from small household systems up to large commercial plants of several thousand

<sup>88</sup> The Schumacher Centre for Technology & Development, Recycling organic wastes, technical brief, page 3



cubic meters. For the Suriname-Brazil border region the small scale household biogas system is further analyzed.

#### **4.4.1 Bio-energy in Kwamalasamutu**

The village of Kwamalasamutu has about 200 to 220 households existing of 4 to 5 persons that do not have any sanitary facilities. The local people (about 1,200 people) are used to using the river to bathe, wash clothes, or for their sanitary needs. At the same time the people throw away their food or other small household wastes in the river and clean the dishes at the same river side. Since these river sides are used intensively, they form areas where there is a great health risk, due to water pollution. Also over the years the river water and soil will become more polluted with nutrients that may cause water ecology changes (for example, eutrophication) and that certain water plants or organisms may disappear, which may cause shifts in the food chain of fishes and can lead to decreasing quantities.

By looking at the composting and in particular the bio digestion of human, animal and food waste produced in Kwamalasamutu many of the above named problems can comprehensively be resolved. The digestion of organic waste yields several benefits as the production of methane (biogas) for use as fuel, the waste is reduced to slurry which has a high nutrient content which makes it suitable to use as fertilizer and during the digestion process pathogens in the manure are killed, which forms a great solution to health risks.

In many other isolated areas in countries as China and India, decades of experience has been built up in processing biodegradable wastes at the household level into biogas, converting enough biogas for all the primary energy needs in a household<sup>89</sup>. The by-product is used on agricultural lands as fertilizer to increase crop yields.

#### **Bio digestion designs**

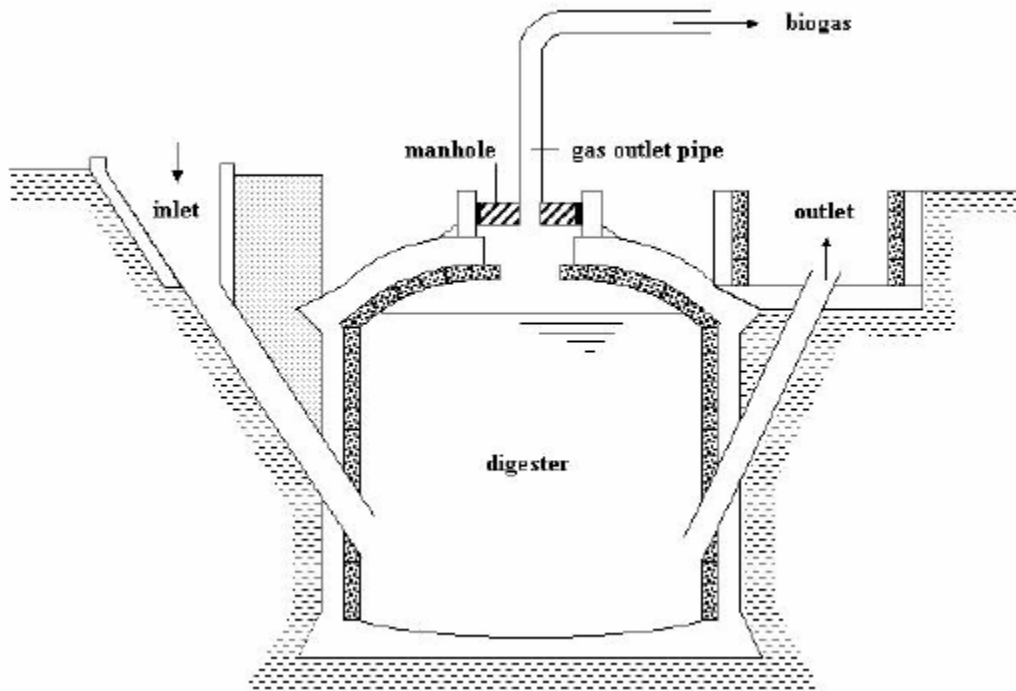
Anaerobic bio digestion is the most common process for converting wet biomass into biogas. Since various chemical and microbiological reactions take place in a bio digester, it is also known as bio-reactor or anaerobic reactor. The main function of this structure is to provide anaerobic conditions (oxygen free environment) within it. As a chamber, it should be air and water tight. The designs for rural and small scale use can be made of various construction materials and in different shape and size. See figures 4.6 to 4.8 for layout of current available bio-digestion designs for rural use. All these designs are dimensioned in the size to convert human and animal waste of one household and to deliver the energy demand of this household for cooking and lighting.

Figure 4.6 shows the Chinese fixed dome digester. The average volume capacity of the digester is 5-10 m<sup>3</sup> and delivers about 0.5 m<sup>3</sup> per digester volume<sup>90</sup>, depending on the feedstock input. The design can be constructed using local available materials as clay or bricks.

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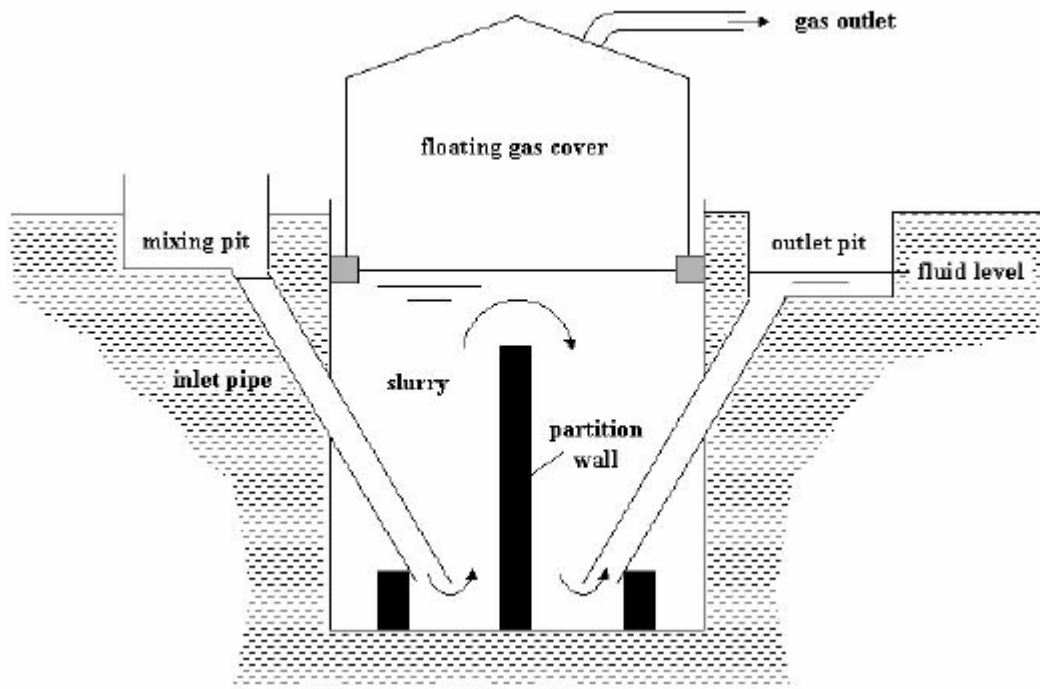
<sup>89</sup> Source : <http://www.cityfarmer.org/biogasPaul.html>

<sup>90</sup> Plochl, M. and Heiermann, M., Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?, Leibniz Institute of Agricultural Engineering Potsdam-Bornim, Germany, March 2006.



**Figure 4.6 The Chinese fixed dome digester**

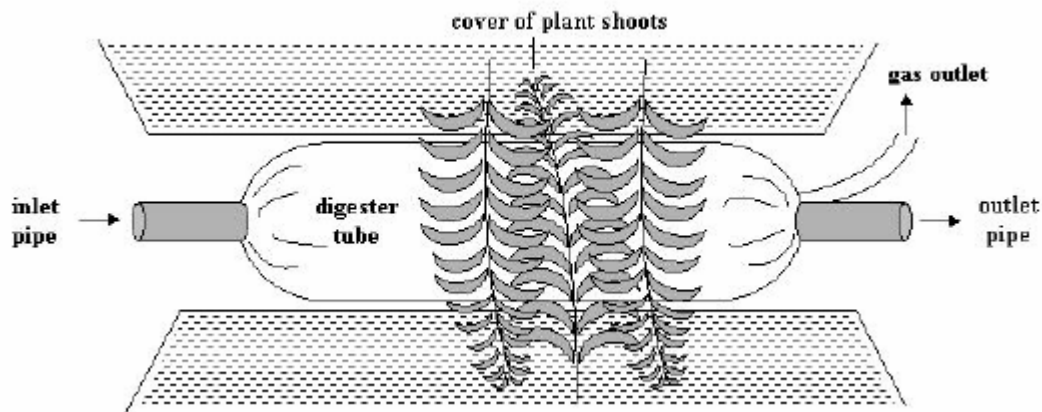
On figure 4.7 the layout of the Indian floating drum digester is shown. This digester is constructed with concrete and steel.



**Figure 4.7 The Indian floating drum digester**

Figure 4.8 shows the layout of the tube digester. This digester is constructed with folded polyethylene foils and porcelain pipe as inlet and outlet. The tube is usually covered with

plant shoots like palm leaves or banana leaves to prevent destruction of the foil and create a greenhouse effect. The tube design is also relative easy to install and available in different sizes.



**Figure 4.8 The tube digester**

The three designs have basically the same working principal. The feedstock enters through the inlet pipe either directly or after a mixing pit the digester tank. This is either a one-compartment tank or a two-compartment one where the substrate has an average retention time of 10 to 30 days. The gas is collected above the slurry and leaves the tank through a gas pipe in the top of the cover. The digested slurry leaves the digester through an outlet pipe and is collected in an outlet pit or a displacement tank. This can be used as fertilizer on agricultural lands.

The main difference between the Chinese fixed dome design and the Indian floating drum design is that in the case of the Indian design a constant biogas output pressure can be created. This is because the floating gas cover moves vertically depending on the gas accumulation. The weight of the cover influences the pressure. While in the case of the Chinese design the top of the digester is made of the same material as the rest of the digester.

The digesters do not have facilities for controlling or maintaining a constant temperature and also do not have facilities to remove sand or other inert materials, which will, over the years, decrease the volume capacity of the digester and also its conversion efficiency. Also in general there is a limited storage capacity, thus gas exceeding the demand needs to be released from the digester and the efficiency of the gas stoves or equipments are low due to the low pressure of the gas (except for the Indian design). But on the other hand, the digesters, in particular the tube digester, have the advantages that they can be inexpensive compared to high-tech designs, the tube materials can easily be handled and transported and do not contain moving parts prone to failure and that require maintenance, also since the feedstock is locally available it decreases the dependancy on importing of energy sources as diesel. Alternatively the produced biogas can be compressed and stored in gas bottles to distribute among the village. Please note that this is just a theoretical approach, more specific data and assessment studies need to be performed.

Since the transportation to Kwamalasamutu is a major constrain, and the operation of the bio-digester should be simple and local materials can be used, the tube digester seems to be an interesting alternative for the village.

## Biomass feedstock

Any biodegradable organic material can be used as inputs for processing inside the bio digester. However, for economic and technical reasons, some materials are more preferred as inputs than others. If the inputs are costly or have to be purchased, then the economic benefits of outputs such as gas and slurry will become low. That is why one of the primary criteria for the feasibility of the biogas technology is the availability of abundant and freely organic waste to generate biogas out.

Assuming the households in Kwamalasamutu exist of 4-5 people per household and we only look at the use of toilet waste. From general values we can assume that the human waste (urine, feces and toilet water) production per day is 2.17 kg/person-day<sup>91</sup>. Table 4.5 shows the biogas production potential from human dung, which is between 0.020 – 0.028 m<sup>3</sup>/kg human dung or toilet waste.

**Table 4.5 Biogas production potential of various types of dung<sup>92</sup>**

Types of Dung	C : N ratio <sup>93</sup>	Gas Production Per Kg Dung (m <sup>3</sup> )
Cattle (cows and buffaloes)	18	0.023 - 0.040
Pig	-	0.040 - 0.059
Poultry (Chickens)	7	0.065 - 0.116
Human	6 – 10	0.020 - 0.028

The potential biogas production for a 4 person household is between 0.17 – 0.24 m<sup>3</sup>/household-day while a household of 5 persons produces between 0.22 – 0.30 m<sup>3</sup>/household-day. Note that the conversion values used are general numbers that vary per average ambient temperature, diet and food consumption of family, and digestion design used. Taking in mind that the yearly temperature in the Suriname-Brazil border region is fairly stable around 27 °C, and the range around 30 degrees is the optimal temperature range for bacterial activity, the anaerobic digestion process in Kwamalasamutu may have higher conversion efficiencies than in other regions.

## **Village level**

### *Electricity production from biogas*

There are about 210 – 250 houses in Kwamalasamutu the village the biogas production is between 36.5 m<sup>3</sup>/(210 x 4person)-day to 54.3 m<sup>3</sup>/(250 x 5 person)-day. Thus a total yearly production between 13,323 – 19,820 m<sup>3</sup> / year. Biogas contains typically between 60-70% methane<sup>94</sup> with a calorific value of 4MJ/m<sup>3</sup><sup>95</sup>. This means that a primary energy between 53.3 – 79.3 GJp is available for either as fuel for cooking or running in a small gas engine. By combusting the biogas in a gas engine with an electrical efficiency of 75% (70-80%)<sup>96</sup> an amount of 40.0 – 59.5 GJe is produced. This is equal to:

$$40.0 \text{ GJe} * 0.2778 \text{ MWh/GJ} * 0.8 \text{ (load factor)} = 8.9 \text{ MWh}$$

<sup>91</sup> Source: <http://oregonstate.edu/~atwaterj/fo.htm>

<sup>92</sup> Source : Update Guidebook on Biogas Development, 1984, extracted from, FAO website: <http://www.fao.org/sd/EGdirect/EGre0022.htm>

<sup>93</sup> The Schumacher Centre for Technology and Development, Recycling Organic Waste, UK

<sup>94</sup> CanREN, Natural Resources Canada, source: [http://www.canren.gc.ca/tech\\_appl/index.asp?CaID=2&PgId=1114](http://www.canren.gc.ca/tech_appl/index.asp?CaID=2&PgId=1114)

<sup>95</sup> HOMER biogas fuel properties (LHV = 5.5 MJ/kg with a density of 0.72 kg/m<sup>3</sup>, thus about 4 MJ/m<sup>3</sup>)

<sup>96</sup> U.S. Environmental Protection Agency (EPA), Catalogue of CHP Technologies, Technology Characterization: Gas Turbines, USA, 2002

$$(8.9 \text{ MWh} * 1000 \text{ kWh/MWh}) / (365 * 24\text{h}) = 1.02 \text{ kW}$$

$$59.5 \text{ GJ} * 0.2778 \text{ MWh/GJ} * 0.8 \text{ (load factor)} = 13.2 \text{ MWh}$$

$$(13.2 \text{ MWh} * 1000 \text{ kWh/MWh}) / (365 * 24\text{h}) = 1.51 \text{ kW}$$

Thus there is a potential of 1.02 – 1.51 kW if all the households in Kwamalasamutu have a toilet that is connected to a digestion plant. A problem is that many of the houses are randomly spread over the village which makes the feasibility to design a common digester with large capacity require extra infrastructural work for installing micro sewer systems, that will make the capital cost of the system increase.

Note that here the calculations are based on using only human waste from toilets, and that other sources as agricultural residues, food and animal waste are potentially available but their quantities are not analyzed in this study.

### **Household level**

A typical household in Kwamalasamutu is between 4-5 persons per house. As indicated before the bio waste production per person is about 2.17 kg/person-day. With a gas production potential between 0.020 – 0.028 m<sup>3</sup>/kg, the biogas production in a year will be:

$$4\text{persons} * 2.17 \text{ kg/person-day} * 0.020 \text{ m}^3/\text{kg} * 365 \text{ days/year} = 62.1 \text{ m}^3/\text{year}$$

$$5\text{persons} * 2.17 \text{ kg/person-day} * 0.028 \text{ m}^3/\text{kg} * 365 \text{ day/year} = 109.5 \text{ m}^3/\text{year}$$

Thus the biogas production will range between 62.1 – 109.5 m<sup>3</sup>/year.

