

# **AREA 1: METHODOLOGY FOR PREPARATION AND ASSESSMENT OF SOLAR PV PROJECT PROPOSALS**

**Draft Version**

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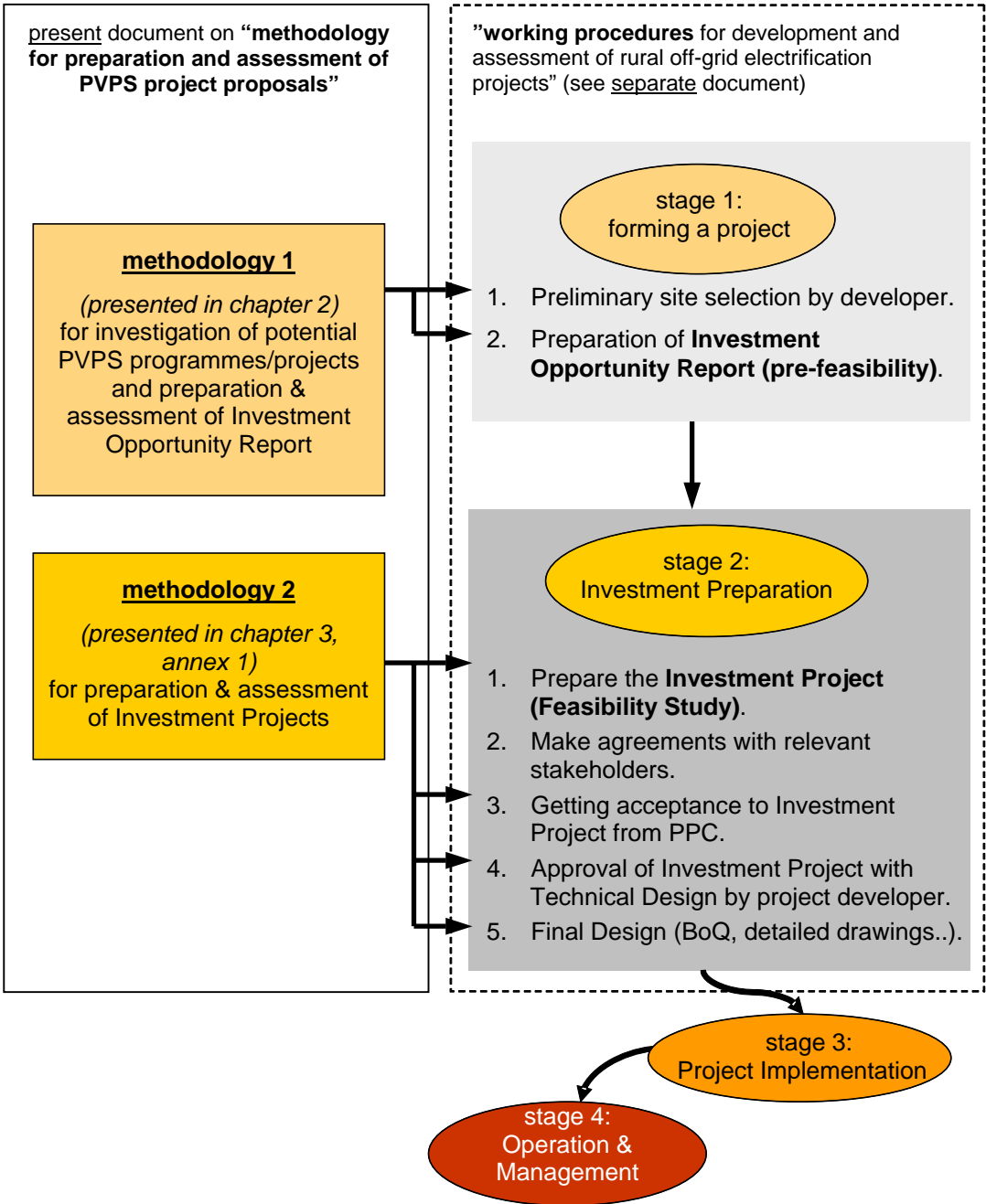
List of abbreviations:

A	Ampere
Abm	Annual recurrent cost for regular O&M (PV system with battery)
Abr	Annual recurrent cost for replacements (PV system with battery)
Abt	Annual equipment related recurrent cost (PV system with battery)
AC	alternating current
Ah	Amperehour
Am	Annual recurrent cost for O&M (PV system without battery)
Aop	Annual recurrent cost not related to equipment
Ar	Annual recurrent cost for O&M (PV system without battery)
As	Annual recurrent cost in total for the project
At	Annual recurrent cost for O&M (PV system without battery)
B <sub>f</sub>	battery discharge factor, the useful fraction of nominal capacity
B <sub>C</sub>	battery capacity in Ah
BoS	balance-of-system, the rest of a PV system except modules (& battery)
Br	cost of a battery cell or block in a battery
Bv	voltage of battery cell or battery block in a battery
category	group of similar PV systems of same size and capacity
C <sub>η</sub>	Coulombic efficiency of a battery (charge- and discharge efficiency)
Cr	Cost a category of PV systems
C <sub>xx</sub>	Nominal battery capacity at xx hours discharge rate, e.g. C <sub>10</sub>
DC	direct current
DoD	Depth of Discharge (for a battery)
E	average daily load of a PV system kWh/day
EU	European Union
EVN	Electricity of Vietnam
GEF	Global Environment Facility
HH	house hold
I	average daily irradiation (insolation) in kWh/m <sup>2</sup> /day on a flat surface
IEA	International Energy Agency
IEC	International Electrotechnical Committee
IMH	Institute of Meteorology and Hydrology
ISO	International Standards Organisation
It	total annual income by PV system category
Ita	annual income in total for the project
Km	kilometre
kWh	kiloWatthour
kWp	kiloWattpeak, express nominal capacity of a PV array
m <sup>2</sup>	square meter
MPP	Maximum Power Point: the V and A values at which a PV module has max output
MPPT	Maximum Power Point Tracking: a facility often included in inverters and advanced charge controllers
Mr	cost of a PV module
mW	miliWatts
MW	MegaWatts
N	Number of days of required PV system autonomy
Nb	Number of cells or block of cells in a battery
Nc	Number of PV systems per category of PV systems

NGO	Non-Government Organisation
Nm	Number of PV modules in an array
$\eta$	Overall PV system electrical efficiency
Or	estimated cost of transport, installation, commissioning and training
Pa	Nominal capacity of PV array
Pc	Average daily load per PV system in a category of PV systems
PV	Photovoltaic, conversion of light into electricity
PV-GAP	PV Global Accreditation Programme
PVPS	PV Power Systems Implementing Agreement (of the IEA)
Sg	Specific gravity (measure of battery acid density)
Si	Silicon
SLI	Start-Light-Ignition: acronym for an automotive start battery
Sr	cost of balance-of-system for a PV system
Tem	tariff for PV electricity – metered in kWh
Tf	tariff for PV electricity – monthly flat rate
To	Total other (not PV system related) investment cost
Tr	Total estimated project investment cost for PV systems
Tt	Total estimated project investment cost
V	Volt
$V_B$	Battery voltage
$V_{pc}$	Volts per cell (in a battery)
WB	World Bank
Wp	Wattpeak, express nominal capacity of a PV module

### Context

The present document describes a methodology developed for the preparation and assessment of photovoltaic power systems (PVPS) programme/project proposals. As illustrated in Figure 1.1, this methodology follows the working procedures elaborated in a separate document.

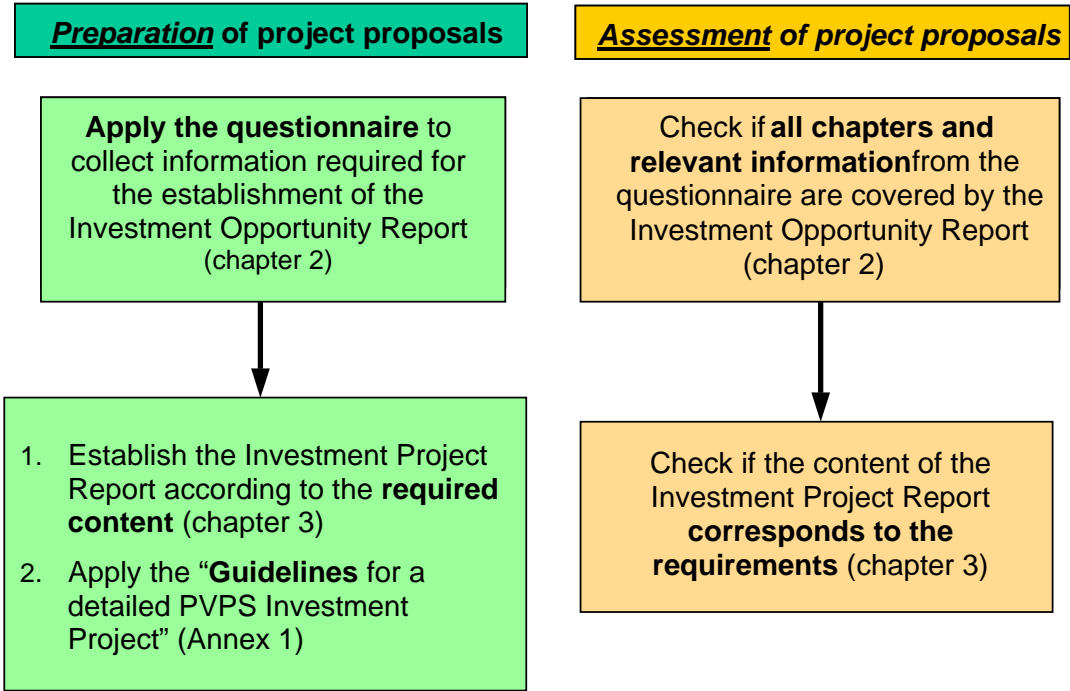


**Figure 1.1: Presentation of working procedures and appropriate methodologies**

The two expressions “**Investment Opportunity Report**” and “**Investment Project**” which are used in the Vietnamese context correspond to the formerly used terms “**Pre-Feasibility Study**”

and “**Feasibility Study**”. In order to avoid confusion in the following sections the first two expressions will be used.

Figure 1.2 illustrates how the proposed methods can serve for both, **preparation and assessment of project proposals**. The methods and tools presented in the following are based on broad experience from PVPS programme/project development collected and assessed by international organisations such as the International Energy Agency (IEA) and the World Bank and from actual programmes and projects in many different developing countries. They consider specific Vietnamese conditions by taking advantage of the experience from the World Bank financed RARE project. The resources (handbooks, software etc.) listed and described under chapter 5, like e.g. the many IEA PVPS guidelines and recommendations, the REToolkit, the RETScreen, the PVSyst etc., provide similar tools and methods for PVPS project development. However, the methods described in the present document, extract the most relevant aspects, yet setting value on completeness and sufficiency.



**Figure 1.2:** Application of methods and tools for preparation and assessment for project proposals

The first method presented in chapter 2 is based on a questionnaire which is used to collect all relevant information required for the preparation of the Investment Opportunity Report. It can be used for preparing the report (e.g. by a consultant) but also for checking its completeness (by the relevant authority). The second method, presented in chapter 3 together with the detailed specifications given in appendix 1 are means thought for the preparation of an Investment Project whereas for its assessment mainly the method in chapter 3 is of relevance. The concerned authority can use it to check if all essential aspects, i.e. technical, economical, social, environmental etc. are properly covered by the report. In case that further details are required, also the assessing authorities can consult the specifications in the appendices.

According to the Vietnamese legal framework, a “Basic Design” has to be prepared during the Investment Project stage. For PV projects, this basic design is in many respects already very close to the final design, meaning that only minor additional processing and specification is needed, namely for the bill of quantities and eventual detailed drawings.

# 1. Introduction to PV Technology

Photovoltaic (PV) power systems convert light directly into electricity without any moving parts or any emissions, which means PV systems normally can be implemented directly at the site of the electric load to be supplied, one the great advantages of the PV technology.

Furthermore the PV technology is inherently modular of nature, which means PV systems can be designed to a wide range of electric loads from milli-Watt's to Mega-Watt's. The modular nature is illustrated to the right

The basic PV element is the PV cell. A typical Silicon cell has an output voltage of 0,5 V and can produce about 3,5 A depending on solar irradiation, tempe-rature and the area of the cell.