### *Electricity production*

Knowing that the average heating value of biogas is about 4 MJ/m<sup>3</sup> and using a gas engine with a conversion efficiency of 75% and a load factor of 0.8, the total electricity production per year is:

$$62.1 \text{ m}^3/\text{year} * 4 \text{ MJ/m}^3 * 0.75 * 0.8 * 0.2778 \text{ kWh/MJ} = 41.4 \text{ kWh/year}$$

$$109.5 \text{ m}^3/\text{year} * 4 \text{ MJ/m}^3 * 0.75 * 0.8 * 0.2778 \text{ kWh/MJ} = 73.0 \text{ kWh/year}$$

The total electricity production per household per year may range between 41.4 – 73.0 kWh/year. From section 3.4.1., we know that the demand per household is 59.9 kWh/year for scenario K1, and 248.2 kWh/year for scenario K2. This means that theoretically only in the case of a 5 persons household and having an optimal gas conversion of 0.028 m<sup>3</sup>/kg, the biogas production may be sufficient to cover the electricity demand over a year. Note that generators are available till a certain minimal size that hampers the possibility of household level generation. Nevertheless in this study only human waste is considered in the calculations to project the minimal outcome, thus there is great potential in increase of biogas production when integrating agricultural and animal waste into the feedstock of a bio-digester.

### **Primary school in Kwamalasamutu**

One interesting option is the local school. This school has about 230 students and has currently two toilets installed. Using a bit more pessimistic value of 1.75 kg/person-day (since the toilets are only used for about 8 hours a day). The total biogas production can be:

$$230 \text{ students} * 1.75 \text{ kg/person-day} * 0.024 \text{ m}^3/\text{kg} = 9.66 \text{ m}^3/\text{day}$$

### *Electricity production*

$9.66 \text{ m}^3/\text{day} * 365 \text{ days/year} * 4 \text{ MJ/m}^3 * 0.75 \text{ (energy efficiency)} = 10.6 \text{ GJe/year}$   
 $10.6 \text{ GJe} * 0.2778 \text{ MWh/GJ} * 0.8 \text{ (load factor)} * 0.9 \text{ (distribution losses)} = 2.12 \text{ MWh/year}$   
(0.30kWp)

The school demands  $2.40 \text{ kWh/day} * 365 \text{ days/year} = 876 \text{ kWh/year}$

An average household (scenario 2) requires  $0.68 \text{ kWh/day} * 365 \text{ days/year} = 248 \text{ kWh/year}$

$$\frac{2120 \text{ kWh/year} - 876 \text{ kWh/year}}{248 \text{ kWh/year}} = 5.0 \text{ houses}$$

This means that there is potential to produce energy to supply the school and additional 5 houses with electricity for the whole year from biogas production using only human waste as input.

The challenge is to find commercially available micro gas engines (10-100 W)<sup>97</sup>. Unless the biomass feedstock is substantially increased the option of using biogas for electricity production in the case of Kwamalasamutu is very difficult.

### *Biogas as direct fuel*

The available biogas can be also used as fuel for biogas lamps for public lighting or communal cooking. A typical biogas lamp consumes about  $0.07 \text{ m}^3 \text{ gas per hour}$ <sup>98</sup>. Say you want to know how much biogas lamps you can light for 10 hours/day:

$$9.66 \text{ m}^3/\text{day} / (0.07 \text{ m}^3/\text{hour} * 10 \text{ hours/day}) = 13.8 \text{ lamps}$$

About 13 biogas lamps can be lighted for 10 hours a day. Since the village representatives indicated that public lighting is one of the priorities this could be an interesting alternative.

Note that there are many factors influencing the biogas production, these are the characteristics and in which quantity the feedstock is available, the digestion design (conversion efficiency and biogas capture capacity), the retention time, the climate conditions, the construction materials used and microbial conditions.

## **4.4.2 Bio-energy in the Suriname-Brazil border region**

For the Suriname-Brazil border region the same assumption as done for Kwamalasamutu can be used in other villages in the region. One important aspect to consider is the specific data related to bio-waste or organic materials or even crops that could be used to increase to bio-energy potential. The characteristics of each biomass source have to be determined more carefully to be able to assess the biogas production potential. One should also evaluate the best biomass-to-energy conversion routes, either by using the biogas as fuel in a gas engine to generate electricity or by using biogas directly for cooking or lighting.

## **4.5 Rational for pre-selecting Renewable Energy Alternatives**

Since the infrastructure for installing PV systems is available and experience has been build up during the years and other renewable energy alternatives as bio-digestion and micro-hydro power need further analysis, it is more likely that solar PV systems could be used as short term solution

<sup>97</sup> Source: <http://www.stormingmedia.us/44/4465/A446583.html>

<sup>98</sup> Source: <http://www.ias.unu.edu/proceedings/icibs/ic-mfa/karki/paper.html>

to electrify the households in Kwamalasamutu. This provides more time to make a better assessment for other identified renewable energy potentials in this report. These alternatives will certainly be required in the mid to long term perspective, since the electricity demand will increase steadily, either due to population growth, new economic activities or use of higher intensity appliances. Thus the future energy system does not have to exist of only autonomous Home PV systems, but one could think of creating a mini grid that is interconnected to either diesel, micro-hydro power or bio-energy systems.

### Electricity production systems

As electricity production systems, the solar PV, micro-hydro power and anaerobic digestion are pre-selected based on the available energy sources and the energy demand. See table 4.6 for more detail.

**Table 4.6 General overview of electricity production potential of pre-selected RETs**

Pre-selected Renewable Energy Technologies				
Year	Scenario 1: Energy demand (MWh/year)		Scenario 2: Energy demand (MWh/year)	
20	18.7		71.6	
Solar PV systems				
Rated capacity	55	Wp	220	Wp
Battery capacity	100	Ah	200	Ah
Energy demand per household	164	Wh/day	680	Wh/day
Required PV arrays (period 0-20 yrs)	298 x 0.055 kWp = 16.4 kW		285 x 0.220 kWp = 62.7 kW	
Micro Hydro Power systems				
Bush Papaja	21 – 28	kW	147 – 196	MWh/year
Sir. W. Raleigh	177 – 235	kW	1240 – 1647	MWh/year
Karina Ituru	39 – 52	kW	273 – 364	MWh/year
Anaerobic Digestion systems				
Village size	1.02 – 1.51	kW	8.9 – 13.2	MWh/year
Primary school	0.30	kW	0.25	MWh/year

- Solar PV systems could supply the whole electricity demand over 20 years if dimensioned and planned correctly. For the solar PV alternative a total of 16.5 kWp PV capacity (298 x 55 Wp) is required to cover the energy demand over 20 years for the case of scenario K1. In scenario K2 the required rated PV installed capacity is about 62.8 kWp (285 x 220 Wp).
- The wind speeds measured in and around the area of Kwamalasamutu or the Suriname-Brazil border region are on average not enough to make a wind system technically viable. On anemometer height the wind speed levels are between 1.80 – 1.91 m/s while the minimal wind speed requirement is 3-4 m/s or higher.
- The potential production capacity of mini-hydro power investigated at sites around Kwamalasamutu could cover the whole village demand over 20 years. In the case of the smallest micro-hydro power production capacity, Bush Papaja, 141 – 188 MWh/year could be delivered to Kwamalasamutu and is more than enough to supply the village demand of 71.6 MWh/year (in 20 years). But feasibility of these projects depends on the physical restrictions in the rough and pristine natural area to install transmission lines and mini-grid.
- The total potential capacity of bio-digestion (using only human waste) to produce electricity via (bio)gas engines is between 8.9 - 13.2 MWh/year, this is not enough to

cover the total village demand of 18.7 MWh/year (scenario 1). But when incorporating other bio waste sources as feedstock this production potential could vastly increase. Also bio-digestion could be considered on smaller/medium scale, as in the example of the primary school where it may become technically feasible. The option to use the produced biogas directly as fuel for cooking or lighting seems to be more interesting since this prevents losses due to an extra conversion step and prevents use of kerosene and firewood.

### **Fuel production systems**

- As general recommendations, the total biogas production capacity from central households (as in the case of the primary school), could be an interesting option to prevent firewood use or kerosene for cooking or public lighting.
- Solar cooking/ovens, could mitigate the amount of firewood or kerosene use at the households in Kwamalasamutu.

The further economical analysis focuses only on the pre-selected electricity production systems.



## 5. Economical assessment

This chapter deals with the general turnkey costs of possible options to energy saving or production in a Kwamalasamutu and the Suriname-Brazil border region. Based on the gathered data in the previous chapters alternative energy production systems are proposed and discussed as part of the sustainable energy development for the Suriname-Brazil border region. The first sections are specifically focused on Kwamalasamutu and the remaining sections of the chapter renewable energy alternatives for the Suriname-Brazil border region are discussed.

### 5.1 Global investment cost of Renewable Energy Technologies<sup>99</sup>

In this study we limit ourselves to the global Renewable Energy Technology (RET) price developments, because as a region part of countries located in Latin America you are dependent on the global availability of the RETs and the global market price development. Also a detailed techno-economic analysis is out of the time and scope of this study.

To be able to calculate the possible future prices of each RET, the current global prices of the renewable technologies are required. From a World Energy Assessment report, data was collected on the turnkey investment costs per installed capacity (US\$/kW) for each RET in the year 1998. The turnkey investment cost is the investment cost related to the preparation, purchase and installation of a total functioning system. Thus in the case of a PV system, this turnkey investment cost covers the PV arrays, the converter, batteries and wiring. See table 5.1.

**Table 5.1 Range of current costs ('98 US Dollars) of renewable electricity production according to the World Energy Assessment, and the arithmetic average used as default in this study (WEA<sup>100</sup>)**

Renewable electricity source	Turnkey Investment Cost <sup>101</sup> (US\$/kW)	Default value use in this analysis (arithmetic average) (US\$/kW)	Operating capacity, end 1998 (GWe)
Large hydropower	1,000 – 3,500	2,250	640
Small hydropower	1,200 – 3,000	2,100	23
Biomass	900 – 3,000	1,950	40
Wind	1,100 – 1,700	1,400	10
Solar Photovoltaic	5,000 – 10,000	7,500	0.5
Geothermal	800 – 3,000	1,900	8
Solar thermal <sup>102</sup>	3,000 – 4,000	3,500	0.4
Marine	1,500 – 3,000	2,250	0.3

For this study an assumption is made to consider the default values in the third column as starting point for the analysis in 2001 (see table 5.2)

<sup>99</sup> Extracted from: de Cuba, K.H., Towards a Sustainable Energy Plan for St. Kitts & Nevis, OAS/UU, 2006

<sup>100</sup> World Energy Assessment, UNDP/UNDESA/WEC, United Nations Development Programme, New York, 2000 (Chapter 7), see: <http://www.undp.org/seed/eap/activities/wea/drafts-frame.html>

<sup>101</sup> Turnkey Investment Costs means the total capital cost for preparation, purchase and installation of the power system

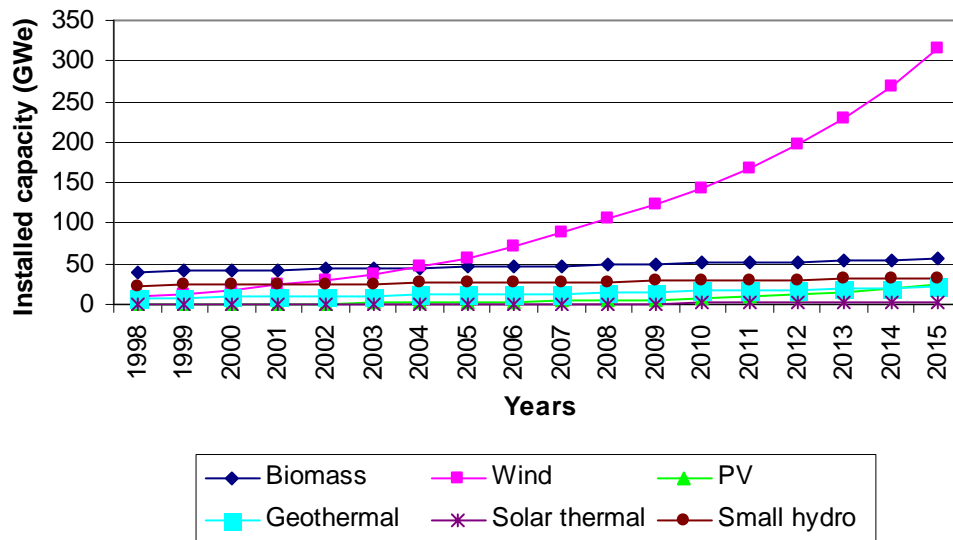
<sup>102</sup> This is Solar Thermal technology for electricity production, low-temperature solar water heaters are in the range of 500 – 1,700 US\$/kW.

The European Renewable Energy Council (EREC)<sup>103</sup> has published a document containing projections of renewable energy technologies development up until the year 2040. They give an overview of possible annual growth rates in energy supply for each RET until 2040. See table 6.8.

**Table 5.2 Annual growth rates for the electricity production by source. The growth rates from 1996 – 2040 are taken from the DCP<sup>104</sup> EREC scenario (adapted from EREC)**

Period	Large Hydro	Small Hydro	Biomass	Wind	PV	Geo thermal	Solar Thermal	Solar Thermal Electricity	Marine (tidal/wave /ocean)
1996-2001	2%	6%	2%	33%	25%	6%	10%	2%	0%
2001-2010	1%	8%	2%	25%	25%	6%	12%	16%	8%
2010-2020	1%	8%	2.50%	17%	27%	6%	14%	18%	15%
2020-2030	1%	6%	3%	9%	22%	4%	12%	16%	18%
2030-2040	0%	4%	2.50%	4%	15%	3%	8%	13%	16%

Figure 5.1 shows the electricity production development using the annual growth rates given in table 5.2. As initial starting point the global operating capacity (GWe) shown in table 5.1 is used.



**Figure 5.1 Production of global renewable electricity by source in GWe in the DCP/EREC scenario (adapted from EREC)**

Now we know the possible development of electricity production by the selected RETs (biomass, wind, geothermal, PV) for this study. Solar thermal is projected along since there is interest in the Caribbean for this technology.

To continue this price development analysis in a correct way, we have to take in mind that we are dealing with two different sets of information and thus will have to combine them in order to know the investment cost reduction per year. Another important factor that has to be taken in mind is the technological energy conversion efficiency improvement of RETs.

<sup>103</sup> Source: [http://www.erec-renewables.org/documents/targets\\_2040/EREC\\_Scenario%202040.pdf](http://www.erec-renewables.org/documents/targets_2040/EREC_Scenario%202040.pdf)

<sup>104</sup> Dynamic Current Policy (DCP) scenario. This scenario can be considered as intermediate and is based on less international co-operation than the Advanced International Policy (AIP) scenario, see EREC.

Graph 5.1 plots the global electricity production in GWe against time in years. By using the experience curve theory it will be possible to calculate the investment costs development per year. The theory is based on the reduction of the global production cost in this case (US\$/kW) against the doubling in growth in electricity production in GWe. See below for a brief description of the experience curve theory.

### The experience curve theory

$$C_{Cum} = C_0 * Cum^b \quad (5.1)$$

$$\log C_{Cum} = \log C_0 + b * \log Cum \quad (5.2)$$

$$PR = 2^b \quad (5.3)$$

With

- $C_{Cum}$  = Cost per unit
- Cum = Cumulative (unit) production
- PR = Progress Ratio
- $C_0$  = Cost of the first unit produced
- b = Experience index

The unit Cum in this context, means the energy operating capacity of a PV panel, wind turbine, etc. The progress ratio (PR) is a parameter that expresses the rate at which costs decline each time the cumulative production doubles. For example, a progress ratio of 0.8 (80%) equals a learning rate of 0.2 (20%) and thus a 20% costs reduction for each doubling of the cumulative capacity.

In this study, as progress ratios (PR) we use 90% for wind energy and 80% for solar photovoltaic. These data are derived from Neij<sup>105</sup>. For the rest of the RETs progress ratio of 80% will be used, this is the general accepted PR for RETs<sup>106</sup>.