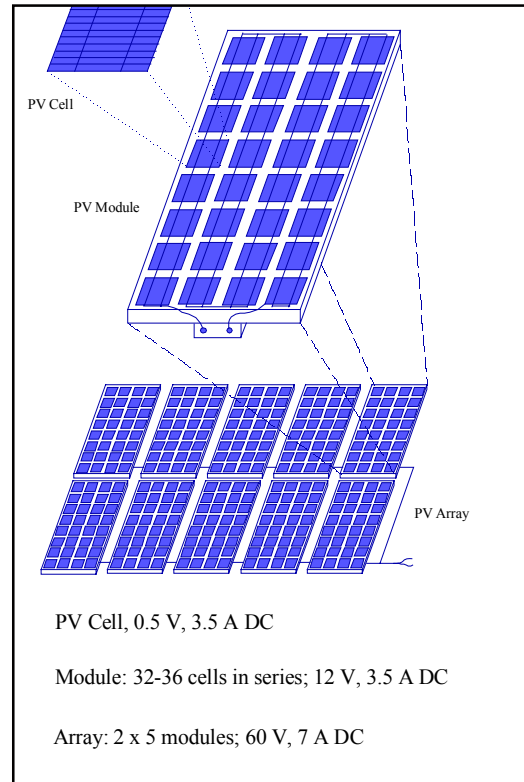
In a module a number of cells are connec-ted in series and parallel to obtain a more applicable voltage and current range. Modules exist in a wide range of sizes. The module also provides protection of the fragile cells and constitute in practical terms the smallest building block.

PV modules can be connected in series and/or in parallel almost without limitation meeting any almost any power need. The typical module design consist of a glass front cover, some layers of transparent foils in which the cells are embedded and a rear side foil – all baked together into a laminate. Normally the module will have an Aluminum frame partly to protect the laminate partly to facilitate mounting of the module on a support structure.

PV modules are very durable and come often with a 20 or 25 year warranty. PV modules should be certified to IEC standards or equivalent.

Most PV modules on the market, about 90 %, include cells of mono- or poly-crystalline Silicon, but many other cell materials and designs can be found e.g. thin-film types – some of these types more suitable for special applications.

However, for subsidized off-grid applications in rural Vietnam it is in general recommended only to use certified PV modules of the mono- or polycrystalline Silicon technology, as they have the best track record, the longest lifetime and the best market availability.



There are two basic types of PV systems as illustrated to the right.

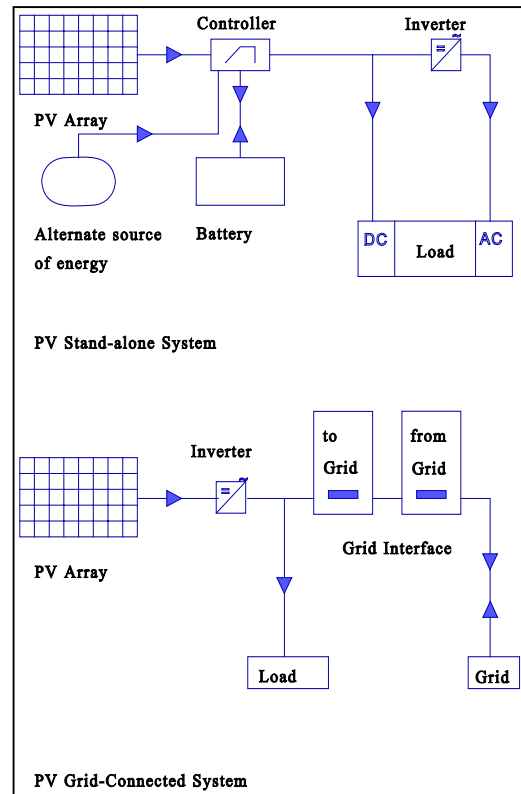
- stand alone systems
- grid-connected systems

The *stand-alone PV system* consists typically of a PV array, a storage battery to provide electricity when there is no light, a controller to govern the state-of-charge of the battery and to distribute electricity to one or several loads.

The controller normally also include some indicators or a display to inform about state of operation and may have switches for manual control.

A diesel generator or another source of electricity may be connected to the PV system in order to provide additional power.

The output from the controller is in the form of DC (direct current), which can be used to power lights, a fan, a radio or a TV, a computer or other appliances which can operate on DC.



If AC (alternating current) is needed an inverter is applied to convert the DC to AC.

In a typical *grid connected PV system* the output of the PV array is feed directly into an inverter. The AC output of the inverter can be used to power a local AC load or be feed into the electric grid via a grid-interface. As the PV array capacity normally will be insignificant compared to the capacity of the grid, all available power will be feed into the grid acting as an immense power sink. When the inverter output is insufficient to power the local AC load additional power can be supplied from the grid. Most inverters for grid-connected applications switch off automatically if the grid fails for reasons of person safety and material protection.

If the PV array capacity is significant compared to that of the grid, e.g. in a small hybrid PV / diesel generator system, a special type of inverter or a more complicated system configuration will be needed.

It is worth noting, that PV systems for water pumping in many ways will exhibit characteristics similar to that of a grid connect PV system.

*The main characteristics of applied PV technology can be summarized as:*

- ◆ a PV system can be implemented almost anywhere very close to the actual load advocating de-central and relatively small scale applications; however, the PV array shall have a free field of insolation (no shadowing by obstacles);
- ◆ Due to reasons of high cost PV technology will normally only constitute a least cost solution in connection with relative small electrical loads; PV technology can be combined with other generators of electricity forming a hybrid system, which may viably serve bigger electrical loads;

- ◆ PV technology exhibit very low scale-of-economy, and there is normally few if any reasons to centralize and up-scale PV systems;
- ◆ PV technology is expensive and it will normally be worthwhile to optimize balance between PV system size and load, e.g. primarily use high efficiency electric appliances in order to reduce PV system size and cost;
- ◆ the modular nature of PV technology and the above strong linkage to size of the load very often advocates the use of a number of standard PV “packages” including the relevant appliances, each package targeting a specific service or combination of services. Provision of PV packages tend to reduce cost of design, procurement, installation and maintenance;
- ◆ PV technology is environmentally benign provided that eventually spent batteries are adequately recovered and recycled. Recycling techniques exist for all PV system components;
- ◆ economic system lifetime normally varies from 10 to +30 years depending on system size and configuration – energy pay-back time for a PV system will typically range between 3-5 years;
- ◆ although maintenance requirements are few and relatively easy to master a competent and dedicated maintenance scheme is crucial for the performance, reliability and lifetime of a PV system;
- ◆ PV is a mature technology for which a number of internationally recognized standards, recommended practices and guidelines can be found provided by organizations<sup>1</sup> such as the IEC, the PV-GAP, the IEA, the EU, the World Bank and a range of other international, regional and national certification laboratories, engineering organizations and standard associations. Recommendations and guidelines encompass technical, institutional, financial and maintenance issues;
- ◆ PV systems can be analyzed and designed using relatively simple manually techniques or using free or commercial simulation software of various degrees of sophistication;

In order to assess the technical, economic, institutional, social and environmental viability of a PV project a number of data is needed and certain methodologies are recommended. These will be detailed in the following sections.

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<sup>1</sup> IEC: the International Electrotechnical Committee; PV-GAP: the PV Global Accreditation Programme; IEA: the International Energy Agency; EU: the European Union.

## 2. Methodology to Identify and Investigate Potential PV projects

### 2.1 General Aspects

A considerable amount of data of and experience with PV technology and projects have been accumulated over the last two to three decades. In an ongoing process this information is being collected and analyzed by international bodies such as:

1. The International Energy Agency (IEA) Photovoltaic Power Systems (PVPS) Implementing Agreement, which deals with PV technology also for developing countries. Much data, experience and many guidelines are available, see [www.iea-pvps.org](http://www.iea-pvps.org).
2. The World Bank REToolkit, which presents data and methodologies for the preparation and assessment of renewable energy (RE) projects including PV, see [www.worldbank.org](http://www.worldbank.org) (search: REToolkit).
3. The Global Environment Facility (GEF), which has reported on the experience with PV projects in many developing countries, see: [www.gefweb.org](http://www.gefweb.org).

Standards for PV technology and systems are well developed and documented by international bodies such as:

1. The International Electrotechnical Committee (IEC), see: [www.iec.ch](http://www.iec.ch)
2. The PV Global Accreditation Programme (PV-GAP), see: [www.pvgap.org](http://www.pvgap.org).

More resources and tools including software relating to the PV technology are mentioned in chapter 5 of this document.

*Based on these significant international resources and on experience with applied PV technology from many developing countries the present document has been developed as an easy to use tool to help develop and assess PV projects in Vietnam.*

A typical PV project will include either a number of small systems, e.g. for electrification of households or small rural institutions or a single or a few more large scale systems, e.g. community - often hybrid<sup>2</sup> - electrification systems.

The first step of the procedure leading to the compilation of an “Investment Opportunity Report” will be to collect a number of data in a combination of desk and field work. The second step will be to analyze the data and assess the results.

The tool for the first step includes the following issues:

1. General information and information on site / sites
2. Insolation, ambient temperatures and evt. supplementary climate data
3. Existing and future risks of shadowing of PV array
4. Electrical loads and growth projection
5. Preliminary technical specifications
6. Grid extension / alternative electrification projects
7. Tariffs, tariff collection, ability and willingness to pay
8. Institutional issues

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<sup>2</sup> PV technology can co-generate with other sources of electricity such as diesel generators, wind generators, small hydro generators, etc.

9. Enabling environment, socio-economic details (also theft, vandalism flora fauna)
10. Maintenance issues
11. Need of training
12. Environmental issues
13. Estimated project investment cost
14. Estimated project recurrent cost
15. First financial assessment
16. Appendices

The tool (questionnaire) in the next section can be used for a professional screening of potential PV projects, as it provides all the information necessary for the compilation of an Investment Opportunity Report and the subsequent assessment of that report.

## 2.2 Reference Tool to Prepare PV Investment Opportunity Reports

NB! The Tool encompass data for up to three different categories or types of PV systems in the same project, data for each category indexed as appropriate: <sub>1, 2 or 3</sub>. If several different load & PV system categories are included describe in the same format as the Tool but in annex to be attached and clearly referenced.

More detailed narratives may be annexed to the questionnaire – if so please make clear reference to the annex.

<b><u>1. General</u></b>	<b>Instructions</b>
Name of project:.....	Reference name of project
Main project objective:..... ..... .....	Brief description of main project objective, e.g.: “!PV electrification of 100 households by individual PV systems”, or “PV system in support of existing diesel powered mini-grid system”.
Location:.....	
Commune (-s) / Village (-s): ..... .....	
Province / District (-s):..... .....	
Contact person (-s):..... ..... .....	Name of local contact person (-s) and how to contact.
Date of completion of questionnaire:...../...../.....	
Questionnaire completed by.....:	
Signature:..... Phone / e-mail:.....	
<b><u>2. Description of Site (-s) / Area (-s)</u></b>	
Describe topography: ..... ..... .....	Site/Area description with focus on being able to establish and keep a free field of insolation for the PV array (-s), e.g.: flat or hilly, trees or other vegetation, open land, ridge or ravine, etc.
Special local conditions:..... .....	General local conditions that may affect a PV system, e.g.: salty air (corrosion risk), risk of fog, dusty air, risk of lightning, etc.

<p>Shadowing:.....:.....</p> <p>.....</p> <p>Risks:.....</p> <p>.....</p> <p>.....</p> <p>Accessibility:.....</p> <p>.....</p> <p>.....</p> <p>All year access:.....[Yes/No]</p>	<p>General risks of shadowing array (-s) e.g.: by trees, bird droppings, high horizon, etc.</p> <p>Assess and describe factors, which may have destructive influence on PV system, e.g.: plants, animals, vandalism, theft, landslides, earthquakes, etc.</p> <p>Describe the general accessibility of the site (-s) with focus on transport of material and initial installation and on periodic maintenance visits.</p>
<p><b><u>3. Grid Extension of EVN / other electrification projects</u></b></p> <p>Closest EVN grid point:.....</p> <p>Direct distance:..... [km]</p> <p>Plan to extend the grid to the PV site (-s)?..... [Yes / No]</p> <p>Other plans to electrify the site (-s) / area (-s)? .....</p> <p>.....</p> <p>.....</p> <p>Any other PV system (-s) in the area and if so what is the experience?</p> <p>.....</p> <p>.....</p>	<p>Indicate the end point of the EVN grid and the direct distance to the intended PV site (-s).</p> <p>Indicate any known proposals or plans to bring electricity closer the intended PV site (-s) area (-s).</p> <p>If other PV systems exist in the area list the name of the site/pro-ject and briefly indicate the expe-rience with the system (-s)</p>
<p><b><u>4. Solar Resource &amp; Other Climate Data</u></b></p> <p>Solar irradiation data:.....</p> <p>.....</p> <p>.....</p> <p>Max., min. and average insolation [kWh/m<sup>2</sup>/day]:.....</p> <p>.....</p>	<p>Specify source, location (-s) and format of solar irradiation data to be used in designing the PV system, e.g.: Institute of Meteorology and Hydrology (IMH), DaNang, average daily global irradiation per month.</p> <p>Indicate seasonal variation in irradiation.</p>