**Table 5.3 Overview of input data for the calculation of the experience curves**

RET	PR	b	Ccum (US\$ <sub>2005</sub> /kW) <sub>107</sub>	Cum (GW)	Co
Biomass	0,80	-0,32	2415	40	7918
Wind	0,90	-0,15	1734	10	2460
PV	0,80	-0,32	9287	0,5	7430
Solar thermal	0,80	-0,32	4334	0,4	3227
Small hydro	0,80	-0,32	2600	23	7135

In table 5.3 the input data for the calculation of future investment costs are shown. On the hand of the parameters Ccum and Cum that are known from the table 5.1 and figure 5.1, the constant Co

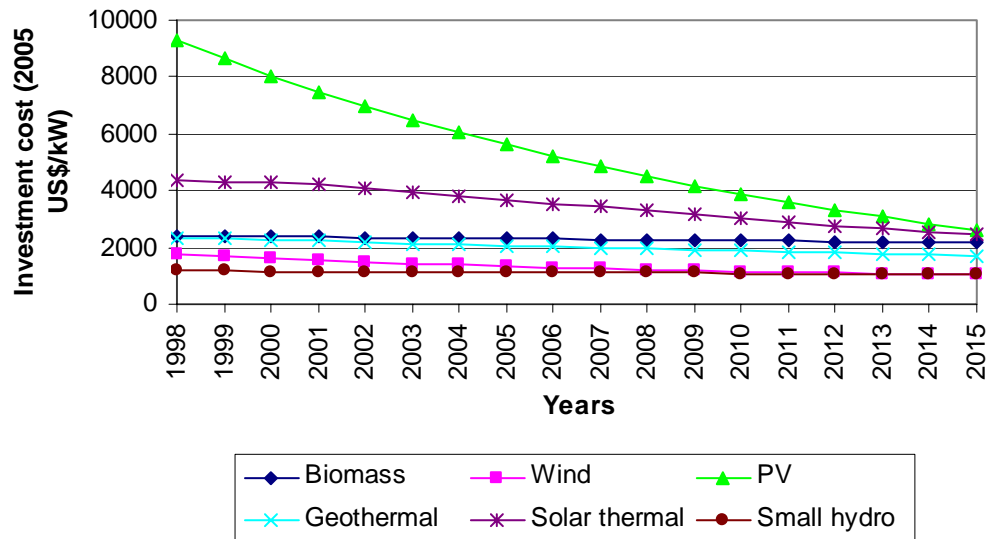
<sup>105</sup> In her thesis, Lena Neij found a progress ratio for wind energy in the following ranges 0.89 – 0.98 and 0.88 – 0.91 (Table 4.3). This percentage is the progress ratio for the costs per kWh, i.e. it takes all factors that lead to cost reduction into account, including higher capacity factors and lower O&M costs. For photovoltaic solar she found progress ratio of 0.79 – 0.82. See L. Neij, Dynamics of Energy Systems, Ph.D. Thesis, Lund University, 1999.

<sup>106</sup> Experience Curves for Energy Technology Policy, International Energy Agency, Paris, 2000. See: <http://www.iea.org/textbase/nppdf/free/2000/curve2000.pdf>

<sup>107</sup> This is calculated as follows: US\$<sub>1998</sub> value \* (1+0.03)<sup>^(2005-1998)</sup>

can be calculated. Since the values in table 5.1 are shown in US\$<sub>1998</sub> this is corrected for inflation by using an average inflation rate of 3% for OECD<sup>108</sup>.

By filling in the growth development of the energy supply of each RET from figure 5.1 in formula 2 we can calculate the decrease in investment costs per year. See figure 5.2 for the results.



**Figure 5.2 Investment cost development of RETs in the period 1998-2015**

From figure 5.2 the turnkey investment cost per each renewable energy technology can be determined. Table 5.4 gives an overview of these costs for the year 2006. Note that in this study we limit ourselves to general global market prices.

**Table 5.4 Global turnkey investment costs for general RETs in year 2006**

	Investment cost (US\$(2005)/kWp) Year 2006	Investment cost (US\$(2005)/Wp) Year 2006
Biomass	2295	2.30
PV	5227	5.23
Solar thermal	3543	3.54
Small hydro	1117	1.12

The global turnkey investment costs provided in table 5.4 are very rough estimated costs. This is because the investment cost on the one hand depends on the unit or system capacity size. On the other hand some categories, as the biomass category, include a large variety of sub-technologies that are based on thermal or biochemical processes and therefore require different sets of equipment or designs. Nevertheless these investment costs will be used as reference point in case no other specific investment cost data is found related to small scale hydro power, anaerobic digestion or PV systems.

#### Small anaerobic digester investments

For the biomass category the turnkey investment cost is about 2295 US\$/kW, it is more difficult to assess the investment cost for the Anaerobic Digestion (AD) compared to the PV category. Not

<sup>108</sup>Ciccarelli, M. and Mojon, B., Global Inflation, European Central Bank, Working Paper Series no 537, October 2005

only the investment costs varies by capacity size, also, in the case of the biomass category, it includes a large variety of conversion technologies, as digestion, combustion, gasification or composting that are either based on thermal or biochemical processes that require different sets of equipments or designs. From literature a turnkey investment cost ranging 641 – 1281 US\$/plant<sup>109</sup> for Chinese or Indian type bio digester and 38 – 64 US\$/plant tube digester with capacity varying between 5 – 10 m<sup>3</sup> is provided. An AD plus 75 kW generator set requires an investment cost of about 5000 US\$/kW<sup>110</sup>. When including a generator set the investment cost increases considerably, this is because there is an extra conversion step which lowers the overall system energetic efficiency and the generator may be used on low loads since the biogas production tends to be smaller in relation to the generator capacity size. The average investment cost value for the Chinese and Indian design only producing biogas is about **961 US\$/plant** or 120 US\$/m<sup>3</sup>. And for the tube design the average investment cost is about **51 US\$/plant** or 6.38 US\$/m<sup>3</sup>.

#### *Small Gas engine investments*

In the case one analyzes the electricity production via biogas combustion a quick scan is done on the investment costs for small gas engines.

**Table 5.6 Investment costs of Small Gas engines (2.9 – 4.3 kWp)**

Gas generator	Capacity (Wp)	Investment cost (US\$/Wp)
DeWalt	2900	0.62 <sup>111</sup>
DeWalt	4300	0.61

For gas engines ranging between 2.9 – 4.3 kWp the investment cost ranges are 610 – 620 US\$/kW. The option of using the biogas as fuel for small gas engines should only be considered on medium or village level size biogas digestion units. Since we do not have information on this matter, an investment cost of 3650 US\$/kW or **3.65 US\$/W** (average of 2295 – 5000 US\$/kW) is used in the further analysis.

#### PV investments

The investment cost for PV systems is around 5227 US\$/kW. Since we are dealing with small capacities, as in the case of solar PV in rated Wp. The turnkey investment cost for PV will be around 5.23 US\$/Wp, thus to install a 55Wp PV system with its BOS, the investment cost will be US\$<sub>2005</sub> 287.7 per system. Note that this number is based on the average of an initial investment cost range between 5,000 – 10,000 US\$/kW in 1998, see table 5.1.

To double check this price range, the literature shows that the investment costs range between 3.50 US\$/Wp<sup>112</sup> (2004) – 5.0 US\$/Wp<sup>113</sup> (2000) for a PV module. In a report from 1993 related to the energy sector of Suriname<sup>114</sup>, a total investment cost of US\$<sub>1993</sub> 811.7 per 40Wp PV system was calculated. With a correction to US\$<sub>2005</sub> this amounts to US\$ 1157.3 per system<sup>115</sup>, thus 28.9 US\$/Wp (1993). This investment cost seems very high, but is already over 12 years old and includes all the extra fuel and travel costs from Paramaribo to Kwamalasamutu. In this study the mean of the cost range 3.5 – 5.0 US\$/Wp is used, these data are already 2 to 6 years old, thus an

<sup>109</sup> Plöchl, M. and Heiermann, M., Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?, Leibniz Institute of Agricultural Engineering Potsdam-Bornim, Germany, 2006, page 13

<sup>110</sup> Source: [www.state.co.us/oemc/programs/agriculture/hog\\_wastes/fact\\_sheet.pdf](http://www.state.co.us/oemc/programs/agriculture/hog_wastes/fact_sheet.pdf)

<sup>111</sup> Source: <http://www.tylertool.com/generator2.html>

<sup>112</sup> Schmid et al., Replacing diesel by solar in the Amazon: short-term economic feasibility of PV-diesel hybrid systems, Ministry of Mining & Energy, Brazil, 2004

<sup>113</sup> Omer, A.M., Solar waterpumping clean water for Sudan rural areas, NCMWE, Sudan, 2000, page 250

<sup>114</sup> Jansen, J. and de Castro, J.F.M., “Alternatieve Elektriciteitsvoorziening in het binnenland van Suriname”, ECN and CCE, 1993

<sup>115</sup> Calculated as follows: US\$<sub>1993</sub> value \* (1+0.03)<sup>(2005-1993)</sup>

assumption is made that the minimal investment costs of PV arrays and inverter is about **4.25 US\$/Wp**.

#### Small/Micro Hydro Power investments

The current global turnkey investment cost for small hydro power systems (1001 – 6000 kWp) is about 1117 US\$/kW. An investment cost range of 2000 – 5000 US\$/kW for Micro Hydro Power systems (101 – 1000 kW) with production capacity ranging 10 – 35 kW is mentioned in the Suriname Master Energy Plan (2000). Also an investment cost between 1538 – 4485 US\$/kW<sup>116</sup> is found with average installed capacity of 700 kW for each SHP plant.

We know from table 4.4 that the potential power capacity can be between 21 – 235 kW. This falls under Micro Hydro Power systems. In 2000 we know that the investment costs were between 2000 – 5000 US\$/kW. This means that after 6 years the costs have decreased. Thus an assumption is made that the current costs are about 3000 US\$/kWp or **3.0 US\$/Wp**.

## **5.2 Investment costs of Small Diesel generators**

An inventory is made of investment costs of small portable diesel generators ranging between 1,000 – 12,500 Wp. The sources vary from US based market prices to prices of generators sold in UK. One can note that the Honda EU series that are available on the UK market are more expensive than the other generators that are sold on the US market.

**Table 5.5 Investment costs of Small Diesel generators (1.0 – 50 kWp)**

Diesel generator	Capacity (kWp)	Investment cost (US\$/Wp)	Year
Honda EU10i	1.0	1.13 <sup>117</sup>	2006
Pramac EG 2800	2.8	0.19 <sup>118</sup>	2006
Pramac ES 3000	3.0	0.25 <sup>119</sup>	2006
Baldor DG3E	3.0	0.78 <sup>120</sup>	2006
Honda EU20i	3.0	1.19 <sup>121</sup>	2006
Not known	3.0	1.09 <sup>122</sup>	2000
„	5.0 – 12.5	0.52 <sup>123</sup>	2004
„	12.5 - 25	0.42 <sup>123</sup>	2004
„	25 - 50	0.33 <sup>109</sup>	2004
„	50 - 100	0.24 <sup>109</sup>	2004

In the further economical analysis it is chosen to use the average of the values ranging between 1000 – 3000 Wp for the techno-economic analysis on household level, thus investment costs between 0.19 – 1.19 US\$/Wp, resulting in **US\$0.77/Wp**.

See table 5.6 for an overview of the costs for varying battery capacities and types.

<sup>116</sup> Source: <http://www.esha.be/index.php?id=50>

<sup>117</sup> Source: [http://www.dieselgenerators.com/honda\\_eu.htm](http://www.dieselgenerators.com/honda_eu.htm)

<sup>118</sup> Source: <http://www.southwestfastener.com/productsPramac.htm>

<sup>119</sup> Source: <http://www.southwestfastener.com/linkPM-ES3000.htm>

<sup>120</sup> Source: [http://www.power-generators.net/portable\\_diesel1.htm](http://www.power-generators.net/portable_diesel1.htm)

<sup>121</sup> Source: [http://www.dieselgenerators.com/honda\\_eu.htm](http://www.dieselgenerators.com/honda_eu.htm)

<sup>122</sup> Suriname Master Energy Plan, (2000), table 8.1.2

<sup>123</sup> Schmid, A.L. and Hoffmann, C.A.A., Replacing diesel by solar in the Amazon: short-term economic feasibility of PV-diesel hybrid systems, Ministry of Mining and Energy, Brazil, 2004

**Table 5.6 Costs of batteries (100 – 200 Ah/12V)**

Brand	Type	Capacity (12V)	Lifetime (years) <sup>124</sup>	Battery costs	
n.k.	Sealed	100 Ah	4-8	110	US\$/bat. <sup>125</sup>
n.k.	Sealed	100 Ah	4-8	180	US\$/bat. <sup>126</sup>
Union	Sealed	100 Ah	4-8	150	US\$/bat. <sup>127</sup>
Gel Tech	Deep cycle	98 Ah	5-10	355	US\$/bat. <sup>128</sup>
Gel Tech	Deep cycle	108 Ah	5-10	395	US\$/bat. <sup>129</sup>
Concorde	Deep cycle	96 Ah	5-10	345	US\$/bat. <sup>130</sup>
AGM	Deep cycle	200 Ah	5-10	200	US\$/bat.
Toyo	Sealed	200 Ah	4-8	230	US\$/bat. <sup>131</sup>
Lifeline	Sealed	210 Ah	4-8	350	US\$/bat.

There is a large variety of batteries available on the market. The types range from lead acid based automotive batteries, sealed, stationary or solar deep cycle to Ni-Cd based sealed and unsealed batteries. The sealed batteries have longer lifetime than automotive batteries but less than deep cycle batteries, also they can only be discharged up to 20%. The deep cycle batteries have lifetime between 6-7 years thus do not need to be replaced as frequently as the sealed types and can be discharged up to 40%. The cost of deep cycle batteries is also larger than the sealed batteries. The prices decrease by increasing battery capacity. For the analysis the sealed types are considered with a lifetime of 6 years to create the least profitable conditions. This means for 100 Ah (147 US\$/battery) and for 200 Ah (282 US\$/battery).

### 5.3 Comparative economical analysis

In this section several possible systems are compared to each other based on their techno-economic performance. An analysis is made on household level and on village level. Also a sensitivity analysis is performed to identify the parameters with the highest influence on the cost of electricity production and that will need to be verified or assessed to more detail.

#### 5.3.1 Decentralized (Household level)

On household level the solar home PV system is compared with a diesel system. The bio digestion option is not included because electricity production via combustion of biogas on household level requires minimally the optimal conditions of feedstock also the power capacity of gas engines is difficult to match to the available biogas in one household, see section 4.1.1. As starting point of the economical analysis the energy demand per scenario is used to determine the capacity size required of each electricity production system. As reference or energy production target, the household electricity demand of 59.7 kWh/year (after 20 years) in scenario K1 is used, for scenario K2 the electricity demand is 248.2 kWh/year (after 20 years).

<sup>124</sup> Knowledge and Information centre, The Schumacher Centre for Technology and Development, Batteries, UK

<sup>125</sup> Source: [http://www.batterymart.com/battery\\_mv?p=SLA-12V100](http://www.batterymart.com/battery_mv?p=SLA-12V100)

<sup>126</sup> Source: [http://www.lowcostbatteries.com/product\\_p/12V-100-AH.htm](http://www.lowcostbatteries.com/product_p/12V-100-AH.htm)

<sup>127</sup> Source: <http://shopping.microbattery.com/s.nl/sc.2/category.622/it.A/id.5339/f>

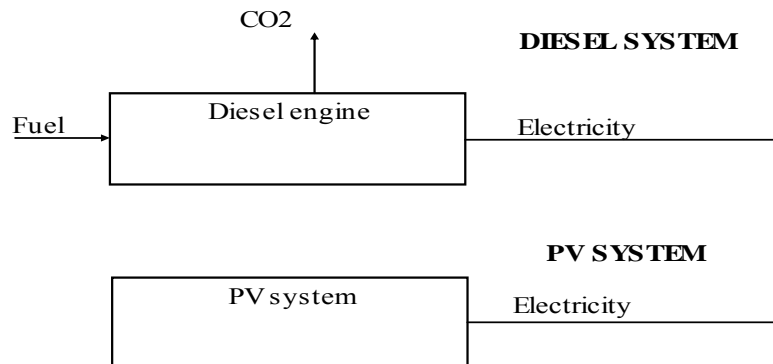
<sup>128</sup> Source: [http://www.solaronline.com.au/cgi/index.cgi/shopfront/view\\_product\\_details?category\\_id=1107143916&product\\_id=1107358641](http://www.solaronline.com.au/cgi/index.cgi/shopfront/view_product_details?category_id=1107143916&product_id=1107358641)

<sup>129</sup> Source: [http://www.solaronline.com.au/cgi/index.cgi/shopfront/view\\_product\\_details?category\\_id=1107143916&product\\_id=1107358642](http://www.solaronline.com.au/cgi/index.cgi/shopfront/view_product_details?category_id=1107143916&product_id=1107358642)

<sup>130</sup> Source: [http://www.solaronline.com.au/cgi/index.cgi/shopfront/view\\_product\\_details?category\\_id=1107143916&product\\_id=1107358633](http://www.solaronline.com.au/cgi/index.cgi/shopfront/view_product_details?category_id=1107143916&product_id=1107358633)

<sup>131</sup> Source: [http://www.sunelec.com/Distributors/\\_Batteries/body\\_batteries.html](http://www.sunelec.com/Distributors/_Batteries/body_batteries.html)

See figure 5.3 for a schematic overview of the diesel and PV options. The diesel system requires fuel to generate electricity. As environmental impact, CO<sub>2</sub> gas is emitted due to the combustion of diesel fuel. The solar PV converts sunlight directly into electricity and does not emit any global warming gasses.



**Figure 5.3 Schematic view of a small portable diesel and a Solar Home PV system**

In the case of diesel generation, the smallest size of a portable diesel is 1000 Wp. This means that there will be excess electricity produced, if only connected to one household. See tables 5.6 and 5.7 for an overview of input variables used to calculate the levelized electricity production cost of both systems.

**Table 5.6 Energy cost calculation factors: Household level Diesel system**

Parameter	Value (Scenario 1)	Value (Scenario 2)	Unit
Electrical demand	59.7	248.2	kWh/year
Unit capacity	1000	1000	Wp
Investment cost	0.77	0.77	US\$/Wp
Interest rate	0.1	0.1	
Load factor	0.17	0.17	
Energy efficiency	0.35	0.35	
Fuel type	Diesel	Diesel	
LHV fuel	36	36	MJ/L
Fuel price	2.91	2.91	US\$/L
Fuel cost	0.08	0.08	US\$/MJ
Fuel consumption	622	622	L/year
Emission factor	74.1	74.1	g CO <sub>2</sub> / MJ
Lifetime	5000	5000	hours
Daily use of diesel generator	5	5	hours/day
Lifetime under current use	2.74	2.74	years
Real use	1460	1460	hours/year
Typical use	8760	8760	hours/year
Ratio (real/typical)	0.17	0.17	hours/year
Investment	770	770	US\$
O&M costs <sup>132</sup>	30.8	30.8	US\$/year
Fuel costs	1213.9	1213.9	US\$/year
<b>Levelized cost of electricity</b>	<b>1.07</b>	<b>1.07</b>	<b>US\$/kWh</b>
Excess electricity	11921.5	10316.7	kWh
Loss value	10491 <sup>133</sup>	9079	US\$

<sup>132</sup> 4% of total investment cost of system

<sup>133</sup> multiplying by the LLC if diesel runned at 24h/day (0.88 US\$/kWh)

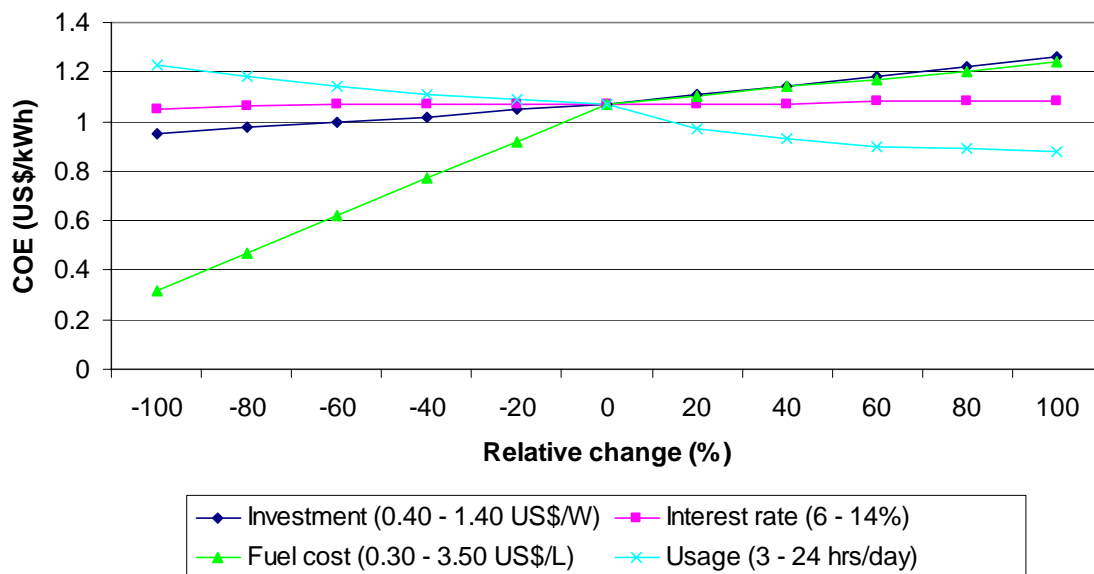


From table 5.6, one can see that the levelized cost of electricity is 1.07 US\$/kWh over a project lifetime of 20 years. This is very high, but not unrealistic. Another document related to the energy production in Brazilian parts of the Amazon, show electricity production costs 0.25 – 1.04 US\$/kWh<sup>134</sup>, for varying diesel capacities, where the smallest diesel units (5.0 kW) generate the highest electricity costs.

This high electricity prices is caused by the usage profile of the diesel generator, on average a household only uses the generator for 5 hours a day, this to save fuel. These 5 hours a day cause that the load factor decreases drastically. Thus much less electricity is produced, while the investment cost remains the same. With other words, the generator is not optimally used, first of all it does not operate 24 hours a day and the nominal capacity is larger than needed. This can be seen when comparing the excess electricity of both scenarios. There is about 13.5% less excess electricity in the case of scenario 2 compared to scenario 1. This is because the electricity demand is higher.

#### *Sensitivity portable diesel system*

Figure 5.4 shows the result of the sensitivity analysis for the 1 kW diesel system. One can see that the fuel cost and the usage (hrs/day) are important factors that influence the COE considerably.



**Figure 5.4 Results of sensitivity analysis for the 1 kW portable diesel system**

As conclusion, the nominal capacity of a small portable diesel generator will in most cases be much larger than the demand of an average household in Kwamalasamutu, whether you supply electricity for basic needs, or for premium needs. If the generator is run 24 hours per day, the electricity production may decrease to 0.88 US\$/kWh.

Table 5.7 shows the parameters used to calculate the levelized electricity cost for the PV systems. The nominal capacities in the calculations are extracted from table 4.1.

<sup>134</sup> Schmid, A.L. and Hoffmann, C.A.A., Replacing diesel by solar in the Amazon: short-term economic feasibility of PV-diesel hybrid systems, Ministry of Mining and Energy, Brazil, 2004

**Table 5.7 Energy cost calculation factors: Solar Home PV system**

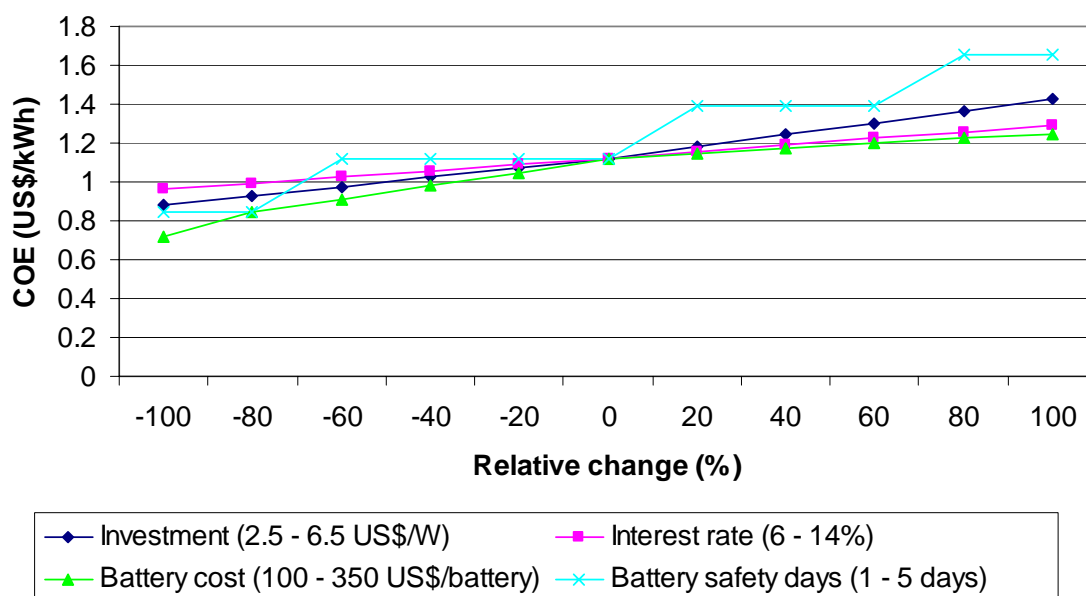
Parameter	Value (Scenario 1)	Value (Scenario 2)	Unit
Electrical demand	59.7	248	kWh/year
Unit capacity	55	220	Wp
Investment cost PV array + inverter	4.25	4.25	US\$/Wp
Lifetime PV array + inverter	20	20	years
Interest rate	0.1	0.1	
Battery capacity	100	200	Ah
Battery lifetime	6	6	years
Safety days (cloudy days)	2.5	2.5	days
Battery costs	147	282	US\$/battery
Batteries needed	1	2	#
Investment PV + inverter	234	935	US\$
Investment battery	147	564	US\$
O&M costs <sup>135</sup>	9	39	US\$/year
<b>Levelized cost of electricity</b>	<b>1.14</b>	<b>1.12</b>	<b>US\$/kWh</b>
Excess electricity	31.3	1650	kWh

In table 5.7 the levelized cost of electricity for scenario 1 is 1.14 US\$/kWh and for scenario 2, 0.12 US\$/kWh over a project lifetime of 20 years. These costs of electricity production are higher than the electricity costs of the diesel system.

Note that there are many factors that are uncertain in this analysis that may lead to this result. Important factors could be: 1. the investment cost of the PV array + inverter, note that this is 5.5x higher than the diesel system, and that the chosen investment cost is estimated, thus more detailed analysis is required to find the real investment costs of the PV arrays + inverter by taking in account geographical and logistical factors that play an important role in the case of Kwamalasamutu. 2. The diesel fuel price, this can be higher or lower and has to be analyzed into more detail to find the real local price of diesel. 3. Batteries type and size, in this analysis sealed batteries are used, while deep cycle batteries in general perform better, also the dimensioning of the battery is important since costs largely vary between 100 – 200 Ah batteries. 4. The interest rate is set on 10%, this factor in general also has large impact on the levelized cost of electricity.

#### *Sensitivity Solar Home PV system*

<sup>135</sup> 4% of total investment cost of system



**Figure 5.5 Results of sensitivity analysis for the Solar Home PV System (scenario K2)**

#### Summary of results at household level

See table 5.8 for a summary of the economical analysis at household level in Kwamalasamutu. In this analysis instead of looking at the electricity supply fraction, a focus is set on the value loss due to loss of excess electricity. In the case of the diesel system, since the smallest available capacity is 1000 W, there is always excess electricity produced and is lost money. By dimensioning the PV system adequately this loss of excess electricity value can be limited.

**Table 5.8 Summary of economical analysis result at household level in Kwamalasamutu**

Parameter	Value (Scenario 1)		Value (Scenario 2)		Unit
	PV system	Diesel system	PV system	Diesel system	
Electrical demand	59.7		248.2		kWh/year
Installed capacity	55	1000	220	1000	Wp
<b>Investment</b>	<b>381</b>	<b>770</b>	<b>1499</b>	<b>770</b>	<b>US\$</b>
O&M costs <sup>136</sup>	9	30.8	39	30.8	US\$/year
Fuel costs	-	1213.9	-	1213.9	US\$/year
<b>Levelized cost of electricity</b>	<b>1.14</b>	<b>1.07</b>	<b>1.12</b>	<b>1.07</b>	<b>US\$/kWh</b>
<b>Electricity supply fraction</b>	<b>&gt;100</b>	<b>&gt;100</b>	<b>&gt;100</b>	<b>&gt;100</b>	<b>%</b>
Excess electricity	31.3	11922	1650	10317	kWh
Loss value <sup>137</sup>	27.5	10491	1452	9079	US\$

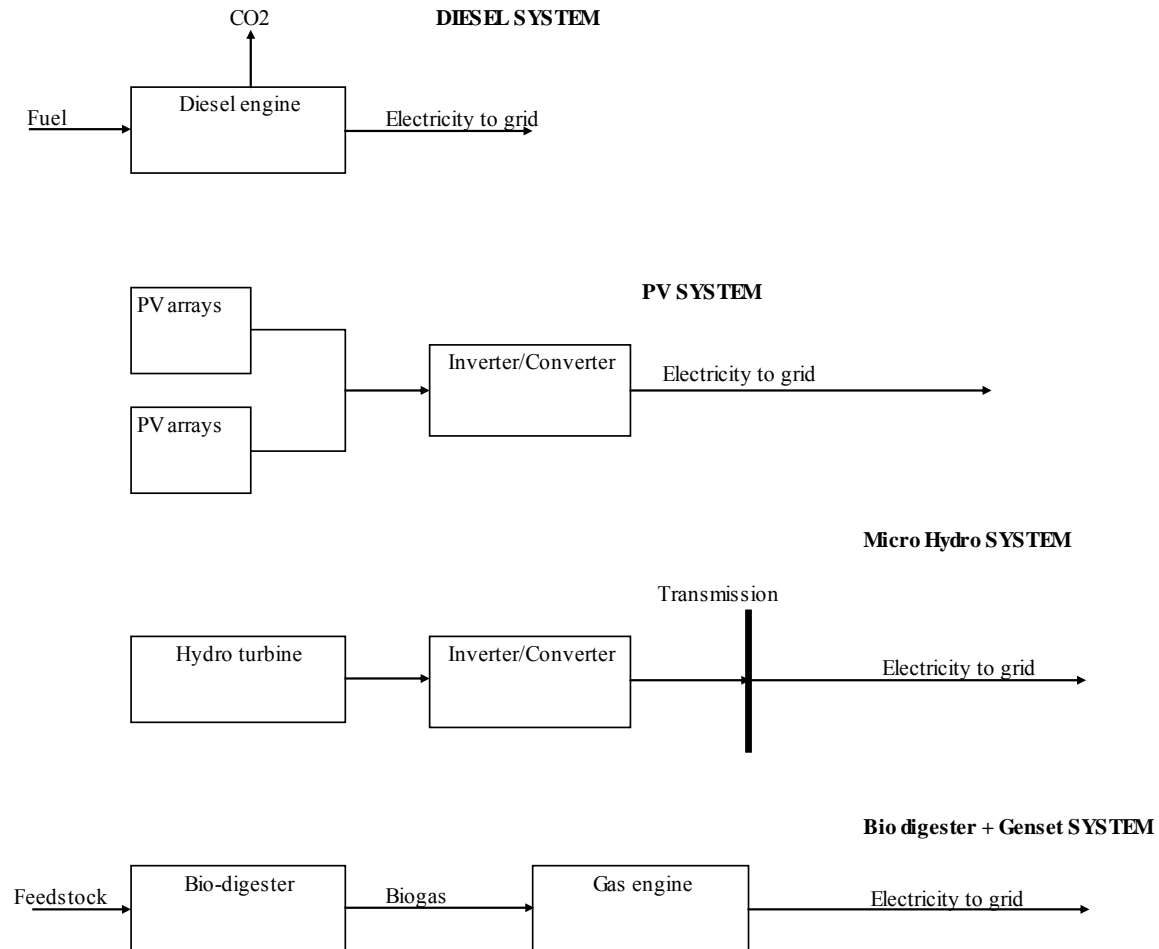
In section 5.3.3 a general sensitivity analysis is performed to determine the parameters that have the largest influence on the cost of electricity with this knowledge these factors can be recommended for more detailed research to assess the real costs for Kwamalasamutu.

<sup>136</sup> 4% of total investment cost of system

<sup>137</sup> multiplying by the LLC if diesel runned at 24h/day (0.88 US\$/kWh)

### 5.3.2 Centralized electricity production (Village / Medium size level)

On village level next to a PV and diesel system, the micro hydro power option and the bio digester system are included in the comparative techno-economic analysis. All the electricity production systems are grid connected, thus the electricity price delivered to the local grid in Kwamalasamutu is analyzed.



**Figure 5.4 Schematic overview of centralized electricity production systems for Kwamalasamutu**

In this case of centralized electricity production we have to specify each analysis separately. The grid connected PV systems are dimensioned to comply with the total electricity demand of Kwamalasamutu over a period of 20 years (in scenario 1 and 2), thereby comparing the systems on their nominal capacity to cover this demand. This means that all systems should produce the same amount of electricity per year.