<p>Additional climate data:.....  .....  .....</p>	<p>Specify source, location (-s) and format of eventual additional climate data relevant in design of PV systems, e.g.: ambient temperature, cloud cover /clearness index, precipitation, etc.</p>
<p><b><u>5. Load data</u></b></p> <p>General description of the electrical load (-s) to be supplied:  .....  .....</p> <p>Estimated average daily load per PV system category:  Category 1: <math>P_{c1} = \dots\dots\dots</math> [average kWh/day]  Category 2: <math>P_{c2} = \dots\dots\dots</math> [average kWh/day]  Category 3: <math>P_{c3} = \dots\dots\dots</math> [average kWh/day]</p> <p>Number of PV systems per category:  Category 1: <math>N_{c1} = \dots\dots\dots</math>  Category 2: <math>N_{c2} = \dots\dots\dots</math>  Category 3: <math>N_{c3} = \dots\dots\dots</math></p> <p>Load vary regularly by day/week/month?.....[Yes/No]</p> <p>If Yes, can load profile (-s) be established?..... [Yes/No]</p>	<p>Specify the load (-s) to be supplied by the PV system (-s), e.g.: households, institutions, mini-grid, mini-grid with other power source,</p> <p>Indicate estimated average load or output per PV system or category of PV system. If several different load &amp; PV system categories are included describe in annex to be attached.</p> <p>Specify total number of PV systems per category.</p> <p>Indicate if the load (-s) vary regularly, e.g. day, week or month.</p> <p>Indicate if load profile (-s) (load variations with time) can be documented.</p>
<p><b><u>6. Preliminary Technical Specifications</u></b></p> <p>Estimated average irradiation: <math>I = \dots\dots\dots</math> [kWh/m<sup>2</sup>/day]</p> <p>Estimated average daily load: <math>E = \dots\dots\dots</math> [kWh/day]</p> <p>Estimated PV system efficiency: <math>\eta</math>  <math>\eta = 0,85</math> for grid connected PV system  <math>\eta = 0,7</math> for stand alone system with DC load (-s)  <math>\eta = 0,6</math> for stand alone system with AC load (-s)</p> <p>Estimated PV array size: <math>P_a = E / (I \times \eta)</math> [kWp]</p> <p><math>P_{a1} = \dots\dots\dots</math> [kWp]</p> <p><math>P_{a2} = \dots\dots\dots</math> [kWp]</p> <p><math>P_{a3} = \dots\dots\dots</math> [kWp]</p>	<p><b>Note:</b> The calculations performed in this section is only to provide a first estimate of PV system (-s) and a base for later economic estimates, and should <b>not</b> be used for any concrete system sizing.</p> <p>Perform a preliminary calculation of the needed PV array size per category of PV systems.</p>

List expected nominal PV module capacity to configure PV array:

Table 1.

Array	Nominal module capacity [Wp]	No. of modules in series	No. of modules in parallel	Total no. of modules [Nm]
Array 1				[Nm <sub>1</sub> ]
Array 2				[Nm <sub>2</sub> ]
Array 3				[Nm <sub>3</sub> ]

Required PV system time of autonomy: N [days]

$$N_1 = \dots\dots \text{ [days]}$$

$$N_2 = \dots\dots \text{ [days]}$$

$$N_3 = \dots\dots \text{ [days]}$$

Estimated battery charge/discharge efficiency:  $C_\eta = 0,95$

Estimated max. battery discharge factor:  $B_f = 0,6$

Estimated battery nominal voltage:  $V_B = \dots\dots\dots \text{ [V]}$

Estimated battery capacity:  $B_C \text{ [Ah]}$

$$B_C = (E \times N \times 1000) / (V_B \times B_f \times C_\eta) \text{ [Ah]}$$

$$B_{C1} = \dots\dots\dots \text{ [Ah]}$$

$$B_{C2} = \dots\dots\dots \text{ [Ah]}$$

$$B_{C3} = \dots\dots\dots \text{ [Ah]}$$

List expected nominal battery cell or block capacity and voltage [Ah@V] to configure battery:

Table 2.

Battery	Nominal cell or block capacity [Ah@V]	No. of cells or blocks in series	No. of cells or blocks in parallel	Total no. of cells or blocks
Battery 1				[Nb <sub>1</sub> ]
Battery 2				[Nb <sub>2</sub> ]
Battery 3				[Nb <sub>3</sub> ]

Specify the expected PV modules to be used to configure the array (-s).

**Note:** the total number of PV modules times the nominal capacity shall approximately correspond to Pa, and the number of PV modules in series times the nominal module voltage shall correspond to the battery voltage Vb.

**Note:** N should normally not be less the 3.

If several different load & PV system categories are included describe in annex to be attached.

Battery average coulombic efficiency.

The fraction of the nominal battery capacity to be used.

Indicate expected battery (and PV array) voltage.

For stand-alone systems perform a preliminary calculation of the required battery capacity per category of systems.

**Note:** This battery calculation presumes insolation with little seasonal variation.

If several different PV system categories are included describe in annex to be attached.

Specify the expected selection of battery cells or block of cells to be used to configure the battery.

**Note:** the total number of battery cells or blocks times their nominal capacity shall approximately correspond to Bc, and the number of battery cells or blocks in series times their nominal voltage shall correspond to the battery voltage Vb.

**7. Estimated income from PV System (-s)**

Value of electricity per category of system:

Category 1:

a) monthly flat rate:  $Tf_1 = \dots\dots\dots$  VND/month

b) metered:  $Tem_1 = \dots\dots\dots$  VND/kWh

Category 2:

a) monthly flat rate:  $Tf_2 = \dots\dots\dots$  VND/month

b) metered:  $Tem_2 = \dots\dots\dots$  VND/kWh

Category 3:

a) monthly flat rate:  $Tf_3 = \dots\dots\dots$  VND/month

b) metered:  $Tem_3 = \dots\dots\dots$  VND/kWh

Income calculation (F: flat rate; M: metered)

Table 3.

Catego.		Calculation	Subtotal
			[VND]
Cat. 1	F	$Tf_1 \times Nc_1 \times 12 = \dots\dots\dots =$	
	M	$Pc_1 \times Tem_1 \times Nc_1 \times 365 : \dots\dots\dots =$	
		Total annual income Category 1: $It_1 =$	
Cat. 2	F	$Tf_2 \times Nc_2 \times 12 = \dots\dots\dots =$	
	M	$Pc_2 \times Tem_2 \times Nc_2 \times 365 : \dots\dots\dots =$	
		Total annual income Category 2: $It_2 =$	
Cat. 3	F	$Tf_3 \times Nc_3 \times 12 = \dots\dots\dots =$	
	M	$Pc_3 \times Tem_3 \times Nc_3 \times 365 : \dots\dots\dots =$	
		Total income Category 3: $It_3 =$	
Extra		Total extra income (spec. below): $It_E =$	
Total		Total annual income: $It_1 + It_2 + It_3 + It_E = It_A =$	

specify eventual extra incomes:.....

.....  
 .....  
 .....

**8. Enabling environment**

General interest & understanding:.....  
 [Good/Fair/Poor/None]

Awareness of need to pay for electricity:.....  
 [Yes/Some/No]

Knows PV benefits and limitations:.....  
 [Yes/Some/No]

Name and sectors of relevant organizations (NGOs, women's, youth, unions, others etc. active in the area:

Specify expected value/tariff of electricity per PV system category.

**Note:** Flat rate presumes SHS

If several different PV system categories are included describe in annex to be attached.

Calculate expected income per category of systems per year according to estimated tariffs.

If several different PV system categories are included describe in annex to be attached.

List and specify eventual extra or additional incomes, e.g.: from sale of electricity to special purposes.  
 Add the total extra annual income ( $It_E$ ) to Table 3 and calculate the total annual income ( $It_A$ ).

Rate the interest and understanding of the local people to receive the PV electricity. Assess whether they appear to be aware of the main benefits and the limitations of the PV technology, and the usefulness and danger of electricity.  
 Note the names of any organization (NGO, union, agency etc.), which could be of support to the project and briefly describe how they could provide help to the PV project.

<p>.....</p> <p>.....</p> <p>How can they assist the PV project and evt. other comments:</p> <p>.....</p> <p>.....</p> <p>.....</p>	
<p><b>9. Management / Institutional set-up</b></p> <p>Has the organization or set-up proposing the project any previous experience with PV projects:.....[Yes/No]</p> <p>If Yes describe the experience (-s):.....</p> <p>.....</p> <p>.....</p> <p>Is any organization (cooperative, community based or company) already existing that has the capacity to take over the PV project management / ownership:</p> <p>.....</p> <p>Contact details:.....</p> <p>Proposed ownership (private, company, community, government):</p> <p>.....</p> <p>.....</p> <p>Entrepreneurial spirit level:.....[high/medium/low]</p> <p>Envisaged community participation level:..... [high/medium/low/none]</p> <p>Comment:.....</p> <p>.....</p> <p>.....</p> <p>Availability of skilled local people:</p> <p>-managerial/business skills:.....(good, fair, poor)</p> <p>-technical/mechanical skills:..... (good, fair, poor)</p> <p>Comments:.....</p> <p>.....</p>	<p>Indicate if the project proposer (-s) has any previous experience with PV technology and/or PV projects.</p> <p>Describe previous PV experience (-s) and their location.</p> <p>Specify any existing organization with capacity to viably take over management / ownership of the PV project, and if found specify contact details.</p> <p>Specify the ownership structure proposed for the PV project.</p> <p>Estimate the level of entrepreneurial ability of the management compared to that of other business people of the area (-s).</p> <p>Assess the expected level of community participation in the PV project, e.g.: is the community involved in setting tariff/value rates, how to handle payment defaulters, etc.</p> <p>Assess whether access to PV electricity can be expected to keep and/or to attract more skilled persons to the area (-s).</p>

**10. Environmental issues**

Main environmental problem of PV technology relates to spent batteries. Is a collection scheme for spent batteries included in the project:.....[Yes/No]

If Yes, how does it work:.....  
 .....  
 .....

How are the collected batteries disposed of:.....  
 .....

Where will the disposal take place:.....

Are implementation of the envisaged PV systems expected to have any negative impact on the local environment:.....[Yes/No]

If Yes, comment:.....  
 .....

PV technology is in general environmentally benign. However, eventual spent batteries should be collected and safely disposed of. Specify whether a battery collection scheme is part of the project and if yes – how it is supposed to work.

Specify how collected batteries will be disposed of, e.g. recycling, safe waste treatment, etc.

Specify the location of the disposal, e.g. where in Vietnam, outside of Vietnam.

Assess any negative environmental impacts due to the implementation and operation of the PV systems.

**11. Socio-economic details**

Ethnic groups in project area (-s):

Table 4.

Ethnic Group	No. of HHs	Comments
<b>Total</b>		

What is the percentage of households in the area (-s) that will gain access to electricity through this project?  
 .....  
 .....

List the distribution of the various ethnic groups in the supply area (-s) according to number of house-holds.

The total number of households should correspond to/reflect the numbers mentioned under section 4 (NC<sub>1-3</sub>).

If more than one area is included in the PV project repeat this step in a an annex according to the actual number of areas

Indicate the share of households in the area which will gain access to electricity through the project.

Table 5.

Occupation / Income Source	No. of HH	Involved Members	Women Involved	Comments
Agriculture				
Army Pension				
Business				
Employee				
Labourer				
Money lending				
Pottering				
Other.....				
<b>Total</b>				

Average household land holdings in area:.....

List the distribution of occupations or income sources across the supply area and include the number of members of the households involved in the occupation and the number of women involved. Note that one household may be involved in more than one occupation / income source, and one person may also be involved in more than one.  
 "Employee" means employed by either private company or public / government institutions. The total households may not correspond to/reflect those of NC<sub>1-3</sub> (section 4) because some / most households may have more than one occupation or income source.

**12. Estimated project cost**

a) Estimated cost of main PV system components:

Table 6.

Type:	Capacity/ Unit:	VND/ unit	Comments (\$ = USD)
Module 1	[Wp]	=[Mr <sub>1</sub> ]	
Module 2	[Wp]	=[Mr <sub>2</sub> ]	
Module 3	[Wp]	=[Mr <sub>3</sub> ]	
Battery 1	[Ah@V]	=[Br <sub>1</sub> ]	
Battery 2	[Ah@V]	=[Br <sub>2</sub> ]	
Battery 3	[Ah@V]	=[Br <sub>3</sub> ]	
BoSa	5 [\$ /Wp]	75.000 =[Sr <sub>1</sub> ]	
BoSb	5 [\$ /Wp]	75.000 =[Sr <sub>2</sub> ]	
BoSc	7 [\$ /Wp]	105.000 =[Sr <sub>3</sub> ]	
Spare parts (all)	5 % of initial system cost		Factor: 1,05
Contingencies	10 % of initial system cost		Factor: 1,10

NB! BoSa: for grid connected PV systems, estimated at USD 5/Wp

BoSb: for stand-alone systems with DC load, estimated at USD 5/Wp

BoSc: for stand-alone systems with AC load, estimated at USD 7/Wp

b) Estimated cost of transport and installation, etc:

Table 7.