For the micro hydro power systems, their total electricity production potential is compared to the same size diesel systems. Thus for the micro hydro power systems we consider the three locations that were identified in the resource assessment (section 4.3) and are compared to similar size diesel systems. Note that the locations are located outside Kwamalasamutu and require transmission infrastructure to supply the electricity to the village.

The bio digester to electricity production system is analyzed based on the smallest commercially available gas engine capacity. In this way it is possible to determine what the minimal daily biomass feedstock requirement is to run such a gas engine to produce reliable electricity.

In all the analysis a focus is set on the CO<sub>2</sub> mitigation when considering renewable options. The reason for this is that some of these renewable projects may fall under the Clean Development Mechanism (CDM) procedures as part of the Kyoto Protocol<sup>138</sup>, where CO<sub>2</sub> emission credits can be awarded to co-financers and carbon credits can be traded on the carbon market.

#### Grid connected PV compared to Diesel

In scenario 1 the demand in year 20 is 18.7 MWh/year and in scenario 2, 71.6 MWh/year. The diesel investment costs decreases by increase in size / capacity, when this capacity is between 5 – 100 kW.

**Table 5.8 Energy cost calculation factors: Diesel systems per scenario**

Diesel based			
Parameter	Value (Scenario 1)	Value (Scenario 2)	Unit
Electrical demand	18.7	71.6	MWh/year
Unit capacity	3.05	11.7	kW
Investment cost	0.77	0.52	US\$/W
Interest rate	0.1	0.1	
Load factor	0.70	0.70	
Energy efficiency	0.35	0.35	
Fuel type	diesel	diesel	
LHV fuel	36	36	MJ/L
Fuel price	2.91	2.91	US\$/L
Fuel cost	0.08	0.08	US\$/MJ
Fuel consumption	7965	30496	L/year
Emission factor	74.1	74.1	g CO <sub>2</sub> / MJ
Lifetime	12500	12500	hours
Daily use of diesel generator	24	24	hours/day
Investment	2348.2	6071.8	US\$
O&M costs	93.9	242.9	US\$/year
Fuel costs	15547.7	59530.3	US\$/year
Levelized cost of electricity	<b>0.911</b>	<b>0.885</b>	US\$/kWh
CO <sub>2</sub> emission	<b>121</b>	<b>465</b>	ton CO <sub>2</sub> / project

From table 5.8 one can see that the annual fuel costs form a large part of the annual costs of the diesel systems and cause the electricity cost to become high. Note that the fuel price can fluctuate and that the diesel system may result to become more or less expensive.

In table 5.9 an overview is shown of the parameters used to perform the economical analysis and the results for the grid connected PV systems. Note that no battery is included in this analysis.

<sup>138</sup> Source: <http://unfccc.int/2860.php>

**Table 5.9 Energy cost calculation factors: grid connected PV systems by scenario**

PV system			
Parameter	Value (Scenario K1)	Value (Scenario K2)	Unit
Electrical demand	18.7	71.6	MWh/year
Solar radiation	4.51	4.51	kWh/m <sup>2</sup> /day
Required PV capacity	16228	62136	Wp
Capacity PV array	220	220	Wp
Amount of PV arrays	74	282	#
Investment cost PV array <sup>139</sup>	4	3.5	US\$/Wp
Efficiency overall system	0.7	0.7	
Lifetime PV system	20	20	years
Required inverter capacity	2	9	kW
Investment cost inverter	650	650	US\$/kW
Interest rate	0.1	0.1	
O&M costs	0.04	0.04	of tot. investment
Investment PV	64913	217477	US\$
Investment inverter	1542	5903	US\$
O&M costs	2658	8699	US\$/year
Levelized cost of electricity	<b>0.560</b>	<b>0.488</b>	US\$/kWh
Carbon mitigation value	2142	8231	US\$

The electricity production costs in the case of the grid connected PV system for both scenarios, 0.56 US\$/kWh (scenario 1) and 0.49 US\$/kWh (scenario 2), are lower than the electricity cost of 0.91 US\$/kWh (scenario 1) and 0.89 US\$/kWh (scenario 2) in the case of diesel systems.

One of the main differences between this grid connected PV systems to the household level PV system is the use of batteries. The batteries have on average 6 years of lifetime, and need to be replaced at least 3-4 times in a period of 20 years. The grid is assumed to have the capacity to function as storage. But in practical cases it is best to consider hybrid systems, where the PV could cover the load over the daytime and have a diesel or other alternative to cover the evening load.

The total CO<sub>2</sub> emission over the 20 years project lifetime is 121 ton CO<sub>2</sub> (scenario 1) and 465 ton CO<sub>2</sub> (scenario 2), see table 5.8. The current CO<sub>2</sub> market price is 17.7 US\$/ton CO<sub>2</sub><sup>140</sup>, this means that the carbon mitigation value for scenario 1 is about US\$2142 and for scenario 2 about US\$8231 for a project of 20 years.

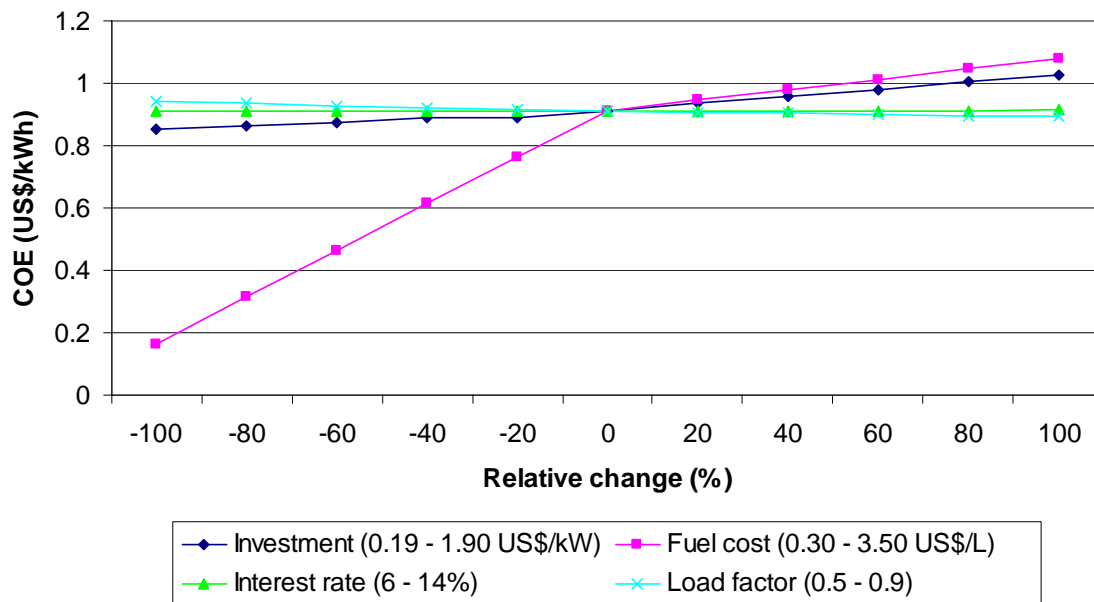
#### *Sensitivity Diesel and PV systems*

The sensitivity analysis helps to identify the input parameters that have a large influence on the final cost of electricity production. Fluctuating data as the fuel cost development and other data influenced by time, as the investment cost per nominal capacity (US\$/kW), are important to look at since they may have large impact on the COE (US\$/kWh).

See figures 5.5 and 5.6 for the results of the sensitivity analysis for both the 3.05 kW grid connected diesel and 74x220W PV systems in scenario K1. The conclusions from these results can in general be considered also for scenario K2.

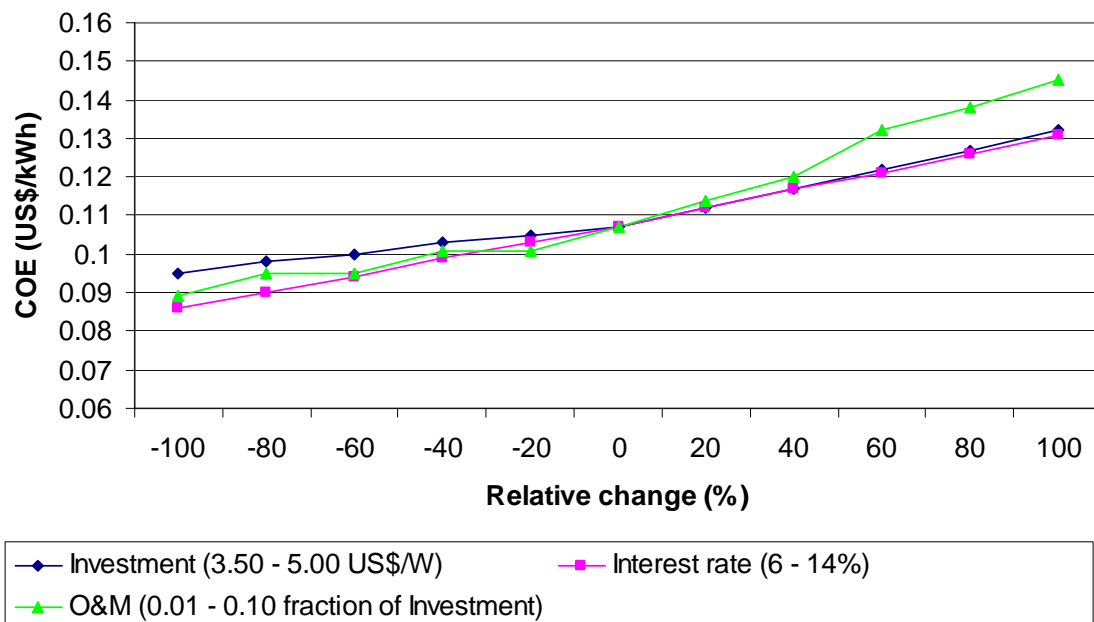
<sup>139</sup> It is assumed that due to economies of scale the investment cost per PV array may decrease from 4 to 3.5 US\$/Wp.

<sup>140</sup> Point Carbon website: <http://www.pointcarbon.com/Home/Carbon%20Market%20Europe/category150.html>



**Figure 5.5 Results of sensitivity analysis grid connected Diesel system (scenario K1)**

From figure 5.5 we can conclude that the fuel cost has a high influence on the cost of electricity production in case of the Diesel system. If the fuel price decreases to the current diesel price in Paramaribo of 1.06 US\$/L (May 2006) the cost of electricity production will decrease to 0.365 US\$/kWh. Thus it is important to optimize the transportation and other logistical matters to decrease the price of the fuel. Due to uncertainty in fuel development one can only say that the COE for this system can range between 0.165 – 1.080 US\$/kWh.



**Figure 5.6 Results of sensitivity analysis grid connected PV system (scenario K1)**

In the case of the PV system there is no significant difference in COE output between the input factors. Only in the case that the O&M costs reach higher levels (10% of total investments), this

may increase the COE from 0.107 to 0.145 US\$/kWh. On the overall, one can say that the COE for this system ranges between 0.086 – 0.145 US\$/kWh.

#### Grid connected Bio digester compared to Diesel

In this analysis the aim is to determine the minimal daily biomass feedstock required to run a commercially available gas engine with a capacity of 2.9 kW to produce electricity.

**Table 5.10 Energy cost calculations: Bio digestion – Diesel systems**

Parameter	Bio digestion	Diesel	Unit
Electricity production	20.32	17.78	MWh/year
Unit capacity	2.90	2.90	kW
Investment cost gas engine	3.65	0.77	US\$/W
Load factor	0.8	0.7	
Energy efficiency	0.85	0.35	
Lifetime diesel / gas engine	12500	12500	hours
Fuel type	Biomass	Diesel	
Biomass feedstock	<b>2456</b>	-	kg/day
Biomass feedstock price	0	-	US\$/kg
LHV fuel	-	36	MJ/L
Fuel price	-	2.91	US\$/L
Fuel cost	-	0.08	US\$/MJ
Fuel consumption	-	<b>7574</b>	L/year
Emission factor	-	74.1	g CO <sub>2</sub> / MJ
Gas production	0.024	-	m <sup>3</sup> /kg
LHV biogas	4	-	MJ/m <sup>3</sup>
Biogas consumption	21519	-	m <sup>3</sup> /year
Biogas price	0	-	US\$/m <sup>3</sup>
Size of bio digester	10	-	m <sup>3</sup>
Amount of digesters	12	-	#
Required digester volume	118	-	m <sup>3</sup> /day
Capacity factor	0.5	-	m <sup>3</sup> biogas /m <sup>3</sup> digester
Investment cost	120	-	US\$/m <sup>3</sup>
Interest rate	0.1	0.1	
Project lifetime	20	20	Years
Investment gas or diesel engine	10585	2233	US\$
Investment bio digester	14149	-	US\$
Diesel fuel cost	-	14785	US\$/year
O&M costs	989	89	US\$/year
Electricity costs	<b>0.19</b>	<b>0.91</b>	US\$/kWh
CO <sub>2</sub> emission	-	<b>115</b>	ton CO <sub>2</sub> / project
Carbon mitigation value	2036	-	US\$

In table 5.10 the minimal required biomass feedstock to run a 2.9 kW gas engine is calculated to be 2.46 ton/day. This means that about 12 bio digesters with 10m<sup>3</sup> capacity are needed to produce 118 m<sup>3</sup>/day of biogas that can be combusted in the gas engine.

The electricity production costs are 0.19 US\$/kWh for the bio digestion to electricity system and 0.91 US\$/kWh for the 2.9 kW diesel system. Note that in this analysis the biomass feedstock cost

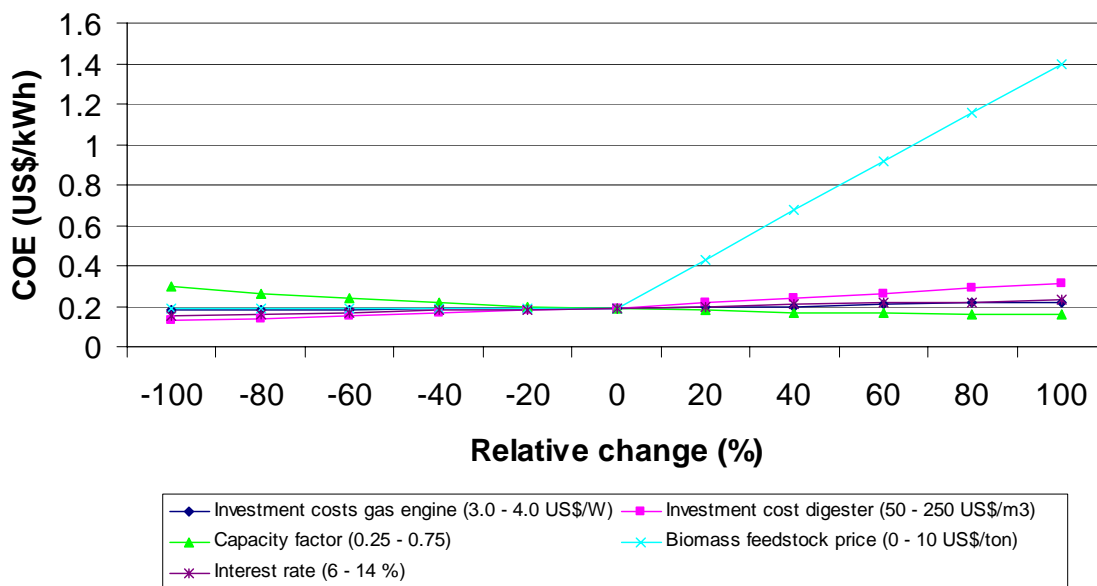


is set on 0, while in practice if considering agricultural residues, animal waste and/or energy crops there are costs related to the harvesting, handling and transportation. This will make the electricity production cost to increase. See the sensitivity analysis for more detail.

In total the bio digestion to electricity system can mitigate about 115 ton of CO<sub>2</sub> over the 20 year project lifetime. The current CO<sub>2</sub> market price is 17.7 US\$/ton CO<sub>2</sub><sup>141</sup>, this means that the carbon mitigation value is about US\$ 2036 for this project.

#### *Sensitivity bio-digesters*

Figure 5.7 shows the results of the sensitivity analysis for the bio digestion system. One can see that the biomass feedstock cost has a large influence on the COE. Just by a price increase of 0 to 2 US\$/ton for the biomass feedstock the COE increases from 0.19 to 0.43 US\$/kWh.