Type:	Capacity/ Unit:	VND/ unit	Comments
System category 1	Cost/system	=[Or <sub>1</sub> ]	
System category 2	Cost/system	=[Or <sub>2</sub> ]	
System category 3	Cost/system	=[Or <sub>3</sub> ]	

c) Estimated total cost per PV system in a category:

Cost of PV system category 1: [Cr<sub>1</sub>]

$$Cr_1 = ((Nm_1 \times Mr_1) + (Nb_1 \times Br_1) + (Pa_1 \times BoSx)) \times 1,05 \times 1,10$$

$$Cr_1 = \dots \dots \dots = \dots \dots \dots [VND]$$

Cost of PV system category 2: [Cr<sub>2</sub>]

$$Cr_2 = ((Nm_2 \times Mr_2) + (Nb_2 \times Br_2) + (Pa_2 \times BoSx)) \times 1,05$$

$$Cr_2 = \dots \dots \dots = \dots \dots \dots [VND]$$

Cost of PV system category 3: [Cr<sub>3</sub>]

$$Cr_3 = ((Nm_3 \times Mr_3) + (Nb_3 \times Br_3) + (Pa_3 \times BoSx)) \times 1,05$$

$$Cr_3 = \dots \dots \dots = \dots \dots \dots [VND]$$

d) Estimated total project investment cost: [Tr]

$$Tr = (Cr_1 \times Nc_1) + (Cr_2 \times Nc_2) + (Cr_3 \times Nc_3)$$

$$Tr = \dots \dots \dots = \dots \dots \dots [VND]$$

List and specify estimated cost of main PV system components. If several different PV system categories are included describe in annex to be attached.

List expected PV modules as to capacity (ref. Table 1 on PV modules in point 6) and specify expected cost per module. List expected battery cells or blocks as to capacity and voltage (ref. Table 2 on battery cells or blocks in point 6) and specify expected cost per cell or block.

The cost of the rest of the PV system components, the Balance-of-System (BoS), have been predetermined for typical PV system based on global market cost levels and experience. Spare parts are set at 5 % of initial PV systems investment. Contingencies are set at 10 % of initial PV systems investment.

**Note:** If precise local cost data will be available, use them instead of the predetermined data.

Specify estimated average cost per PV system category for transport of materials to site, installation and commissioning and initial end-user training.

Calculate the estimated investment cost of a PV system for each category.

**Note:** select the BoS figure to be included in the formula from the above Table 6 according to type of PV system, e.g. stand-alone with DC load, stand-alone with AC load etc.

Calculate the estimated investment cost of all categories, that is the estimated total project investment cost related to PV systems.

<p>e) Estimated other project costs: [To]</p> <p>Type:.....Cost:.....[VND]</p> <p>Type:.....Cost:.....[VND]</p> <p>Type:.....Cost:.....[VND]</p> <p style="text-align: center;">Total other project cost [To] .....[VND]</p> <p>f) Estimated total project investment cost: [Tt] Tt = Tr + To</p> <p>Tt=.....=[VND]</p>	<p>List eventual other project cost not related to PV systems.</p> <p>Add the other costs to the total other cost [To].</p> <p>Calculate the total estimated project investment cost.</p>
<p><b><u>13 Estimated annual recurrent costs</u></b></p> <p>A) For PV systems with battery (per system):</p> <p>Cost for regular system maintenance: [Abm] Abm = Cr x 0,04 (~ 4 %/year)</p> <p>Cost for replacement of components: [Abr] Abr = Cr x 0,06 (~ 5 %/year)</p> <p>Total cost for annual recurrent cost: [Abt] Abt = Abm + Abr (~ 9%/year)</p> <p>B) For PV systems without battery (per system):</p> <p>Cost for regular system maintenance: [Am] Am = Cr x 0,02 (~ 2 %/year)</p> <p>Cost for replacement of components: [Ar] Ar = Cr x 0,03 (~ 3 %/year)</p> <p>Total annual recurrent cost: [At] At = Am + Ar (~ 5%/year)</p> <p>C) Equipment related annual recurrent cost: [Ap] For each category (indeks 1-3) of PV systems calculate: - if with battery: Nc<sub>x</sub> x Abt - if without battery: Nc<sub>x</sub> x At Ap = (Nc<sub>x</sub> x Abt) + (Nc<sub>x</sub> x At)</p> <p>Ap:.....[VND]</p>	<p>Estimate and list the recurrent cost in the project:</p> <ul style="list-style-type: none"> <li>- regular maintenance (O&amp;M)</li> <li>- replacement of components</li> </ul> <p>The given factors for regular maintenance presumes bi-annual service visits to PV systems with batteries and annual service visit to PV systems without batteries, and battery replacement every 4<sup>th</sup> year.</p> <p>The factors given here are based on international averages, but can in reality differ somewhat depending on number and geographical spread of PV systems and type &amp; quality of components.</p> <p>Note: Service visits should be carried out by trained and competent technician, e.g. by the suppliers staff under long term contract or similar.</p> <p>Calculate the total equipment related recurrent costs. Note: Remember which PV system category includes batteries and which do not. If several different PV system categories are included describe in annex to be attached.</p>

<p>D) Other annual recurrent costs: [Aop]</p> <p>Type:.....Cost:.....[VND]</p> <p>Type:.....Cost:.....[VND]</p> <p>Type:.....Cost:.....[VND]</p> <p>    Total other recurrent cost [Aop] .....[VND]</p> <p>E) Project annual recurrent cost: [As]</p> <p>As = Ap + Aop</p> <p>As = .....=.....[VND]</p>	<p>List eventual other non-equipment related annual recurrent costs, e.g. cost of tariff collection, etc. Add the costs listed.</p> <p>Calculate the total project annual recurrent cost.</p>
<p><b><u>14. Preliminary financial assessment</u></b></p> <p>Annual income (Ita, point 7): .....[VND]</p> <p>Annual recurrent cost (As, point 13).....[VND]</p> <p>Difference Ita – As: .....[VND]</p> <p>Calculated NPV of surplus: ..... [VND]</p> <p>Calculated need of subsidy: .....[VND]</p>	<p>Compare the annual income to the annual recurrent cost. If the income is less than the cost the project will not be sustainable even with a 100 % investment subsidy. If the income is higher than the recurrent cost it is recommended to calculate the net present value (NPV) of the surplus over the estimated project/system lifetime and this way estimate the necessary investment subsidy. Attach these calculations as an annex.</p>
<p><b><u>15. Annexes</u></b></p> <p>List below the items annexed to this document</p> <p>Annex 1:.....</p> <p>Annex 2:.....</p> <p>Annex 3:.....</p> <p>Annex 4:.....</p> <p>Annex 5:.....</p> <p>Annex 6:.....</p> <p>Annex 7:.....</p> <p>Annex 8 :.....</p> <p>Annex 9 :.....</p>	<p>List all documents annexed to the present document.</p> <p>If possible include photos of sites and areas as an annex.</p>

### 3. Methodology for preparation and assessment of solar PV investment Project Reports.

The method described in this chapter can be used for both the preparation and the assessment of the Investment Project Report. For preparation of the report, besides the general requirements as to content as described in the following sections, also the annex 1 “Guidelines for a detailed solar PV Investment Project” should be consulted and considered.

The detailed Investment Project Report should cover the solar resource, the power demand and end-use possibilities, the technical viability, policy, institutional and social issues, environmental aspects, project costs and financial issues. In the following sections an appropriate format and the required contents of the report are presented. The report should be consistent and kept as brief as possible while containing all necessary information including the technical aspects. The following sections provide an overview of the issues that should be covered. The presented summaries on requirements also provide a tool to verify the accuracy and to check the completeness and sufficiency of Investment Project Report submitted, respectively Investment Projects. For a more detailed assessment of a solar PV project Investment Project Report, the annexes, as mentioned above, should be consulted.

#### 3.1 Major data and parameters

At the start of the report a listing of major data and parameters should be compiled. An example of such data and parameters is presented below. The consultant (or the editor of the study) should add further site and/or project specific information pertinent for the scheme.

##### Example: Data and parameters

Location:	Village/District/Province
Main purpose of project	E.g. : Electrification of 200 households, co-generation with exiting diesel generator
Single or multiple PV systems	No.
Location and distance to nearest grid point	Name, km
Available insolation data	Source, site and format, e.g. IHM, Da Nang, kWh/m <sup>2</sup> /day/month
Available additional climate data	Max, min. and average ambient temperatures, etc.
Type of PV system (-s)	Grid connected, stand-alone DC, stand-alone AC
Nominal capacity of PV system (-s)	kWp
Nominal average load per PV system	kWh/day
Type of PV module (-s)	Make, cell type, Wp, VDC
Type of charge controller (-s)	Make, A, VDC
Type of battery (-ies)	Make, battery type, Ah, VDC
Type of inverter (-s)	Make, kW
Total beneficiary households	No.

Other beneficiaries	Specify
Ownership	Type (community, business, private, etc) and name
If batteries included in PV systems	Battery recollection scheme foreseen? Yes/No
Cost per Wp	VND/Wp
Proposed tariff	VND/kWh or VND/month
Total annual income	VND
Total annual recurrent cost	VND
Total project cost	VND
Proposed subsidy	VND
Additional finance	Type (loan, equity etc.), VND

### 3.2 Summary and technical viability

A brief summary of the report should be presented including the main findings, conclusions and recommendations. It should be clearly stated in this section whether the project is technically viable and financially feasible and thus is recommended for implementation. The statement on the overall viability of the project should be based on the content of the report.

### 3.3 Background

Information regarding how the need or demand for the detailed Investment Project came about should be discussed in this section. Similarly, the location of site or sites, accessibility, transport possibilities for materials, time of site (-s) visit (-s) and list of professional staff involved should be mentioned in this section.

### 3.4 Methodology

The methodology employed to undertake the study should be briefly explained and described. This should include a description of the survey work, data availability and data collection, summary of community meetings, other sources of socio-economic data and how the information collected were analyzed.

### 3.5 Power demand

The demand for power and end use possibilities should be stated in the report. The primary use of solar PV systems in the rural context of the country is for household lighting and radio and TV. Thus, in order to optimise the use of the PV system (-s) plant (and thus increase the financial feasibility), the installed capacity should be governed by the demand of households using high efficiency appliances. This power demand can be met by several approaches:

- ◆ A central PV battery charging station, where households weekly bring their batteries for re-charging; this solution provides very limited access to electricity.
- ◆ A small PV system at each household – a so called Solar Home System (SHS).
- ◆ A central PV system feeding a local distribution grid.
- ◆ A hybrid system feeding a local distribution grid, where the PV system co-generates with another source of electricity, e.g. a diesel generator.

The choice between approaches is mainly determined by level of ambition as to electrification and of course economic constraints. The distance between individual household plays an important role when choosing between a SHS approach or a central system with distribution grid.

However, also other small scale special productive end uses (non-lighting uses) can be considered as complement to the household use, e.g. charging of mobile phones, powering of computers, powering of internet connectivity. PV technology is also often a least cost solution for provision of small scale electricity to rural institutions such as schools, health clinics and administrative facilities. Access to small amounts of electricity can vastly improve the service of such rural institutions. However, other approaches to sizing the plant capacity may also be proposed, provided that the financial feasibility can be demonstrated. In order to access the power requirements, the number of beneficiary households and the average power demand per household should be determined based on discussions with the community, and with focus on the use of high efficiency appliances in the households. As mentioned earlier attempts should be made to find the optimal balance between the solar PV technical and economical characteristics and the local demand for electricity.

A list a typical high efficiency appliances and their demand for electricity is given in Table 4.1

**Table 4.1.:** Example of high efficiency appliances with required capacities and operating times

Appliance:	Power [W]	Typical number	Daily use [hours]	Daily power consumption [Wh]
Indoor light	11	3-5	4	132-220
Outdoor light	8	1-2	12	96-192
Radio	10	1	8	80
TV (BW)	20	1	5	100
Fan	15	2	12	360

Summarising, the relevant chapter of the Investment Project Report should briefly discuss how the installed capacity has been determined based on the demand for electricity. The number of households to be electrified and average power allocation per household should be stated. The type of special end uses and the corresponding capacities, operating hours, estimated days in a year that such end uses are expected to be operated should be stated. The intended approach to PV system design, ref. the above mentioned four approaches, should be discussed and argued. Considerations for future expansion (if any) and eventual system losses assumed to arrive at the installed generating capacities should also be discussed.

**3.6 Technical design**

This section should present the selection, design and sizing of the various technical components of the solar PV project. Sub-sections should be used to discuss the individual components of the scheme. The technical aspects that should be covered in the report (text) and the corresponding drawings required are presented in Table 4.2. The technical design (i.e., text and drawings) should be presented such that in its basis, a competent contractor is able to quote a price within reasonable limits for the implementation of the scheme. Furthermore, the contractor should be able to source components, construct (or supervise construction of) the necessary structures and to install equipment. It should be noted that detailed specifications and construction drawings are not essential but the basis for working specifications and drawings should be incorporated.

**Table 4.2:** Technical requirements for detailed solar PV Investment Project Report

<b>Drawings</b>	<b>Description of Drawings</b>	<b>Corresponding details required in Report</b>
a. Project area map	Show the project area including the area covered by the eventual distribution lines based on available published maps (e.g., district maps etc.).	Mention the location of the project, accessibility, routes to site and communities/villages covered by the individual PV systems or the distribution network.
b. General layout plan of the scheme	Show/specify locations of all PV systems.	Brief description of scheme layout, including approach to overall PV system configuration, ref. section 5. The technical and economic feasibility of different approaches or options should be compared.
c. Site (-s) lay-out	Sketch the site lay-out around the PV array and indicate any obstacle between the array and the daily path of the sun over the year, e.g. building, vegetation, mountains/ridges etc. For PV arrays > 2 kWp include panoramic photos from center of array site.	Brief description of the site surrounding the PV array specifying any shadowing obstacle and the risk of shadowing occurring in the future (vegetation, new constructions, wildlife, etc.)
d. PV system (-s) lay-out	For each category of PV systems sketch the overall physical lay out including location of PV array, eventual storage batteries, power electronics and eventual main distribution cubicle.	Location, dimensions and type of key components and support structures. Specify eventual fencing of site/array and the reason the fence (wildlife, risk of theft/vandalism, person safety, etc.)
e. Loads	Specify for each category of PV systems how the electric load is configured and connected.	Specify how the load data has been acquired or determined and the degree of data accuracy. Specify what will be done to minimize risk of not known loads being connected (overloading of PV system).
f. System configuration	For each category of PV systems show in diagram the system design and electrical interconnections. Indicated the orientation and tilt of the PV array. Indicate grounding system and interconnections. Indicate lightning protection system.	Provide information on how the overall sizing of the PV system (-s) has been carried out (insolation & climate data, sizing process/tools and selection of main components, wiring-length and dimensions). Describe considerations / facilities for later PV system expansion.

<p>g. Distribution</p>	<p>For eventual distribution system (-s) present a diagram of the system including lighting protection, grounding, fuses and eventual power limiters. A single line diagram is sufficient. Indicate the position of eventual electricity meters.</p>	<p><b>Type of system:</b> Mention the type of the system adopted.  <b>Conductor:</b> Mention type, size and length of conductor.  <b>Voltage drop:</b> Mention the voltage drop at each node of the distribution system.  <b>Poles:</b> Mention the specification (type, size number etc) of the poles in detail.  <b>Stay sets:</b> Mention the number of stay sets required.  <b>Lightning arrestors / Earthing:</b> Mention type, size and number of lightning arrestors and earthing required in the system  <b>Insulators / D-clamp:</b> Mention type, size and number.  <b>Service wire / cable:</b> Mention the type, size and length of the wire/cable. Also mention the length of the cable require per households.  <b>Load limiting device:</b> Give brief description of the load-limiting device to be installed in the house.  <b>Switch/Fuse unit:</b> Mention the type, size and number of switch/fuse unit installed at the branch points of the distribution system.  Describe considerations / facilities for later grid system expansion or eventual adding of additional generating capacity.</p>
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### 3.7 Socio-economic status

The number of beneficiaries, ethnic composition, general socio-economic condition of the area as well as existing end uses and the future prospects once electricity is made available should be discussed. Similarly, if certain areas in the vicinity of the project area are excluded from the beneficiary groups, the justification for such exclusion should be stated (e.g. technical difficulty, unwillingness of the households to participate etc.). Subheading may be used for clarity. Brief comments should be provided if socio-economic findings during the detailed Investment Project are significantly different from those of the Investment Opportunity Report.

### 3.8 Management and institutional set-up

The commitment of the developer/community to implement the scheme and the ability to own and manage the plant should be assessed. This should include the general perception of solar PV technology and its main characteristics, ref. the chapter 1. Introduction, and perception of the service of electricity of the developer and the community, the need for operation and maintenance of the PV systems as well as financial feasibility and sustainability issues.

Any institutions such as NGOs or government line agencies (Women's Union, Youth Union etc.), which are active in the project area and are likely to contribute in the implementation and operation of the scheme, should be contacted. The nature of assistance that such institutions may contribute should be assessed.

The respective chapter of the Investment Project Report should discuss the **ownership** of the scheme and the proposed **management structure**. The legal status (PLC, joint stock company, cooperative or other legal form of community based organisation) of the owner or group of owners should be mentioned. It should also be stated if the organisation form provides for any kind of community participation. Besides the issue of ownership, the description of the organisation form should also comment on the **repartition of responsibilities**, like technical operation and maintenance, accounting, tariff collection etc. and conclude if and how the sustainability of management and operation will be ensured on the long run (e.g. in case major repair/replacement is required). It should be stated whether the developer or an assigned organisation / subcontractor has the capacity to manage the PV systems, meaning that the capacity of future O&M and Management staff should be appraised. If necessary **training measures** for households and others and a corresponding budget should be specified in order to enhance necessary technical and managerial skills.

### 3.9 Project costs, income and financial analysis

Based on the technical design of the scheme, the total project implementation cost should be determined based on prevailing material, equipment, labour and transport rates that are specific to the site. Recurrent costs such as salaries to eventual operator, PV system maintenance costs as well as annual income should also be determined.

Based on discussions with the community members and/or the prospective developer, it should also be suggested how the scheme is to be financed (e.g., loan, community contribution/equity and external support/subsidy). Finally, the financial feasibility of the scheme as per defined requirements should be demonstrated.

In this section of the Investment Project Report, the estimated total project cost including a summarised bill of quantities with costs mentioned for the major components of all the PV system categories should be presented. The bill of quantities should be included as one of the appendices. The summary of costs and basis at which these figures were arrived at such as rate for local labour, material and transport/portering costs should also be presented. Annual operation and maintenance cost including number of staff required should also be included in this section. Similarly, estimated annual income including those from households and eventual other end uses and how these figures have been arrived at should be mentioned.

Finally, the financial feasibility of the scheme should be exhibited. A very basic requirement for sustainable operation of PV systems will be, that the annual total income is equal to or higher than the annual total recurrent cost. If this is not the case it should be highlighted how the annual deficit will be covered. For community based PV projects a significant external subsidy can be foreseen. In order to determine the subsidy required, the net present value of the eventual surplus (annual income vs. annual recurrent cost) should be calculated. The net present value (NPV) of

equity investment at different discount rates (e.g. 8 %, 10 %, 12 %) and 15 years of economic life should be calculated. Similarly, a cash flow table and the Internal Rate of Return (IRR) of the project should be calculated.

### **3.10 Policy issues**

The detailed Investment Project Report should adequately address policy issues required for the PV systems or project to be eligible for any potential subsidy support. These can include:

- Whether the national electricity grid is likely to reach the plant's distribution area within the next 5 years.
- Whether any adverse environmental impacts are possible due to the implementation of the scheme.
- Social considerations – access to electricity for remote communities
- Financial viability according to certain defined criteria (e.g. NPV)
- Cost per Wp of installed capacity

As policy requirements may change over time, it is recommended that the consultants analyses the policies that are applicable during the time of their studies.

### **3.11 Comments**

The differences in the design parameters between this study and the Investment Opportunity Report if any should be explained in this section. Any further comments that are essential to demonstrate the feasibility/unfeasibility of the scheme but do not fit in other (sub)-headings should be included here.

### **3.12 Project monitoring**

Renewable energy technologies provide reliable and often affordable energy supplies to millions of people in developing countries. Timely monitoring and evaluation is an important instrument for national authorities and communities and other organisations to build data and experiences and this way to create base for decision on new procedures, methodologies and concrete activities. Any intended monitoring actions and the target group (-s) for such monitoring should be included here.

### **3.13 Conclusions and recommendations**

This section should briefly summarise and conclude the study and provide recommendations for the implementation and operation phases. Conclusions and recommendations should be related to or justified by the text of the report and the data in the format provided. Based on the technical analysis and financial figures, a clear recommendation should be made to either proceed to the implementation phase or not.

### **3.14 Annexes**

The duly filled detailed pre-feasibility format (see chapter 2), drawings, photographs, flow measurement data sheet, bill of quantity (BoQ) and financial analysis and any other information that is relevant to demonstrate the feasibility of the scheme should be appended at the end of the report or included as a separate volume.

## 4. Further resources and tools regarding PV technology and systems

### 4.1 Bibliography

The following list of publications gives an overview on the most relevant publications for further technical, institutional, economical, environmental etc. details relevant for the development of solar PV projects:

The International Energy Agency, PVPS has published several high class reports and recommendations on PV technology and applications which all can be downloaded at : [www.iaepvps.org](http://www.iaepvps.org). The most relevant in this context are:

Financing mechanisms for SHS in Developing Countries

Summary of models for the implementation of PV SHS in developing countries

PV for rural electrification in developing countries – a guide to capacity building requirements

The role of quality management, hardware certification and accredited training in PV programmes in developing countries

PV for rural electrification in developing countries – programme design, planning and implementation

Institutional framework and financial instruments for PV deployment in developing countries

16 case studies on the deployment of PV technologies in developing Countries

The availability of irradiation data

Understanding temperature effect on PV system performance

Performance analysis of stand-alone PV systems from rational use of energy point of view

PV systems Performance Database (a comprehensive database on PV system performance, which is regularly up-dated)

Managing the quality of stand-alone PV Systems – Case studies

Managing the quality of stand-alone PV Systems – recommended practices

Survey of national and international standards, guidelines and QA procedures for stand-alone PV systems

Guidelines for monitoring stand-alone PV systems

Lead-acid battery guide for stand-alone PV systems

Testing of batteries used in stand-alone PV power supply systems

Recommended practices for charge controllers

Common practices for protection against the effects of lightning on stand-alone PV systems.

Problems related to appliances in autonomous PV applications

The RETScreen website, see below, includes besides software for PV system analysis also PV technology engineering textbooks, training materials and case stories, again free to download.

Comprehensive Information on tools for solar PV system development can also be found in the so-called **Renewable Energy Toolkit Webpage of the World Bank** which can be accessed on <http://www.worldbank.org/retoolkit>. REToolkit provides a broad set of tools to improve the design and implementation of renewable energy (RE) projects, incorporates best practices and lessons learned from RE projects, and is operationally oriented to address practical implementation needs at each stage in the project cycle. The toolkit helps to identify and design feasible RE projects, determine appropriate promotional policies, identify sustainable business models, finance mechanisms and regulatory frameworks - and utilize the best available project tools, including technical standards and generic terms of reference.

#### **4.2 Available software tools**

##### ***RETScreen:***

[http://www.etscreen.net/ang/d\\_o\\_view.php](http://www.etscreen.net/ang/d_o_view.php)

RETScreen software is available for different renewable energy technologies and for each of them includes an energy model, cost analysis, GHG analysis, financial summary and a sensitivity and risk analysis.

One of the software tools is a PV system project model to evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction of central-grid and isolated-grid connected projects, ranging in size from multi-turbine small and mini hydro installations to single-turbine micro hydro systems.

The software also includes product and weather (hydrology) databases and an online manual. Version 3 upgrades include a Metric/Imperial unit switch; updated product data; an enhanced GHG model to account for emerging rules under the Kyoto Protocol and a Sensitivity & Risk Analysis worksheet. The software is based on Microsoft Excel Worksheets and offers specific sheets for hydrology & load, equipment data and cost analysis. It is clearly arranged and easy to understand. From the RETScreen website one can also download engineering manuals for the various renewable energy technologies, training materials and case studies.

##### ***HOMER:***

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

HOMER, is a so-called “micropower optimization model”, which tries to simplify the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. Possible power sources are PV, wind turbine, run-of-river hydro, generator (diesel, biogas etc.), electric utility grid, micro turbine and fuel cells. The user must provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of

components, and generates results that can be viewed as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a variety of tables and graphs that help to compare configurations and evaluate them on their economic and technical merits. The tables and graphs can be exported for use in reports and presentations.

### ***Hybrid2***

<http://www.ecs.umass.edu/mie/labs/rerl/hy2/demo/demo.htm>

Hybrid2 is a hybrid power system simulation model. Hybrid2 was designed to study a wide variety of hybrid power systems. The hybrid systems may include three types of electrical loads, multiple wind turbines of different types, photovoltaics, multiple diesel generators, battery storage, and four types of power conversion devices. An economic analysis tool is also included that calculates the economic worth of the project using many economic and performance parameters.

It performs a more accurate simulation than HOMER does, but it does not do optimization or sensitivity analysis. Hybrid 2 presumes a high level of technology known-how and is not very easy to use.

### ***ViPOR***

<http://analysis.nrel.gov/vipor/>

The Village Power Optimisation Model for Renewables ViPOR is an optimization model for designing village electrification systems. Given a map of a village and some information about load sizes and equipment costs, ViPOR decides which houses should be powered by isolated power systems (like solar home systems) and which should be included in a centralized distribution grid. The distribution grid is optimally designed with consideration of local terrain. Compared to other models ViPOR is focussing mainly on electricity distribution rather than on generation. Besides spatial input data which are required to determine the cost and the proper layout of the distribution grid, the model also requires non-spatial data like load types, source types (with generation cost curve), terrain types, distribution costs etc. Given a particular set of economic assumptions and a particular resource, the cost of a generation system can be calculated for a range of load sizes by a hybrid system design tool like e.g. HOMER. These data can then be imported to ViPOR where this cost information is referred to as a generation cost curve.

### ***PVSyst***

<http://pvsyst.com>

PVSYST 3.41 is a PC software package dedicated only for the study, sizing, simulation and data analysis of complete PV systems. PVSYST is internationally regarded as one of the best PV simulation tools.