**Figure 5.7 Sensitivity results for the grid connected 2.9 kW bio digestion system**

If the biomass feedstock is maintained zero, than the COE ranges between 0.13 – 0.31 US\$/kWh.

#### Micro hydro power compared to Diesel

In the resource assessment three locations were analyzed on the energy production potential. The three locations are Bush Papaja, Sir. W. Raleigh and Karina Ituru. In the following economical analysis these options are compared to diesel systems with equal nominal capacity. See table 5.11 for more details. For the transmission lines a value of 13687 US\$/km is used. This is a value used in the Surinam Master Energy Plan (2000) for a 12 kV line.

<sup>141</sup> Point Carbon website: <http://www.pointcarbon.com/Home/Carbon%20Market%20Europe/category150.html>

**Table 5.11 Energy cost calculations: Micro hydro power compared to Diesel system**

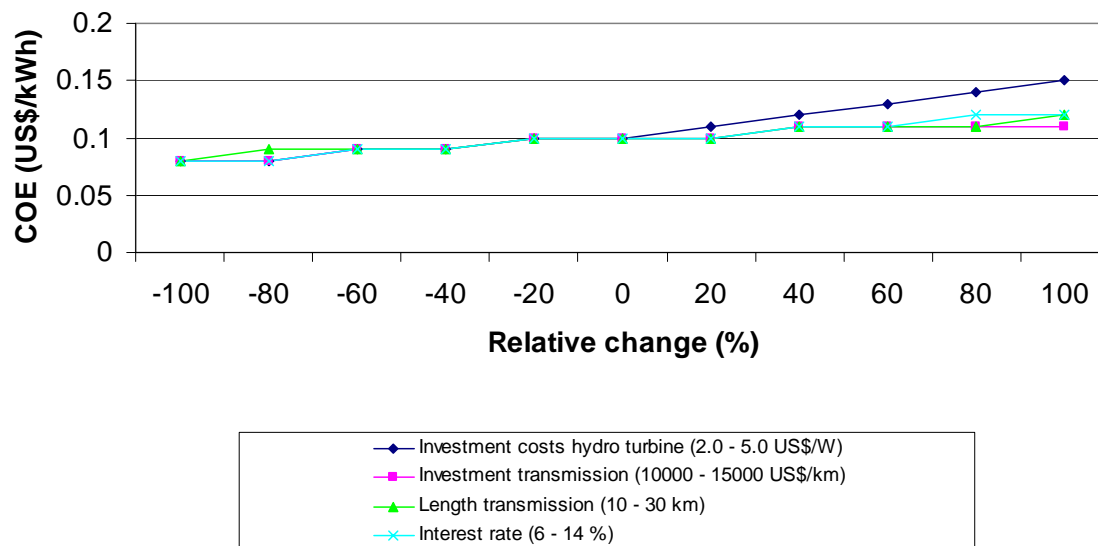
Micro hydro power							
Parameter	Bush Papaja	Diesel 1	Sir. W. Raleigh	Diesel 2	Karina Ituru	Diesel 3	Unit
Electricity production	172	150	1444	1263	319	279	MWh/year
Unit capacity <sup>142</sup>	24.5	24.5	206	206	45.5	45.5	kW
Investment cost	3	0.42	3	0.24	3	0.33	US\$/W
Interest rate	0.1	0.1	0.1	0.1	0.1	0.1	
Load factor	0.8	0.7	0.8	0.7	0.8	0.7	
Energy efficiency	0.7	0.35	0.7	0.35	0.7	0.35	
Lifetime	175200	45000	175200	45000	175200	45000	hours
Fuel type	-	diesel	-	diesel	-	diesel	
LHV fuel	-	36	-	36	-	36	MJ/L
Fuel price	-	2.91	-	2.91	-	2.91	US\$/L
Fuel cost	-	0.08	-	0.08	-	0.08	US\$/MJ
Fuel consumption	-	63989	-	538026	-	118836	L/year
Emission factor	-	74.1	-	74.1	-	74.1	g CO <sub>2</sub> / MJ
Investment cost transmission line	13687	-	13687	-	13687	-	US\$/km
Length of transmission line	4	-	20	-	12	-	km
Investment cost transmission	54748	-	273740	-	164244	-	US\$
Investment hydro turbine / diesel	73500	10290	618000	49440	136500	10920	US\$
O&M costs	5130	412	35670	1978	12030	437	US\$/year
Electricity cost	<b>0.12</b>	<b>0.85</b>	<b>0.10</b>	<b>0.84</b>	<b>0.15</b>	<b>0.85</b>	US\$/kWh
CO <sub>2</sub> emission	-	975	-	8197	-	1810	ton CO <sub>2</sub>
Carbon mitigation value	17258	-	145087	-	32037	-	US\$

In table 5.11 results that the electricity production costs of the micro hydro power systems are lower than the diesel systems. Note that not all cost factors are included in this analysis. Issues as land clearing to install transmission lines are different than assumed in the investment used for transmission lines, the fuel cost may vary considerably and for instance the distances for transmission are estimated.

An interesting point to highlight is that since the production capacity of the hydro systems are relatively large compared to the other renewable options, the carbon credit value is larger and may play a more important role in decreasing the overall capital investment of the whole mini hydro power system.

#### *Sensitivity Micro Hydropower system*

<sup>142</sup> This is the mean power production capacity for each location



**Figure 5.8 Sensitivity results of the 206 kW micro hydropower system**

### Summary of results

Table 5.12 shows the summary of the results of the economical analysis at the village level. PV system 1 is the PV system that is dimensioned to cover the scenario 1 energy demand. PV system 2 is the PV system dimensioned to cover the energy demand of scenario 2. Bio system entails the anaerobic digestion system dimensioned based on a 2.9 kW gas engine capacity. Hydro system 1, 2 and 3 represent the hydro power potential at Bush Papaja, Sir W. Raleigh and Karina Ituru respectively.

**Table 5.12 Summary of results of economical analysis at village/medium size level**

Parameter	PV 1	PV 2	Bio	Hydro 1	Hydro 2	Hydro 3	Unit
Installed capacity	16.3	62.1	2.9	24.5	206.0	45.5	kW
Investment	64913	217477	24734	128248	891740	300744	US\$
Levelized cost of electricity	0.56	0.49	0.52	0.12	0.10	0.15	US\$/kWh
Electricity supply fraction	1	1	0.05 – 0.18	0.4 – 1.5	3.3 - 13	0.7 - 2.8	
Carbon mitigation value	2142	8231	2036	17258	145087	32037	US\$

Based on the analysis and input parameters used we can indicate that the micro hydro power systems generate lower electricity production costs than the other alternatives. But they require on average much higher initial capital investment. Because the hydro micro systems have high electricity production potential they can generate considerable carbon credit values, this can be sub ducted from the capital investment to make this alternative financially more attractive.

The PV systems on average generate the highest electricity production costs. But there is much potential to reduce the costs, the investment cost per nominal capacity can be reduced due to economies of scale, the installment is relatively easier than the other alternatives, and if a solution is found for increasing the frequency and lowering of transport to and from Kwamalasamutu, this alternative may become financially more attractive.

In the case of the bio digestion alternative in this analysis is more challenging to draw conclusions. First of all, no costs are accounted for the biomass feedstock; also the biogas produced has a certain value but is considered 0 in this analysis. The total energy production capacity is not enough to cover the energy demand in Kwamalasamutu, thus it can only be considered as part of an electricity production mix. A positive point is that the initial capital investment cost for this system is the lowest among the alternatives.

As general remark; since all the previous analyzed systems are grid-connected one has to consider extra investment cost for installing a mini-grid that crosses through Kwamalasamutu. This will make the cost of electricity production to increase for all systems.

## 6. Conclusions and recommendations

### 6.1 General conclusions

- Since the infrastructure for installing PV systems is available and experience has been build up during the years and other renewable energy alternatives as bio-digestion and micro-hydro power need further analysis it is more likely that solar PV systems could be used as short term solution to electrify the households in Kwamalasamutu.
- Using the PV systems as intermediate solutions create more time to make better assessments for other identified renewable energy potentials in this report. These alternatives will certainly be required in the mid to long term perspective, since the electricity demand will increase steadily, either due to population growth, new economic activities or use of higher intensity appliances. Thus the future energy system does not have to exist of only autonomous Home PV systems, but one could think of creating a mini grid that is interconnected to either, diesel, micro-hydro power, bio-energy systems or hybrid systems.

### Electricity production systems (technical performance)

#### *Solar PV*

- Solar PV systems could supply the whole electricity demand of 71.6 MWh/year (scenario 2, over 20 years) if dimensioned and planned correctly. For the solar PV alternative a total of 16.5 kWp PV capacity (298 x 55 Wp) is required to cover the energy demand of 18.7 MWh/year over 20 years for the case of scenario K1. In scenario K2 the required rated PV installed capacity is about 62.8 kWp (285 x 220 Wp).
- The angle and direction of a PV array should be installed in such a way to optimize the energy conversion of the PV system. In general if a location is on the northern hemisphere the PV array should be installed towards the south. PV arrays are minimally installed with an angle of 15°, this is to prevent dust accumulation on the PV array that can bring down its energy conversion efficiency. The angle of the direction should be at the position where optimal use is made of the month with the least sun (winter period).

#### *Wind*

- The wind speeds measured in and around the area of Kwamalasamutu or the Suriname-Brazil border region are on average not enough to make a wind system technically viable. On anemometer height the wind speed levels are between 1.80 – 1.91 m/s while the minimal wind speed requirement is 3-4 m/s or higher.

#### *Mini-hydro power*

- The potential production capacity of mini-hydro power investigated at sites around Kwamalasamutu could cover the whole village demand over 20 years. In the case of the smallest micro-hydro power production capacity, Bush Papaja, 141 – 188 MWh/year could be delivered to Kwamalasamutu and is more than enough to supply the village demand of 71.6 MWh/year (in 20 years). But feasibility of these projects depends on the physical restrictions in the rough and pristine natural area to install transmission lines and mini-grid.

#### *Bio digestion*

- The total potential capacity of bio-digestion (using only human waste) to produce electricity via (bio)gas engines is between 8.9 - 13.2 MWh/year, this is not enough to

cover the total village demand of 18.7 MWh/year (scenario 1). But when incorporating other bio waste sources as food, agricultural or animal waste into the feedstock this production potential could vastly increase. Also bio-digestion could be considered on smaller/medium scale, as in the example of the primary school where it becomes technically feasible when considering a 10m<sup>3</sup> bio digester fed daily by human waste of around 200 students. The option to use the produced biogas directly as fuel for cooking or lighting seems to be more interesting since this prevents losses due to an extra conversion step and prevents use of kerosene and firewood.

## **Electricity production systems (economical analysis)**

### *Household level*

- The levelized cost of electricity for the solar home PV systems in scenario 1 is 1.14 US\$/kWh and for scenario 2, 0.12 US\$/kWh over a project lifetime of 20 years. These costs of electricity production are higher than the electricity costs of the diesel system. Note that there are many factors that are uncertain in this analysis that may lead to this result.
- Important factors could be: 1. the investment cost of the PV array + inverter, note that this is 5.5x higher than the diesel system, and that the chosen investment cost is estimated, thus more detailed analysis is required to find the real investment costs of the PV arrays + inverter by taking in account geographical and logistical factors that play an important role in the case of Kwamalasamutu. 2. The diesel fuel price, this can be higher or lower and has to be analyzed into more detail to find the real local price of diesel. 3. Batteries type and size, in this analysis sealed batteries are used, while deep cycle batteries in general perform better, also the dimensioning of the battery is important since costs largely vary between 100 – 200 Ah batteries. 4. The interest rate is set on 10%, this factor in general also has large impact on the levelized cost of electricity.

### *Village / medium size level*

- Based on the analysis and input parameters used we can indicate that the micro hydro power systems generate lower electricity production costs than the other alternatives. But they require on average much higher initial capital investment. Because the hydro micro systems have high electricity production potential they can generate considerable carbon credit values, this can be subtracted from the capital investment to make this alternative financially more attractive.
- The PV systems on average generate the highest electricity production costs. But there is much potential to reduce the costs, the investment cost per nominal capacity can be reduced due to economies of scale, the installment is relatively easier than the other alternatives, and if a solution is found for increasing the frequency and lowering of transport to and from Kwamalasamutu, this alternative may become financially more attractive.
- In the case of the bio digestion alternative in this analysis is more challenging to draw conclusions. First of all, no costs are accounted for the biomass feedstock; also the biogas produced has a certain value but is considered 0 in this analysis. The total energy production capacity is not enough to cover the energy demand in Kwamalasamutu, thus it can only be considered as part of an electricity production mix. A positive point is that the initial capital investment cost for this system is the lowest among the alternatives.

## 6.2 Recommendations

- In order to make good estimations of material needs and to plan installation or reparation activities in the village it is recommended to create a map of existing buildings and infrastructure prior to the initiation of these projects.
- The possible electricity demand of Kwamalasamutu depends very much on the energy demand package required per each household. The population size and growth, number of habited houses, the specific energy requirement of the appliances used and use profile; all are factors influencing the energy demand in the village. More detail analysis is required on these matters.
- Financial scheme is important, to be integrated into other economical and income generating activities. These activities may provide some basic financial conditions for survival of a new energy supply system.
- The government could subsidize the flights to and from Kwamalasamutu and other isolated villages in the South of Suriname in order to give them a chance to export their cultivated or crafted products and gradually become self sustaining. The greatest limitation for development of economical activities in the isolated regions is that the supply and export of materials, goods or services are too costly and not frequent enough to make economical activities feasible.
- There are studies done that show that diesel-PV hybrid systems may operate better than single type systems and that the costs may result to be lower. To be able to perform a hybrid system study more financial and technical data is required, also in many occasions energy models are used to dimension the optimal hybrid system, which was not at disposal in this study.
- In later stages of this project one has to design a fee structure. To create this fee structure issues as defining an affordable basic rate has to be tackled. Also the scaled rate for premium needs. Determine who pays for community power needs and how do local business pay for electricity service.
- Also the composition of management and office personnel to coordinate and monitor the electricity services has to be determined. One should think of choosing a method of selection of personnel. The people will need training in administrative and financial matters to know how the money has to be handled.
- Also maintenance personnel will need to be created. They will have to receive technical training and a system of compensation is needed. Maintenance schedules are important to coordinate the maintenance activities.





## References

Alternative Elektriciteitsvoorziening in het binnenland van Suriname (1993) and Suriname Master Energy Plan study (2000)

Anton de Kom University of Suriname, “Verslag: Elektriciteitsvoorziening in het dorp middels waterkrachtwerken”, Community Development Fund Suriname (CDFS), 2003

Blok, K. and Van Egmond, S., Energy Analysis, Copernicus Institute, Utrecht University, 2005

Calculated based on two sources, de Vries, B. et al., An analysis of Governance, Resource Management and Development Issues, 2003, section 2.2 and Estratégia de Participação das Populações Indígenas, Remanescentes de Quilombos, Mulheres e Jovens Pobres, May 2003, page 34.