It is suitable for grid-connected, stand-alone and DC-grid (public transport) systems, and offers an extensive meteorological and PV-components database.

This software is oriented towards PV system developers, designers and evaluators, such as engineers, consultants, authorities, architects and researchers and holds very helpful tools for education and training in PV system technology

PVSYST 3.41 now offers an ergonomic approach, with a "greenline" guide, and several project levels. Quick and easy-to-do pre-studies of PV projects can be made as well as in-depth detailed and comprehensive PV system analysis and designs including three-dimensional shadow effects. The software package has a comprehensive and user defined data presentation facility.

### ***Meteonorm***

[http://www.meteotest.ch/en/mn\\_home?w=ber](http://www.meteotest.ch/en/mn_home?w=ber)

METEONORM is a global climatological database combined with a synthetic weather generator. With METEONORM can data for insolation and other climate parameters for consequent PV system analysis and design be created for almost any spot on the globe. The output are climatological means as well as time series of typical years for any point on earth. Features of METEONORM 5.x includes:

Climatological data of 7'400 weather stations.

Measured parameters: radiation, temperature, humidity, precipitation, days with precipitation, wind speed and direction, sunshine duration.

New derived parameters: driving rain, spectral UVA/B and erythemal radiation.

Use of satellite data for areas with low density of weather stations.

Complete coverage of the globe, including polar regions.

Interpolation model for parameters for any site in the world.

Inclusion of current monthly radiation and temperature data by internet.

Import of user data.

Calculation of radiation for inclined surfaces.

Effects of high horizon considered in radiation calculations. High horizon calculated automatically for Switzerland, based on digital terrain model.

Adaptation of algorithms to latest results of EU Research Program FP5.

Calculation of daily sunrise and sunset.

Graphical interface: Site selection on map. Data output displayed graphically.

18 different predefined output formats as well user-definable output format.

## 5. Annex 1: Guidelines for a detailed Solar PV Investment Project Report

### 5.1 Introduction

These guidelines have been prepared to provide a basis for concerned authorities to check and assess the quality of submitted Investment Projects. As comprehensive method which includes all required issues these guidelines are also an appropriate tool for consultants who themselves undertake Investment Projects for isolated solar PV systems including technical design.

It is expected that the use of these guidelines will result in a standard approach to designing and reporting on Investment Projects of new solar PV projects. The overall objective of these guidelines is that solar PV plants become sustainable and thus their failure rates are minimised.

The specific objectives are:

- Off grid rural households and eventual special services such as rural institutions are able to receive reliable and affordable electricity mainly for lighting and few other appliances, to improve the **rural living standard**.
- **Technically sound** solar PV projects will be implemented.
- The PV systems will be **cost effective and be as financially viable as possible** minimizing the need of external support for their operation and maintenance.
- **Environmental issues** will be adequately addressed.
- **Safety issues** are adequately addressed.

One of the very fundamental advantages of PV technology is the ability to produce electricity at site of consumption. If this characteristic cannot be turned into a project specific advantage, PV technology is probably not the most suitable electricity generating technology to chose.

The PV technology is based on few but essential building blocks: PV modules, storage batteries and power electronics – all inherently modular, generally applicable and requiring only simple civil works. The PV array can be mounted on simple support structures of either aluminium or galvanized steel on top of concrete pillars or for Solar Home Systems (SHS) on a pole or on the roof of the household. Unless a relative large PV system, PV array > 10 kWp, batteries and power electronics can usually be placed in existing buildings or in a dedicated standard containers, again requiring little in terms of local civil work.

Thus, the detailed Investment Project Report may need second site visit (-s) to the prospective PV site (-s) after an assessment of the information given in the Investment Opportunity Report, however normally this should not be necessary. Thus, the detailed Investment Project Report should build upon the findings of that preliminary study and only if deemed necessary upon additional information received from second site visit (-s).

It should be noted that the Investment Project Report is the final document on which the decision whether or not to implement the solar PV project is based.

It should be noted that the design engineer/consultant may propose alternative designs that are different than those based in the guidelines provided that:

- such designs have sound and state-of-art technical basis,
- they are proven in the context of Vietnam, and
- they are more cost effective than designs based on the guidelines

As a complement to the **content and format for Investment Project Reports** described in chapter 4, the following chapter refer to the technical design of PV systems. There are two different approaches to technical design of PV systems:

1. Many small and identical systems, such as SHS or standardized PV power packages for rural institutions
  2. Individual medium to large scale systems, such as central village power systems or hybrid power systems
- ad. 1. To serve almost identical small loads, PV array  $< 1$  kWp, the modular nature of PV technology advocates the use of “standard packages”. This leads to savings in design and engineering as only a single PV system package has to be detailed and the rest can just be deployed according to a load assessment. This approach will also facilitate later operation and maintenance.
- ad. 2. Medium to large scale PV systems, PV array  $> 5$  kWp, requires individual design and engineering in order to optimize the balance between PV system and load and to make best possible use of the relatively expensive technology.

Regardless of choice of above mentioned approaches *it is strongly recommended to carry out and document a detailed PV system analysis and design using one or more of the software tools described in chapter 4*. It is not recommended to design PV system only using “rule of thumb” calculations.

A multidisciplinary team of experienced technicians (engineers) and socio-economists / sociologists, who are familiar with solar PV, are expected to undertake the Investment Project Reports. Thus basic details and principles are not included in these guidelines.

## 5.2 Technology and technical design

This section will focus on highlighting the main characteristics of the PV system components and guidelines and good PV system practices. However, for general details on rural electrification grids, earthing and lightning protection of same, corrosion issues and other general details please refer to the adequate description provided in section 6.3.5 in appendix 1 of “Guidelines for a detailed MHP Investment Project” or equivalent.

The descriptions and recommendations of the next two sections reflect to some extent the work carried out by the IEA PVPS and various other publicly available PV engineering manuals and recommendations.

### 5.2.1 Introduction

#### 5.2.1.1 Insolation

Solar radiation provides a huge amount of energy to the earth. The total amount of energy, which is irradiated from the sun to the earth's surface equals approximately 10 000 times the annual global energy consumption. On average, 1 700 kWh per square meter is insolated every year.

The light of the sun, which reaches the surface of the earth, consists mainly of two components: direct light and indirect or diffuse light, which is the light that has been scattered by dust and water particles in the atmosphere. Photovoltaic cells not only use the direct component of the light, but also produce electricity when the sky is overcast. So, it is a misconception that PV systems only operate in direct sunshine and are therefore not suitable for use in temperate climates. This is not correct: photovoltaics make use of diffuse solar radiation as well as direct sunlight. To determine the PV electricity generation potential for a particular site, it is important to assess the average total solar energy received over the year, rather than to refer to instantaneous irradiance.

Using photovoltaic cells, this radiation can be used to generate electricity. When sunlight strikes a photovoltaic cell, direct current (d.c.) is generated. By putting an electric load across the cell, this current can be collected. Not all of the light can be converted into electricity however. Photovoltaic cells use mainly visible light. A lot of the sun's energy is in IR- or warmth- and UV radiation, which explains why theoretical conversion efficiencies are as low as 20-30%. Practical deficiencies as impurities may decrease the performance of a photovoltaic cell even further.

The amount of useful electricity generated by a PV module is directly generated to the intensity of light energy, which falls onto the conversion area. So, the greater the available solar resource, the greater the electricity generation potential. The tropics, for instance, offer a better resource for generating electricity than is available at high latitudes. It also follows that a PV system will not generate electricity at night, and it is important that modules are not shaded. If electricity is required outside daylight hours, or if extended periods of bad weather are anticipated, some form of storage system is essential.

In order to capture as much solar energy as possible, the photovoltaic cell must be oriented towards the sun. If the photovoltaic cells have a fixed position, their orientation with respect to the south (northern hemisphere), and tilt angle, with respect to the horizontal plane, should be optimized. The optimum tilt angle lies within a range of approximately 15 degrees of the site latitude. For grid-connected PV systems in Western Europe, for instance, the optimum tilt angle is about 35 degrees. For regions nearer to the equator, this tilt angle will be smaller, for regions nearer to the poles it will be larger. A deviation of the tilt angle of 30 degrees from the optimum angle, will lead to less than 10% loss of the maximum yield.

PV modules are actually more efficient at lower temperatures, so to ensure that they do not overheat, it is essential that they are mounted in such a way as to allow air to move freely around them. This is a particularly important consideration in locations that are prone to extremely hot midday temperatures. The ideal PV generating conditions are cold, bright, sunny days.

#### 5.2.1.2. PV Cells

There are only a handful of materials, especially treated semi-conductors, that are known to display the PV effect with reasonable energy conversion efficiency. At present the vast majority of photovoltaic cells are made from silicon. In general, cells are classified as either crystalline (sliced from ingots or castings or grown ribbons) or thin film (deposited in thin layers on a low cost backing).

##### **Crystalline silicon**

Single crystal silicon cells are usually manufactured from a single crystal ingot, most commonly grown by the Czochralski method. PV cells made from multicrystalline silicon have now become popular as they are less expensive to produce, although slightly less efficient. Multicrystalline cell manufacture usually begins with a thermal process in which silicon is melted and solidified such a way that crystals are oriented in a predetermined direction. This produces a rectangular ingot of multicrystalline silicon that is then cut into blocks or bricks which are finally sliced into thin wafers that are used to make the cells. One way of eliminating the sawing step is to grow ribbons of multicrystalline silicon that are already wafer thin and the correct width for use as PV cells.

The maximum recorded cell efficiency for crystalline silicon is 24,7%. Cell efficiencies greater than 25% have been recorded for cells made from III-V semiconductor material (for example gallium arsenide concentrator systems and for space applications because of their high cost.

##### **Thin film**

Thin film modules are constructed by depositing extremely thin layers of photovoltaic materials on a low cost backing such as glass, stainless steel or plastic. Individual 'cells' are formed by then scribing through the layers with a laser. Thin film cells offer the potential for cost reductions. Firstly, material costs are lower because much less semiconductor material is required and, secondly, labour costs are reduced because the films are produced as large, complete modules and not as individual cells that have to be mounted in frames and wired together. However, thin film modules still exhibit lower life time and poorer stability than the crystalline types.

The most fully developed thin film technology is hydrogenated amorphous silicon. This is the material normally used in consumer applications, although it is used, but less frequently, in power modules. The efficiency of commercial amorphous silicon modules has improved from around 3,5 % in the early 1980's to over 7% currently. The most efficient modules are made with multiple layers of photovoltaic material, for instance three layer amorphous silicon modules with germanium added to two of the layers (a-Si/a-SiGe/a-SiGe) which have a record cell efficiency of 13,5 %. Other types of thin films can be made using polycrystalline silicon, cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS).

Typical and maximum module and cell conversion efficiencies (at Standard Test Conditions, i.e., 1 000 Wm<sup>-2</sup>, 25 degrees Celsius, solar spectrum AM1.5) are given in the table below for some of the commercially available PV technologies.

**Table 2.1 Typical and maximum module and cell conversion efficiencies at Standard Test Conditions**

Type	Typical module efficiency [%]	Maximum recorded module efficiency [%]	Maximum recorded laboratory efficiency [%]
Single crystalline silicon	12-15	22,7	24,7
Multicrystalline silicon	11-14	15,3	19,8
Amorphous silicon	5-7	-	12,7
Cadmium telluride	-	10.5	16.0
CIGS	-	12,1	18,2

### 5.2.1.3 PV Modules

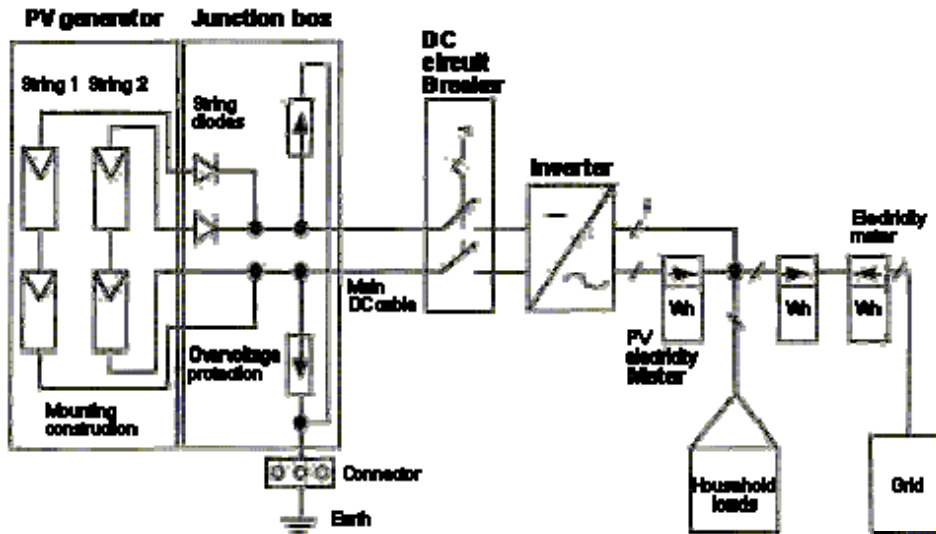
The Photovoltaic (PV) module is the basic building block of PV systems. A PV module is composed of interconnected cells that are encapsulated between a glass cover and eatherproof backing. The modules are typically framed in aluminium frames suitable for mounting. The PV module is the basic building block of any PV power system. The term "solar panel" is often used to refer to a PV module. However, the same expression is also used in reference to solar water heating systems, so to avoid confusion, "photovoltaic module" is preferred.

The performance of a module depends on the cell material. The conversion efficiency of amorphous silicon modules varies from 6 to 8%. This means that at an irradiation of 1 000 W/m<sup>2</sup>, an amorphous module will produce 60 to 80 W/m<sup>2</sup>. Modules of multicrystalline silicon cells have a conversion efficiency of about 15%. Monocrystalline silicon modules are the most efficient; their conversion efficiency is about 16%. Typical sizes of modules are 0,5 x 1 m<sup>2</sup> and 0,33 x 1,33 m<sup>2</sup>, made up of about 36 cells. However, modules of any desired size can be produced. The modules have a transparent front sheet, which is glass or plastic. The back can be opaque. Glass and Tedlar, a plastic that is available in both transparent and opaque, are frequently used. Because of the aforementioned properties of amorphous silicon, modules of this material can have various forms and sizes, though most of the commercially available modules are rectangular and composed like the crystalline ones. Furthermore, amorphous silicon can be deposited on, e.g., windows, metal sheets, plastics and roof tiles.

Standard rectangular modules can be delivered with or without frame. Frameless modules, or laminates, can essentially be processed as normal glass panes. Special attention has to be paid to water tightness, cabling, and shading of the module surface. The thickness of glass-Tedlar laminates is generally 8 mm. Glass-glass laminates are generally at least 10 mm thick.

### 5.2.1.4 Photovoltaic (PV) systems

PV modules are connected in series and parallel to form an array, thus increasing total available power output to the needed voltage and current for a particular application. For connecting the PV modules either in series or parallel, most PV modules are equipped with a junction box at the rear side. These boxes are, in general, 5 to 7 cm deep. In larger PV power systems PV arrays are connected either in series or parallel again, depending on the required input power of the selected inverter. A generic PV system capable of supplying both DC and AC electricity is shown below.



## 5.2.2 Design and technical recommendations

The overall responsibility for the PV systems should rest with the contractor, which includes the supply, delivery, installation and commissioning of the PV system, even if the installation work is sub-contracted to local solar technicians or others – this line of responsibility should be kept completely clear regardless of recommendations as to design, installation, etc.

### 5.2.2.1 Photovoltaic modules

- a) The photovoltaic (PV) array shall consist of one or more mono- or poly-crystalline Silicon modules. Single or multi-junction thin film modules (a-Si, CdTe, CIS, ...) are (normally) not acceptable for off-grid remote use.
- b) PV modules must be certified for compliance with IEC 61215, “Crystalline Silicon Terrestrial Photovoltaic Modules; Design Qualification and Type Approval”.<sup>3</sup> The rated peak power of the PV module shall be stated at Standard Test Conditions (STC) as defined in IEC 61215 and IEC 60904-3.
- c) Indicative PV array capacities are listed for the PV packages in table 3. All PV modules within an array shall be of the same type (same rated peak power) and hence interchangeable.
- d) The minimum acceptable operating voltage at maximum power point (MPP) of a nominal 12V PV module shall be no less than 15 V<sub>DC</sub> at a cell operating temperature of 60 degrees Celsius.
- e) Each module shall be clearly marked (fixed label), indicating: manufacturer, model name/number, serial number, maximum system voltage, peak power rating ( $W_{\text{peak}} \pm \text{tolerance}$ ), current at MPP, voltage at MPP, open circuit voltage and short circuit current.
- f) Actual peak power should not be less than the nominal peak power minus 5%. All PV module performances should be certified by a measurement sheet from manufacturer.

<sup>3</sup> IEC stands for International Electrotechnical Commission. The IEC specification supersedes the ISPRAs specification No. 503.

- g) The PV module shall be equipped with a sealable waterproof IP54 junction box or with a pre-embedded cable with an equivalent junction box fitted to the PV module mounting structure. Junction boxes must make provision for strain relief glands.
- h) The connection terminals in the PV module junction box shall be clearly marked as positive and negative.
- i) Each PV module shall be protected by a blocking diode, either included in the charge regulator or integrated in the junction box. By-passing diodes are only required if more than one module are connected in series.
- j) The modules shall be framed with an aluminium frame in such a way to warranty the structural strength and to allow secure connection to the PV array mounting structure.
- k) Each solar module shall be marked with the programme reference in non-removable paint on the back of the solar module.
- l) PV module warranty: Minimum 20 years on performances and material. Minimum 90% of the nominal power after 10 years.

#### 5.2.2.2 PV array mounting structure

- a) The PV modules shall be mounted to an array structure. The array structure will be either roof-mounted or pole-mounted, and should withstand wind speeds of 100 km/h. The roof- and pole- mounted array structures shall be sufficiently rigid to prevent twisting in the wind.
- b) Ground-mounted structures: Concrete pillars – either pre-fabricated or made at site – shall be firmly anchored into the ground providing a level field for a steel lattice (or eventual a hard-wood lattice) raised at least 0,75 m a.g.l. Using aluminium or heavy duty galvanized mild steel angle iron a support structure for mounting the modules in the correct tilt is constructed. For ease of maintenance the highest point of the array should not be more than 3 m a.g.l.
- c) Roof-mounted structures: These are made from mild steel angle iron or heavy duty galvanised sheet metal (2mm minimum). The angle iron frame must be painted with a primer coat and a double-coated paint finish to protect from corrosion.
- d) Pole-mounted structures: The free-standing metal pole must have a minimum diameter of 50mm, either wall-fixed or anchored in the ground. Corrosion-free material shall be used as for roof-mounted structures. The pole-mounted option is recommended when roof access or orientation or solidity is not appropriate.
- e) For small standardized systems, e.g. SHS, it is encouraged to seek a design of an array structure, which can either be roof-mounted or pole mounted, with a minimum change in structural materials.
- f) All fasteners (nuts, bolts, washers, ...) within the array mounting structure shall be supplied by the contractor and shall be galvanised or of stainless steel material. These include the module-to-structure and the structure-to-roof fasteners.
- g) Tamper-proof (non-removable) bolts/screws for theft-protection are highly recommended, and mandatory if the structure is ground-mounted.
- h) The module array structure shall be able to withstand at least 15 years of outdoor exposure without appreciable corrosion or fatigue.

- i) Tilted angle to the horizontal (after installation) should be selected to optimise the energy collection during the lowest ratio of the monthly mean daily irradiation to the monthly mean daily load. This angle should not be higher than latitude + 10° and lower than 15°. Lower tilt angle than 15° may reduce self-cleaning during rains. Appropriate values in Vietnam range from 15° to 25°, preferably facing due north.
- j) Location of the PV array and structure shall allow expansion possibilities to accommodate additional modules.
- k) Accurate drawings and calculations of the mounting structure should be provided by the contractor to justify tilt (selected in a combination of maximum annual production and minimum seasonal variation), solidity and integrity of the structure.

### 5.2.2.3 Batteries

The following types of lead-acid batteries are considered in this context:

- (i) **deep cycle tubular plate batteries**, and
- (ii) **moderate cycle flat plate batteries** (called also “modified” or “solar”).

Both types can be either sealed (maintenance-free) or vented.

- a) Solar/modified SLI batteries shall be characterised by thicker plates (> 2mm) and higher electrolyte volume (> 1.15 litres / 100 Ah (C20)). Electrolyte density below 1.25 Sg [g/cl] is recommended in order to minimize corrosion.
- b) Sealed batteries requires a careful charge control, especially at variable ambient temperature, to avoid out-gassing.
- c) The rated Amp-hour capacity shall be specified at 25°C at the C20 (20 hours) discharge rate down to 1.75V per cell (VPC). The bidder shall provide the battery data and specification from the manufacturer (at C20/1,75V) to demonstrate the compliance with the following requirements.
- d) The batteries shall comply with the following standards:
- e) IEC 61427-1 : “Secondary cells and batteries for solar PV energy systems – general requirements and methods of test”
- f) IEC 62093 : “Balance of system components for PV systems”
- g) The minimum system autonomy shall be three days by default.
- h) The Depth-of-Discharge (DOD) should never exceed 70% of the nominal capacity but recommended design value should be lower than 40% for modified batteries and 60% for deep-cycle batteries.
- i) Battery cycle life must exceed 1,000 cycles at 10% daily depth-of-discharge (DOD), and 200 cycles at 50% DOD, at 25°C and residual capacity should be at least 80% of the capacity at beginning of life.
- j) The self-discharge rate should not exceed 6% per month of their rated capacity.
- k) Maximum 3 battery strings should normally be connected in parallel and only if they are of the same type, size and age. This recommendation in principle also concerns batteries of larger capacities, however more parallel battery strings may be allowed.
- l) Batteries/cells/blocks shall be interconnected with at least 35 mm<sup>2</sup> flexible copper

conductor or lead plated copper bus-bars, the square of the conductor shall anyway be designed according to the max. current to be carried. Anti-oxidant grease shall be added on battery terminals and connectors.

- m) Each battery shall be engraved with the manufacturing date.
- n) All batteries should be transported and delivered pre-charged and dry with separate electrolyte.
- o) The storage conditions under guarantee should be indicated by the contractor.
- p) The warranty period of the batteries shall be at least one year after starting-up on site.
- q) The contractor shall provide the expected lifetime of each battery type, according to its previous field experiences and specify the maintenance requirements.

#### 5.2.2.4 Battery box or enclosures

- a) Batteries shall be installed in vented and padlocked boxes, racks or cupboards to protect the batteries (terminals) against transfer or accidental short-circuiting and to prevent children having access to the batteries. For large scale battery installations an ISO container or a separate lockable room may be needed. The batteries will however remain easily accessible for checking and maintenance. All parts of the compartment subject to battery acid contact shall be acid resistant.
- b) A warning label with clearly legible words shall warn the user of the associated dangers with the improper use of lead-acid batteries.
- c) Box or enclosure shall have a useful life or more than 15 years without any maintenance.

#### 5.2.2.5 Charge regulator

The function of the charge regulator (CR) is the protection of the battery set, preventing overcharge while providing appropriate charging patterns and protecting against exhaustive discharge.

- a) The regulator shall be compatible with the particular batteries for optimal cycling life.
- b) The nominal voltage of the charge regulator shall be the same as the PV system design (either 12, 24, 48 V DC or higher according to battery voltage).
- c) The charge regulator architecture shall be based on solid-state switching elements.
- d) The regulation shall either be of the shunt type, the series type or a combination of both. A shunt-type charge regulator shall be capable of handling 125% of the PV array's rated short circuit current, while a series-type regulator shall be capable of handling 125% of the rated MPP current of the PV array (operating at normal cell temperatures - NOCT).
- e) The charge regulator algorithm shall incorporate as a minimum a boost (gassing) phase and a float (trickle charge) phase. The algorithm should preferably be implemented through pulse width modulation (PWM) as opposed to ON/OFF regulation. The ON/OFF regulation algorithm is also acceptable with proper motivation and if suitably matched to the battery set.

- f) The charge regulator shall have factory pre-set voltage thresholds (set-points) applicable to the specified battery characteristics and the cycling life requirements. The set-points should be given at 25°C, with an accuracy of 1%, and should be stable in the given conditions (less than 1% change after one year). Indicative values are given below for a cell and a 12 V battery:

Low voltage disconnect:	1.85 VPC	> 11,1 V
Low voltage reconnect:	2.1 VPC	12,6 V
Float voltage:	2.3 VPC	13,8 V
End-of charge or Boost voltage:	2.35 to 2.4 VPC	> 14,1 V
Periodic controlled overcharging	2.5 VPC	15 V <sup>4</sup>

- g) The operating voltage, the maximum current, manufacturer's name, model, serial number, connection points, and polarity shall be clearly marked on the regulator. It is recommended to state the voltage set-points on the back of the unit (float, boost, equalise, disconnect, reconnect).
- h) The charge regulator should include clear indicators (easy-to-understand) of battery state of charge, as well as charging status (PV array side) and discharging status (load side).
- i) In addition, it is recommended to have a full system status indicator that:
- i. Warns the user before reaching the deep discharge cut-off with an audible and visual alarm when the battery voltage drops to within a limit close to the load-shed voltage. This alarm will cease if the voltage recovers above the load-shed voltage.
  - ii. Indicates if the battery has been fully recharged on a particular day or not.
- j) Temperature compensation in the range of  $-3$  to  $-5$  mV/°C/cell is recommended if the ambient indoor temperature vary significantly during the year (more than +/- 10°C).
- k) The charge regulator self-consumption shall normally be below 10 mA. For medium and large scale systems a higher value can be accepted.
- l) The voltage drop across the terminals of the charge regulator ("PV to battery", which includes the blocking diode if present, and "battery to load") shall not exceed 0.75V at rated current.
- m) The charge regulator should be fully protected against reversed polarity by fuses, diodes, etc.
- n) The charge regulator shall be electronically protected against over-current on the PV input (max.  $1,25 \times I_{sc}$ ) and on the load output (max.  $1,25 \times I_{load}$ ) for at least one hour. An over-current situation shall therefore not destroy the regulator fuse.
- o) Disconnection of the battery from the charge regulator ("non-battery") shall not result in any damage to the regulator or the connected loads. The loads shall be protected against over-voltage by the charge regulator.
- p) The fuse holder of the charge regulator is to be mechanically stable. Replacing the fuse shall not result in a loose connection on the fuse holder.