California Energy Commission, A guide to photovoltaic (PV) system design and installation, 2001

Ciccarelli, M. and Mojon, B., Global Inflation, European Central Bank, Working Paper Series no 537, October 2005

Consulting Partners N.V., “Kwamalasamoetoe project dossier”, page 7

de Castro, J.F.M. and Jansen, J.C., “Alternative elektriciteitsvoorziening in het binnenland van Suriname”, ECN and CCE, 1993

de Cuba, K.H., Travel report ““Sustainable Indigenous Energy production and use”, as part of the “Sustainable Development and Bio-cultural Conservation in the Suriname-Brazil border” program, DSD/OAS, April 2006

de Cuba, K.H., Towards a Sustainable Energy Plan for St. Kitts & Nevis, OAS/UU, 2006

de Vries, B. et al., An analysis of Governance, Resource Management and Development Issues, 2003, section 2.2

Energy Unit, Energy and Water Department, The World Bank, Technical and Economic Assessment: Off grid, Mini-grid and Grid Electrification Technologies, Summary Report, 2005, page 27

Gunther, N., Report/Proceedings on the Workshop on Sustainable Development of Indigenous Communities of South Suriname, OSDE/OAS, Paramaribo, April 2005, page 8

Jansen, J. and de Castro, J.F.M., “Alternatieve Elektriciteitsvoorziening in het binnenland van Suriname”, ECN and CCE, 1993

Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 143

Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 143

Joint annual review 2004, Cooperation between European Union and the Republic of Suriname, 2003, page 153

Knowledge and Information centre, The Schumacher Centre for Technology and Development, Batteries, UK

Ministry of Natural Resources, Suriname Master Energy Plan, chapter 8, Paramaribo, 2000

Neij, L., Dynamics of Energy Systems, Ph.D. Thesis, Lund University, 1999

Nurmohamed, R.J. and Naipal, S., Variability of rainfall in Suriname and the relation with ENSO-SST and TA-SST, University of Suriname, Paramaribo, January 2006

Office of Environmental and Social Assessment, NIMOS, Environmental Assessment Guidelines Volume V: Power Generation and Transmission Projects, March 2005

Omer, A.M., Solar water pumping clean water for Sudan rural areas, NCMWE, Sudan, 2000, page 250

Plöchl, M. and Heiermann, M., Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?, Leibniz Institute of Agricultural Engineering Potsdam-Bornim, Germany, 2006, page 13

Population survey per poli, Medische Zending Suriname, November 2005

Schmid, A.L. and Hoffmann, C.A.A., Replacing diesel by solar in the Amazon: short-term economic feasibility of PV-diesel hybrid systems, Ministry of Mining and Energy, Brazil, 2004

The Schumacher Centre for Technology & Development, Recycling organic wastes, technical brief, page 3

Trio and Wayana Stakeholder Consultation, Naks Volkshoge School, Lelydorp, Suriname, April 5 and 6, 2005

US Department of Energy, Office of Energy Efficiency and Renewable Energy, *Photovoltaics*, Federal Energy Management Program, 1999

US Department of Energy, Basic Research Needs for Solar Energy Utilization, Report of the Basic Energy Sciences Workshop on Solar Energy Utilization, April 2005

Van Kampen, M.A. and dos Ramos, O.A., “Zonne-energie Kwamalasamutu, verslag van uitvoering”, October 1994

Vermeieren, J., Comments and Notes from Jan Vermeieren based on the field mission to Suriname, OSDE/OAS, March 2004

**Internet sources:**

Amapa Busca website:

[http://www.amapabusca.com.br/edgar/indios\\_primeiros\\_contatos.htm](http://www.amapabusca.com.br/edgar/indios_primeiros_contatos.htm)

Ashden Awards website:

<http://www.ashdenawards.org/winners/bsp>

Battery Electric website:

<http://www.batteryelectric.com/be-products08-stats2.htm>

Battery Mart website:

<http://www.batterymart.com/battery.mv?p=SLA-12V100>

Canada's Office of Urban Agriculture website:

<http://www.cityfarmer.org/biogasPaul.html>

Caribbean Net News website:

<http://www.caribbeannetnews.com/2005/09/14/price.shtml>

CI Solar Supplies website:

<http://www.cisolar.com/catOutdoorSelfPwrFix.html>

Creative Energy Technologies website:

<http://www.cetsolar.com/sundanzer.htm>

Dag blad van Suriname (Surinamese newspaper), website:

[http://www.dbsuriname.com/archief/nat/2006/jan06/11-01-06/Nat\\_Oplevering%20eerste%20fase%20elektrificatieproject%20Palumeu.asp](http://www.dbsuriname.com/archief/nat/2006/jan06/11-01-06/Nat_Oplevering%20eerste%20fase%20elektrificatieproject%20Palumeu.asp)

Danish Wind Industry Association, See website:

<http://www.windpower.org/en/tour/wres/pow/index.htm>

Diesel generator website:

[http://www.dieselgenerators.com/honda\\_eu.htm](http://www.dieselgenerators.com/honda_eu.htm)

European Renewable Energy Council (EREC) website:

[http://www.erec-renewables.org/documents/targets\\_2040/EREC\\_Scenario%202040.pdf](http://www.erec-renewables.org/documents/targets_2040/EREC_Scenario%202040.pdf)

European Small Hydropower Association website:

<http://www.esha.be/index.php?id=50>

Experience Curves for Energy Technology Policy, International Energy Agency, Paris, 2000. See:

<http://www.iea.org/textbase/nppdf/free/2000/curve2000.pdf>

FAO website:

[http://www.fao.org/documents/show\\_cdr.asp?url\\_file=/docrep/T0541E/T0541E0k.htm](http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/T0541E/T0541E0k.htm)

Generators and generators products website:

<http://www.southwestfastener.com/productsPramac.htm>

Home and Garden, solar lamps website:

<http://www.nextag.com/solar-lamps/search.html?nxtg=2d850a1c052c-EDA8AD917B83275E>

Homer Optimization Model, website:

<http://www.nrel.gov/homer/>

How stuff works website:

<http://science.howstuffworks.com/solar-cell9.htm>

KG Electric Solar Power Company, South Africa, website:

<http://www.kgelectric.co.za/appliance%20power.htm>

Low Costs Batteries website:

[http://www.lowcostbatteries.com/product\\_p/12V-100-AH.htm](http://www.lowcostbatteries.com/product_p/12V-100-AH.htm)

Maporama website:

<http://www.maporama.com/share/>

Micro Battery website:

<http://shopping.microbattery.com/s.nl/sc.2/category.622/it.A/id.5339/.f>

NASA's Surface Solar Energy Data Set website:

[http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?kevinhenry\\_decuba@yahoo.co.uk](http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?kevinhenry_decuba@yahoo.co.uk)

Oregon State University website:

<http://oregonstate.edu/~atwaterj/io.htm>

Powermate portable power generators website:

<http://www.colemanpowermate.com/generators/>

Power tools website:

<http://www.tylertool.com/generator2.html>

Practical Action website:

[www.itdg.org/docs/technical\\_information\\_service/solar\\_refrigeration\\_vaccines.pdf](http://www.itdg.org/docs/technical_information_service/solar_refrigeration_vaccines.pdf)

Small scale biodigester design:

<http://www.habmigern2003.info/biogas/Baron-digester/Baron-digester.htm>

Solar Cooking website:

<http://solarcooking.org/plans.htm>

Solar Cooking and Ovens website:

[http://www.exoticblades.com/tamara/sol\\_cook/types.html](http://www.exoticblades.com/tamara/sol_cook/types.html)

Solar Direct website:

<http://www.solardirect.com/pv/pvlist/pvlist.htm>

Solar Engineering Services website:

[http://www.solarengineering.co.za/biogas\\_html.htm](http://www.solarengineering.co.za/biogas_html.htm)

Solar light exporters website:

[http://hotproducts.alibaba.com/manufacturers-exporters/Solar\\_Light.html](http://hotproducts.alibaba.com/manufacturers-exporters/Solar_Light.html)

Solar Online Australia website:

[http://www.solaronline.com.au/cgi/index.cgi/shopfront/view\\_product\\_details?category\\_id=1107143916&product\\_id=1107358641](http://www.solaronline.com.au/cgi/index.cgi/shopfront/view_product_details?category_id=1107143916&product_id=1107358641)

Solar Ovens website:

<http://www.photomagnets.com/solarovens.html>

Sun Electricity website:

[http://www.sunelec.com/Distributors\\_/Batteries/body\\_batteries.html](http://www.sunelec.com/Distributors_/Batteries/body_batteries.html)

Tageo map website:

<http://www.tageo.com/index-e-ns-v-18-d-m1353523.htm>

UNDP GEF website:

<http://sgp.undp.org/index.cfm?module=Projects&page=SearchResults&CountryID=SUR&FocalAreaIDs=CC>

UNFCCC website:

<http://unfccc.int/2860.php>

University of Cambridge website:

<http://home.btconnect.com/engindia/humanwaste.htm>

University of Central Florida website:

<http://www.fsec.ucf.edu/solar/PROJECTS/solarcooker/cooker.htm>

University of Florida website:

<http://www.phys.ufl.edu/~liz/power.html>

Virginia Polytechnic Institute and State University website:

<http://www.ext.vt.edu/pubs/disaster/490-303/490-303.html>

Washington State University website:

<http://cff.wsu.edu/Publications/WSU%20bio%20small%20scale%20biogas%20handout.pdf>

World Energy Assessment, UNDP/UNDESA/WEC, United Nations Development Programme,

New York, 2000 (Chapter 7), see: <http://www.undp.org/seed/eap/activities/wea/drafts-frame.html>

Yamaha generators website:

<http://www.yamahagenerators.com/default.htm?cart=1147556627317896>



# Appendices

## Appendix A

### **Travel Report: “Sustainable Indigenous Energy production and use” As part of the “Sustainable Development and Bio-cultural Conservation in the Suriname- Brazil border” program (ACT and DSD/OAS)**

#### **Main objective**

The general objective of the project is to collaborate with the indigenous peoples of the Brazil-Suriname border region, Trio and Wayana in Suriname, Tiriyo/Katxuyana and Wayana/Apalai in Brazil to identify appropriate energy production systems that are in balance with the sustainable management of the natural resources and energy needs of the indigenous peoples.

Thereby focusing on the following issues:

8. Examine the energy needs of the indigenous people in the region
9. Examine the current energy production and use in the communities
10. Identify success/failures of previous attempts at renewable energy in the region
11. Conduct a review of successful use of renewable energy under same conditions
12. Provide recommendations for energy production and use in the region

#### **General info, visit to Suriname**

Visit duration: 29 March to 09 April 2006

Place: Paramaribo (29 March – 03 April 2006), Kwamalasamutu (03 – 05 April 2006), Alalapadu (05 – 06 April 2006), Paramaribo (07 – 08 April 2006)

#### **Paramaribo (29 March – 03 April 2006)**

Arrival to Paramaribo: 30 March, 2006 (01:10 AM)

#### **Thursday (30 March 2006)**

14:00 : Ms. M. Kerkhoffs-Zerp, Ministry of Labor and Environment and GEF Technical Focal Point

Collected data

- Background info on the Sustainable Land Management project, this may have impact on feasibility of any energy project in the Sur-Bra region, thus energy options should become an integral part of land management options.
- Info about the land rights problems in Suriname
- General info promotion renewable energy via the ratified Kyoto protocol

#### **Friday (31 March 2006)**

10.00 : Mr. Bruining, Consultant of Blik, Bruining and Partners

Blik, Bruining and Partners is an electro-technical consultancy with specialization in airco's, steam-water systems, electrical kitchen equipments, design of electrical power systems, etc.

Collected data

- Information on the electricity price tariffs per categories in Suriname for May 2004
- An update on executed or ongoing electricity projects in Suriname for the period 2001-2004

11:00 : Mr. J. Abdul, Permanent Secretary Ministry of Natural Resources and Energy

Collected data

- Background information on the energy sector of Suriname
- Economic analysis of energy supply in the interior (Chapter 8 of Suriname Master Energy Plan study)

12:00 : Mr. O. Dos Ramos, Director of Consulting Partners N.V.

Consulting Partners were involved in a Solar PV project for Kwamalasamutu in 1994/95 that was funded by the Dutch Development Program.

Collected data

- Background information of the solar PV project for Kwamalasamutu
- Report: “Alternatieve Elektriciteitsvoorziening in het binnenland van Suriname”, by Jansen, J.C. and de Castro, J.F.M., ECN-beleidsstudies and Castro Consulting Engineer, January 1993. This report is about a general analysis done on the alternative electricity supply in the interior of Suriname done in the early 90s.
- Report: “Zonne-energie Kwamalasamutu, verslag van uitvoering”, by van Kampen, M.A. and dos Ramos, O.A., Consulting Partners N.V., November 1994/edited in January 1996. This is the execution report of the Solar PV project done in Kwamalasamutu in the mid 90s.

14:00 : Mr. C. Nelom, Consultant of the National Institute for Environment and Management in Suriname (NIMOS)

Collected data

- Background information on Environmental Framework Law
- Info about the Biodiversity Action Plan, this can have impact on the feasibility of bio-energy options.
- Info on CDM project development (Ratification of Kyoto protocol)
- Info on the 1<sup>st</sup> National Communication Report (UNFCCC)

There will be a follow up to gather more energy related information via email communication.

15:00 : Delegation Anton de Kom University of Suriname: Messrs. C. Wijngaarde, A. Kalpoe, S. Naipal and Mr. Vasseur

Present at meeting were Mr Wijngaarde and Mr. Kalpoe.

Collected data

- Background information on energy projects done in the interior, with focus on solar and microhydro power options.
- Overview of activities of the University

Follow up required to contact Mr. Naipal (hydro power) and Mr. Vasseur (bio-energy) for technical information

**Monday (03 April 2006)**

Arrival to Kwamalasamutu: 03 April, 2006 (15:00 PM)



15:30 : Walk through Kwamalasamutu

A visit was paid to the central fresh water well, where a pump is required to pump the fresh water to a central point in Kwamalasamutu for the villagers. Also the school was visited and resulted not have have light for more than 6 years, and this hampers the students to do homework or have other educational activities, since at home many don't have light either. The central meeting building (Kroetoe Oso) and other parts of Kwamalasamutu were also visited to get a general impression of the energy needs.

18:00 : Meeting with Granman Asongo and captains

This was an introduction meeting, where the main reason for visiting Kwamalasamutu is explained and background information on the ongoing OAS project is communicated to the Granman and other representatives. During this meeting, the main objectives of the sustainable energy development activity/component are explained.

### **Tuesday (04 April 2006)**

09:00-15:00 : Trip to Wherepai (petroglyphs)

Get general impression of the river for potential minihydro power. During a 1 hour trip upstreams to Wherepai, there were no significant stream accelerations or height differences that could be identified as a source for further microhydro power potential assessment.

17:00 : Walk through Kwamalasamutu

Accompanied by Ken (local villager) several people were approached to get information on their household, energy use and opinion. Also randomly, houses were visited to assess the PV solar systems used and collect data on the usage and maintenance of the systems. Also Mrs. Suzan Macnack (school teacher), was contacted to collect info on the situation of the school, education activities and general info about Kwamalasamutu.

The general impression of an average household in Kwamalasamutu with a functioning solar PV system is that use is made of a radio, tv/dvd and lighting. The number of households with a functioning solar PV system is roughly estimated to be 15-20 of the around 500 households. Also from communication with villagers there are about 10 households that use light motors.

#### **Collected data**

- Technical information of used Solar PV systems
- Inventory of electrical devices used in households
- Opinion of several villagers on energy needs

19:00 : Meeting with Granman and captains

Within the context of further discussions about the OAS project, a general feedback was given to Granman on the collected information and the general objectives of the sustainable energy development project were highlighted. Granman appointed a person, Mr. Opotapo Meukesede, to help with the collection of energy related information.

### **Wednesday (05 April 2006)**

09:00 : Quick walk through Kwamalasamutu

The clinics were visited to gather information on their energy use. And additional villagers were approached for information on energy needs. The PV systems at the ACT clinic are in operation and feed a cooler/freezer, a communication radio and lighting. In the case of the clinic run by the “Medische Zending”, the PV systems supply electricity to a cooler/freezer, a microscope, lighting, and a communication radio.

11:00 : Fly to Alalapadu

11:45 : Meeting with Captain of Alalapadu

Welcome meeting and a walk through Alalapadu. Within the context of the explanation of Brazil nut production and handling a general impression of energy needs were briefly discussed related to the production line.

15:00 : Visit to the river (cascade) in Alalapadu

Impression of the possibility for microhydropower. From communications with a local person, in the 60s or 70s an assessment was performed to evaluate the potential for microhydropower at that location. But no further information is available.

17:30 : Social gathering with the local villagers

#### **Thursday (06 April 2006)**

11:00 : Fly back to Paramaribo

#### **Friday (07 April 2006)**

11:00 : Mr. O. Dos Ramos, Consulting Partners N.V.

Follow up of previous meeting to collect more specific technical data on the Solar PV project in Kwamalasamutu in the year 1994-1995.

12:00 : Ms. Semmoh and Mr. R. Adama, Ministry of Labor, Technology and Environment

An interesting information was that Telesur is planning to buy satellite phones and see for a possibility to install one in Kwamalasamutu, in order to obtain further information on this, Mr. Adama ([cbecaricom@sr.net](mailto:cbecaricom@sr.net)) will be contacted.

#### Collected data

- Background information on the National Technological Development Policy (framework project)
- Information on the tele-communication situation in the interior
- General info on hydrodam near Brownsberg (central Suriname)

13:30 : Ms L. Jubithana, Director Association of Indigenous Village Leaders (VIDS)

Brief explanation of the sustainable energy development project.

For more information please contact me anytime.

Kevin de Cuba

## **Appendix B**

### **Short description of installed PV systems (Kwamalasamutu)**

1. 56 x Solar Home Systems  
Each composing of :
  - 2 x Solar P.V. arrays
  - 2 x Solar accu-batteries each of 12V - 100Ah,
  - 1 x battery charge-controller
  - system wiring
  - 8 x fluorescent lamp-installations of 8W - 12VDC
2. a central energy supply system including:
  - 66 x Solar P.V. arrays
  - 40 x batteries each 12V - 100Ah
  - 1 x battery charge/controller
  - 1 x battery frame
  - 1 x 3 phase inverter 24DC/127/220VAC/3000VA
  - system wiring
  - connection to the existing distribution net
3. a central energy-system for the Polyclinic + connecting buildings including:
  - 14 x Solar PV modules
  - 12 x batteries each 12V - 100Ah
  - 1 x battery charge/controller
  - 1 x battery framework
  - 1 x one phase - inverter 12 VDC, 127V, 1000 VA
  - system wiring
  - 10 x fluorescent lamp-installation 8W - 12VDC

## Appendix C

### Solar PV Arrays

#### R&S Holland Solar PV

Manufacturer:	Renewable Energy Systems Holland
Serial #:	A 04354
Installed:	1995
Max. Power:	not known
Output:	12V DC
Location:	Pole # 044

#### Astro Power

Manufacturer:	Astro Power
Model:	AP-120
Max. Power:	120 W
Rated voltage:	16.9 V
Series fuse:	15 Amps
Max. System open circuit voltage:	600 V
By-pass diode:	8 Amps
Short circuit current:	7.7 Amps
Field wiring:	Copper

#### Solar Shell

Manufacturer:	Solar Shell
Model:	SM 110-12p
Max. Power:	110 W
Rated current:	6.3 A
Short circuit current:	6.9 A
Max. Open circuit voltage:	600 V
Open circuit voltage:	21.7 V
Rated voltage:	17.5 V
Series fuse:	10 A

#### Conergy

Manufacturer:	Conergy
Model:	C 125 PI
Max. Power:	125 W
Rated voltage:	17.2 V
Rated current:	7.3 A
Open circuit voltage:	21.7 V
Short circuit current:	8.14 A
Max. System voltage:	540 V

### Refrigerators

#### Phocos DC Fridge

Manufacturer:	Phocos
Power input:	11-15V DC / 22-30V Max. 3.5 A
Usage:	continous

#### Electroflux Fridge

Manufacturer: Electroflux  
Model: C165  
Power input: 12/24V DC  
Usage: continous

#### ProStar Fridge

Manufacturer: ProStar  
Model: XL 6000  
Power requirement: 12V DC, 7 A  
Usage: continous

### **Batteries<sup>143</sup>**

#### Golf Pro Battery

Manufacturer: Golf Pro  
Model: 220 Deep Cicle

#### US Power Series Battery

Manufacturer: US Power Series  
24-60 CCA 530  
Costs: SUR\$ 145,- (2005)

#### VARTA Battery (2x)

Manufacturer: VARTA  
Model: Vb 6159  
Power: 6.69V (temp 20°C)  
Standby: 7am to 3pm  
Location: Clinic (Medische Zending)  
Website: <http://www.batteryelectric.com/be-products08-stats2.htm>

### **Power converters**

#### Power inverter

Manufacturer: Power Converter  
Power inverter: 400W (800Wp)  
Input: 12V DC (10-15V)  
Output: 110V AC  
Costs: SUR\$ 175,- (2000)

### **Communication radio**

#### I-com radio #1

Manufacturer: I-com  
Model: IC-78 (ser# 0103719)  
Power requirement: 13.8V DC

#### I-com radio #2

Manufacturer: I-com

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<sup>143</sup> <http://www.overboost.com/story.asp?id=311>

Model: IC-77 (ser# 12361)  
Power requirement: 13.8V DC  
Standby: 7am to 3pm

### **Microscope**

Manufacturer: Leica CME  
Model: IC-77 (ser# 12361)  
Power requirement: 120V AC, 50/60 Hz  
Lamp: 6 V – Max. 20W  
Max. Output: 28VA  
Usage: 1 hour/day  
Location: clinic (Medische Zending)

## Appendix D

**Table D-1. Wind speed data for villages within the Suriname-Brazil border region (adapted from NASA's Surface Solar Energy Data Set)**

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Amatopo	10-year Average (50m)	2.78	2.87	2.87	2.77	2.16	1.99	1.91	2.02	2.11	2.24	2.39	2.63	<b>2.39</b>
	Minimum	-11	-15	-22	-19	-13	-17	-14	-18	-18	-13	-17	-14	<b>-16</b>
	Maximum	21	34	26	16	17	13	20	27	21	23	28	19	<b>22</b>
	10-year Average	-20	-21	-21	-21	-21	-20	-21	-20	-20	-20	-21	-20	<b>-20</b>
	Average (10m)	2.22	2.27	2.27	2.19	1.71	1.59	1.51	1.62	1.69	1.79	1.89	2.10	<b>1.91</b>
Apetina	10-year Average (50m)	2.64	2.67	2.52	2.48	2.00	1.89	1.75	1.95	2.14	2.27	2.31	2.48	<b>2.25</b>
	Minimum	-9	-14	-19	-14	-11	-18	-17	-16	-19	-21	-25	-16	<b>-17</b>
	Maximum	16	22	21	20	12	12	18	22	21	31	34	17	<b>20</b>
	10-year Average	-20	-20	-20	-20	-20	-20	-20	-21	-21	-20	-20	-20	<b>-20</b>
	Average (10m)	2.11	2.14	2.02	1.98	1.60	1.51	1.40	1.54	1.69	1.82	1.85	1.98	<b>1.80</b>
Coeroeni	10-year Average (50m)	2.78	2.87	2.87	2.77	2.16	1.99	1.91	2.02	2.11	2.24	2.39	2.63	<b>2.39</b>
	Minimum	-11	-15	-22	-19	-13	-17	-14	-18	-18	-13	-17	-14	<b>-16</b>
	Maximum	21	34	26	16	17	13	20	27	21	23	28	19	<b>22</b>
	10-year Average	-20	-21	-21	-21	-21	-20	-21	-20	-20	-20	-21	-20	<b>-20</b>
	Average (10m)	2.22	2.27	2.27	2.19	1.71	1.59	1.51	1.62	1.69	1.79	1.89	2.10	<b>1.91</b>
Kwamalasamutu	10-year Average (50m)	2.65	2.73	2.65	2.54	1.98	1.90	1.90	2.09	2.22	2.33	2.41	2.56	<b>2.32</b>
	Minimum	-12	-15	-25	-19	-11	-16	-17	-20	-19	-17	-22	-18	<b>-18</b>
	Maximum	17	29	26	18	16	14	21	22	26	22	28	20	<b>22</b>
	10-year Average	-20	-20	-20	-20	-20	-21	-21	-20	-20	-20	-21	-20	<b>-20</b>
	Average (10m)	2.12	2.18	2.12	2.03	1.58	1.50	1.50	1.67	1.78	1.86	1.90	2.05	<b>1.86</b>
Palumeu	10-year Average (50m)	2.64	2.67	2.52	2.48	2.00	1.89	1.75	1.95	2.14	2.27	2.31	2.48	<b>2.25</b>
	Minimum	-9	-14	-19	-14	-11	-18	-17	-16	-19	-21	-25	-16	<b>-17</b>
	Maximum	16	22	21	20	12	12	18	22	21	31	34	17	<b>20</b>
	10-year Average	-20	-20	-20	-20	-20	-20	-20	-21	-21	-20	-20	-20	<b>-20</b>
	Average (10m)	2.11	2.14	2.02	1.98	1.60	1.51	1.40	1.54	1.69	1.82	1.85	1.98	<b>1.80</b>

**Table D-2. Wind speed data for villages within the Suriname-Brazil border region (*Continued*) (adapted from NASA's Surface Solar Energy Data Set)**

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Pelele Tepu	10-year Average	2.64	2.67	2.52	2.48	2	1.89	1.75	1.95	2.14	2.27	2.31	2.48	2.25
	Minimum	-9	-14	-19	-14	-11	-18	-17	-16	-19	-21	-25	-16	-17
	Maximum	16	22	21	20	12	12	18	22	21	31	34	17	20
	10-year Average	-20	-20	-20	-20	-20	-20	-20	-21	-21	-20	-20	-20	-20
	Average (10m)	2.11	2.14	2.02	1.98	1.6	1.51	1.4	1.54	1.69	1.82	1.85	1.98	1.80
Sipaliwini	10-year Average	2.65	2.73	2.65	2.54	1.98	1.9	1.9	2.09	2.22	2.33	2.41	2.56	2.32
	Minimum	-12	-15	-25	-19	-11	-16	-17	-20	-19	-17	-22	-18	-18
	Maximum	17	29	26	18	16	14	21	22	26	22	28	20	22
	10-year Average	-20	-20	-20	-20	-20	-21	-21	-20	-20	-20	-21	-20	-20
	10 m height	2.12	2.18	2.12	2.03	1.58	1.50	1.50	1.67	1.78	1.86	1.90	2.05	1.86



## Appendix E

### Solar Power Technical Terms

<b>Ampere</b>	One amp is produced an electrical force of one volt acting across a resistance of one ohm.
<b>Ampere-hour</b>	Quantity of electricity or measure of charge. How many amps of flow or which can be provided over a one hour period.
<b>Battery</b>	<p>A "deep cycle" battery is rated in Amp hours. The amount of current, in amps, that can be supplied by the battery over a period of time. For example, a 350ah battery could supply 17.5 amps over 20 hours, or 35 amps. over 10 hours.</p> <ul style="list-style-type: none"><li>- a 6 volt 360ah battery = 2160 watts</li><li>- may be wired in series or parallel like solar panels.</li></ul>
<b>Charge controller</b>	Regulates voltage applied to the battery system from the PV array. Insures that the battery gets a charge when one is needed, and that the battery isn't over charged. Rated in amperage that they can take from a solar array.
<b>Inverter</b>	Changes DC power stored in a battery to 120/240 VAC.
<b>Kilowatt-hour</b>	<p>1000 watts over a period of one hour.</p> <ul style="list-style-type: none"><li>- 10 kilowatt hours, or 10,000 watts.</li><li>- 1 kilowatt roughly equals \$1.00 SRD.</li><li>- 1 horsepower = 745.7 watts</li><li>- 1 horsepower hour = 1.341 kilowatt hours, or 13,410 watts.</li></ul>
<b>Load</b>	Refers to the equipment that is powered by electricity.
<b>Parallel wiring</b>	Refers to connecting the positive terminal of one panel to the positive terminal of another. Two 12 volt/3.5 amp panels wired in series produces 12 volts at 7 amps.
<b>Performance Factors</b>	<p>DC watts, cumulative:</p> <ul style="list-style-type: none"><li>- baseline 100%</li><li>- temperature -10% = 90%</li><li>- soiling - 8% = 83%</li><li>- wiring - 5% = 79%</li><li>- tilt - 5% = 75%</li><li>- direction - 2% = 74%</li></ul>

- inverter                      0% = 74%

<b>Peak sun hours</b>	average amount sunlight available per day throughout the year.
<b>Primary components</b>	The four primary components for producing electricity using solar power are: solar panels, which charge the battery, with the charge regulator insures proper charging of the battery. The battery provides DC voltage to the inverter, and the inverter converts DC voltage to AC voltage.
<b>Series wiring</b>	refers to connecting the positive terminal of one panel to the negative terminal of another. Two 12 volt/3.5 amp panels wired in series produces 24 volts at 3.5 amps.
<b>Solar panel</b>	stated in wattage. If an average of 6 hours of peak sun per day is available, then the example solar panel produces an average 360 watt hours of power per day. $60w \times 6 \text{ hours} = 360 \text{ watt-hours}$ .
<b>Volt</b>	A unit of measure of the force, or "push" given the electrons in an electric circuit. One volt produces one ampere of current when acting a resistance of one ohm.
<b>Watt</b>	One ampere of current flowing at a potential of one volt produces one watt of power.
<b>Wattage</b>	volts x amps = wattage. For example: a 12 volt 60 watt solar panel measuring 20 x 44 inches has a rated voltage of 17.1 and a rated 3.5 amperage. $17.1 \times 3.5 = 60 \text{ watts}$ .

## Appendix F

### PV dimensioning<sup>144</sup>

To be able to estimate the total required installed PV capacity to comply with identified demands. This sheet is created to make the calculations more practical.

Energy demand:

**Inventory of appliances and power requirement**

Appliances	Amount	Wattage (rated)		Usage (Hrs/day)		Power requirement (Wh/day)	
		MIN	MAX	MIN	MAX	MIN	MAX
Total							

Required PV capacity:

$$C_p = \frac{E_{MIN}}{MSR_{MIN} * \eta_{TOT}}$$

Where

$E_{MIN}$  = Total minimal energy demand (Wh/day)

$C_p$  = Rated or Nominal capacity (Wp)<sup>145</sup>

$MSR_{MIN}$  = Minimal available nominal solar energy (kWh/m<sup>2</sup>/day)

$\eta_{TOT}$  = Overall PV system efficiency (0.65 – 0.75)

Required battery capacity:

$$Cb = \frac{E_{MIN} * n(days)}{\eta_B * Vb}$$

Where

$E_{MIN}$  = Total minimal energy demand (Wh/day)

$Cb$  = Battery capacity (Ah)

$n(days)$  = Amount of cloudy days

$\eta_B$  = Battery discharge capacity (0.2 - 0.4)

$Vb$  = System voltage (V)

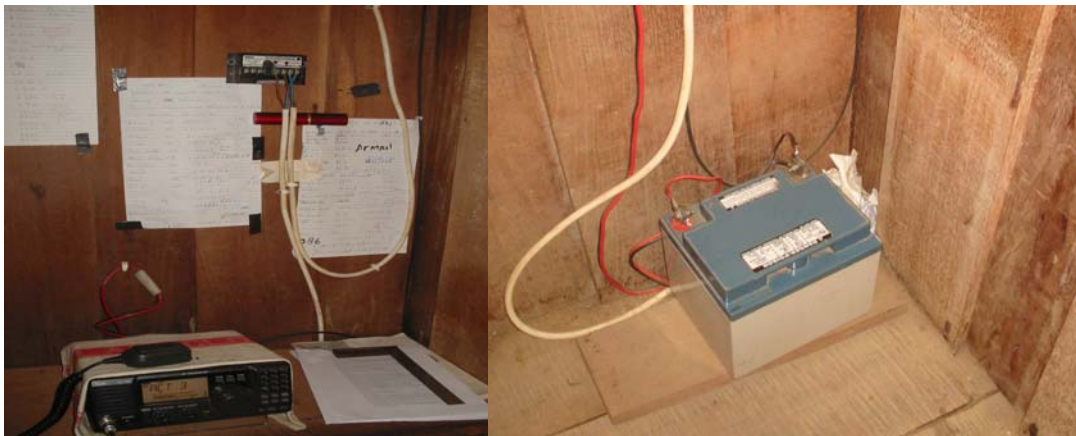
<sup>144</sup> Extracted from Alferink, F., PV systems, 2003

<sup>145</sup> Rated capacity (Watt-peak), that is the maximal power output measured at 1 kW/m<sup>2</sup> radiation at 25°C.

## Appendix G Photo's of Kwamalasamutu



**Figure G-1. PV arrays and fridge installed at the MZ Clinic in Kwamalasamutu (2006)**



**Figure G-2. Impression of the situation in the ACT clinic in Kwamalasamutu (2006)**



**Figure G-3. PV system installed at the research guest house in Kwamalasamutu (2006)**

## Appendix H Estimations of energy demand per public building in Kwamalasamutu

Appliances	Amount	Wattage (rated)	Usage (Hrs/day)	Power requirement (Wh/day)
Church				
Lighting	12	18	3	648
Recreation Hall				
Lighting	12	18	3	648
Primary School				
Fridge	1			500
TV	1	70	4	280
Lighting	18	18	5	1620
Krutu Oso				
Fridge	1			510
TV	1	70	4	280
Lighting	9	18	5	810
Total				5296

Contact information

ing. Kevin H. de Cuba, MSc.

Department of Sustainable Development (DSD)

The Organization of American States (OAS)

1889 F Street NW, Washington DC 20006

tel 1-202-458-6467 / email [kdecuba@oas.org](mailto:kdecuba@oas.org)

URL: [www.oas.org/dsd](http://www.oas.org/dsd)

Author: K.H. de Cuba

**Department of Sustainable Development**

**The Organization of American States (DSD/OAS)**