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<sup>4</sup> Not applicable for sealed (so called maintenance-free) batteries

- q) The case of the charge regulator shall be constructed to prevent entry by insects and dust and be corrosion resistant (protection at least IP 32 for indoor and IP 54 for outdoor installation, according to IEC 529 or DIN 40050). Encapsulation of the charge regulator is recommended. Conform coating on electronic circuits for tropical conditions is a minimum requirement. Terminals should easily accommodate at least 4 mm<sup>2</sup> section cables.
- r) The charge regulator warranty period shall be a minimum of one year.

#### 5.2.2.6 Inverter

The following recommendations mainly targets inverters providing AC to a few local loads. For inverters supplying power to a mini-grid system or co-generating with other electricity generators, e.g. a diesel generator, it is recommended to consult experts for guidelines and recommendations or competent equipment suppliers for options.

- a) The DC/AC inverter can be either true sine-wave or modified sine-wave but shall be capable of operating standard equipment (TV, computer, refrigerator and other tools) that public institutions may acquire.
- b) The inverter shall provide sufficient surge power to start-up TV, computer, refrigerator and other tools (min. 125% overload for one minute).
- c) Tolerance on 220 V output voltage shall be +/- 5% and on 50Hz frequency +/- 1% over the full range of operation of the normal battery operating voltage.
- d) The efficiency of the inverter shall be in excess of 85% (90 % recommended) above 20% load output.
- e) The inverter shall have electronic overload and short-circuit protection. A fused output is not acceptable.
- f) The inverter shall be internally fused at the input of the unit. A DC input circuit breaker is preferred.
- g) The inverter shall have an automatic low-voltage shut-down threshold which, e.g. in a 12 V system, is no lower than 10.5V at 50% load.
- h) Inverter must be clearly labelled with the minimum information:
  - Manufacturer name and model
  - Serial Number
  - Voltage and Current Ratings
  - Battery and load connection points and polarity.
- i) Complete documentation must be provided and included:
  - Installation instructions
  - Operating instructions
  - Technical specifications and ratings
  - Safety Warnings
  - Troubleshooting instructions

- Information pertaining to serviceable parts
- j) The inverter warranty period shall be a minimum of one year.

#### 5.2.2.7 Distribution board

The distribution board (DB) is required at least for PV systems providing 220V AC outlets. All the AC socket outlets shall be operated through the DB and its circuit breaker. Simplified distribution board are also desirable for DC-supply packages with a DC circuit breaker upstream the DC plug. Wiring shall be according to national standard with proper grounding.

- a) The DB will consist of an enclosure (wood, metal or PVC), which houses a double-pole earth leakage unit (ELU) for safety protection and one single pole circuit breaker.
- b) The sensitivity of the ELU shall be 30mA or less and the ELU shall comply to IEC 61008 / 61009 standards.
- c) The switch gear will be rated for 220V<sub>AC</sub> and higher.
- d) The DB will consist of an earth bar for all earth connections. A neutral bar is not compulsory but may be recommended to adhere to standards.
- e) The DB will be sealed in such a way that there is no danger of electrical shock (i.e. no gaps wider than that of a child's finger are allowed).
- f) AC and DC outlets shall be according to national regulations.

#### 5.2.2.8 Electrical wiring and termination

The wiring used in a DC system is critical to the successful operation of a PV package. The size and length of cables thus have to be carefully selected to reduce as much as possible the voltage drops, in particular for 12V DC systems.

- a) All wiring must be sized to keep line voltage losses to :
  - o less than 3% between the PV array and the charge regulator,
  - o less than 1% between the charge regulator and the battery and
  - o less than 5% between the battery and the loads.

The percentages are the maximum allowed at peak current conditions.

- b) All wiring shall be flexible multi-stranded copper conductors with colour-coded and/or labelled thermoplastic insulation.
  - o Conventional colours for two-conductor DC wiring are Red (+) and Black or Blue (-).
  - o 3-wires AC cable convention shall be Red or Brown (Line), Blue or Black (Neutral) and Yellow/Green (Earth).
- c) All external wiring (exposed to the sun) must be UV-resistant according to IEC 60811, or to the relevant national standard. Alternative of protection inside a UV-resistant conduit is also accepted.
- d) Indoor cables should comply with related national standard.
- e) All cables should be firmly fastened to building and/or support structure. Cable

binders, clamps and other fixing material and outdoor connection boxes <sup>5</sup> must also be UV-resistant, preferably made of polyethylene.

- f) Wiring through roofing, walls and other structures must be protected through the use of bushings and glands.
- g) Termination:
  - I. Electrical connections should be secure, mechanically strong and electrically acceptable (voltage losses below 0,5% of nominal voltage)
  - I. Flexible wire shall be terminated with wire ferrules (end sleeves) if connected in a screw connector. This is not required for stranded wire.
  - II. Wires connected in clamp terminals do not require wire ferrule termination.
  - III. All studded terminals (e.g. on battery, in PV junction box, in inverter, etc.) are to be wired with cable lugs, properly crimped to the cable.
  - IV. Large diameter cables, which do not fit into the terminals of a device (e.g. 6mm<sup>2</sup> cable from PV array into a 4mm<sup>2</sup> terminal at the charge regulator) will be terminated either with a wire pin sleeve for direct connection (preferred) or shall be terminated in a junction box for connection to the device.
- h) All cables joints must be in junction boxes. The rated current-carrying capacity of the joint shall not be less than the circuit current rating. Different box and connector sizes should be provided to allow solar module connections (serie/parallel) as well as indoor distribution network.
- i) Junction boxes or enclosures must be dust- and waterproof, non-corrosive and electrically insulated (no metal boxes). Interior junction boxes shall have a protection index of at least IP 32, and external junction boxes a minimum of IP 54 according to IEC 60529 and UV resistant if exposed to the sun.
- j) Fittings for lights and wall switches should not be used as junction boxes.
- k) Fuses or any other components, which can cause sparking shall not be installed in a battery enclosure where there is a possibility of explosion due to hydrogen release.
- l) All wire runs between the charge regulator and loads should be no more than 15 meters. Circuit branching is only allowed on increased wire diameter.
- m) All wiring must be sized to keep voltage losses to:
  - i. Less than 2% between PV array and charge regulator
  - ii. Less then 1% between charge regulator and batter
  - iii. Less then 3% between battery and loads
- n) All wiring subject to motion, by either wind, pulling the wire or extreme thermal changes greater that 20°C, shall be provided with appropriate stress relief.
- o) The warranty for wiring of the entire system shall be one year.

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<sup>5</sup> Comment: Polyvinyl Chloride (PVC) is definitely not UV-resistant and will become brittle within less than one year in direct sunlight – PVC is therefore not acceptable

### 5.2.2.9 Grounding and lightning protection

Grounding (or earthing) refers to the provision of a low-resistance conduction path from points in the solar PV system to the earth ground. There are two types of grounding:

- a) Grounding of equipment casings (e.g. the PV array frames, support structure, inverter casing etc)
- b) Grounding of the electrical circuits

#### Grounding of equipment

- e) The following items should be bounded to a common earth connection through 10mm<sup>2</sup> bare copper earth wire (BCEW):
  - i. The roof of the building
  - ii. The PV array pole structure
  - iii. The inverter casing (earth)
  - iv. The Distribution Board (DB) earth bar.
- f) The above items are to be connected to an earth spike (copper plate ground rods, round Ø 15mm), driven at least 1.5m deep into the ground. In rocky locations a six-meter trench will serve as the earth electrode, by running BCEW in the trench and placing the earth spike horizontally in the trench. The earth spike or rod will be positioned near the PV array pole structure. In any case, the final impedance of the protection ground shall be less than 5 Ohms.
- g) All connections will make use of cable lugs crimped to the BCEW and bolted to the array structure, the sheet metal of the roof, the inverter earth potential and the DB earth bar. Twisted connections are unacceptable and special attention should be made to connect dissimilar metals (special connectors for Al/Cu).
- h) No fuses or circuit breakers shall be installed in a grounded conductor.

#### Grounding of the AC electrical circuit

- e) The neutral output of the inverter shall be connected to the earth bar in the DB (the inverter requires a floating, galvanic isolated (inverter with transformer) output for this wiring layout) before the ELU. This provides the neutral to earth connection.
- f) The AC grounding should be in accordance with national regulation.

### 5.2.2.10 Lightning protection

Lightning protection is only recommended for PV installations larger than 1000W<sub>p</sub>. For these PV systems, it is recommended to use Metal Oxide Varistor (MOV) at the input of the charge regulator and the connection to have a good earthing system to evacuate the lightning currents.

## 5.2.3 Installation guidelines

Standard installation guidelines are provided below, which should be adhered to. The contractor is expected to add the necessary information to these guidelines for the installation technicians to allow for a successful, reliable, safe and long-term operation of the PV systems.

All components of the PV packages shall be installed according to the relevant clauses of the relevant national standards.

#### 5.2.3.1 General

- a) Keep cables to minimum length.
- b) Necessary tools and testing equipment shall be provided for proper installation.
- c) Avoid direct sun exposure with cables, plastic boxes and other accessories whenever possible.
- d) Holes that penetrate external walls shall slope slightly to prevent the ingress of water and be suitably sealed. Cable entries through roofs must be sealed (waterproof).
- e) Glands shall be used for wiring through roofing.
- f) Cables placed above ceiling or underground should be resistant to rodent animals or protected by rigid tubes.
- g) Ceiling- or wall-mounted items (charge regulator, plugs, switches,...) should be firmly fixed with appropriate fasteners for long term utilisation.
- h) Surface-mounted cabling shall be installed using appropriate fasteners at suitable intervals (20 to 30cm) to prevent sagging.
- i) Visible interior cabling or conduits shall be aesthetically tidy, and shall not slant from the vertical or horizontal.
- j) Suspended cables shall be mounted so that the lowest point is at least 2.8m above ground level. Suitable strain relief clamps shall be used on both sides. Suspended cables are only allowed between the PV array structure and the building. The maximum distance allowed for suspended cables is 2m between pole and building. Rigid protective tube UV-resistant are preferred.
- k) Buried cables between buildings are allowed only if distance is less than 3m, depth is more than 30 cm and cable is protected by rigid plastic tube sealed on the extremities.
- l) The warranty for installation and performance of the entire system shall be one year.

#### 5.2.3.2 PV array structure

- a) The array should - unless clearly specified otherwise - face due north and the actual angle of tilt should be between to 15 to 25° as specified.
- b) Place the array in such a position that no shading can occur, also taking into account the seasonal movement of the sun and up-growing vegetation.
- c) For ground mounted structures: Follow the dedicated specifications of the contractor. Make sure the lowest point of the array is minimum 0,75 m a.g.l. and the highest maximum 3 m a.g.l. – unless otherwise clearly specified.
- d) Roof-mounted structures: The minimum clearance between the roof material and the array structure must be 100mm. The array should be firmly fixed to the solid supporting frame under the roofing material (corrugated iron sheet, etc.) with “through-roof J-bolts” or alternatively with threaded studs. Any holes made in the roof are to be sealed after installation (with UV-resistant material). Easy access for

maintenance should also be considered.

- e) Pole-mounted structures: The height of the bottom edge of the array structure must be at least 2m above the ground level. The pole must be firmly fixed to a building wall or set into the ground with concrete, at a minimum depth of 1m.
- f) PV module frames and array structures shall be properly earth-connected in accordance to the previous specifications.

#### 5.2.3.4 Batteries:

- a) The batteries shall be installed in a cool and ventilated place, away from any area or device (relays, etc.) where there is a danger of sparks or open flames and also out of direct sunlight.
- b) The batteries shall be installed in a restricted area. In no case must batteries be accessible for children.
- c) Take due personal care when filling acid and do not spill. *Follow exactly the instructions of the battery manufacturer and/or the contractor.* When filled with acid the battery packs a considerable power and short-circuits can be very dangerous.

#### 5.2.3.5 Charge regulator and inverter:

- a) The charge regulator and the inverter should be installed as close as possible to the battery set.
- b) Temperature compensation: If the temperature sensor is integrated into the charge regulator, then it is essential that the regulator is mounted in the same operating environment as the battery set.
- c) The indicators and the switches of the charge controller and the inverter shall be in a clearly visible position and easy to access.
- d) Install the charge controller and the inverter for optimum ventilation and lowest temperatures.

#### 5.2.3.6 Final check

A final check after installation, prior to the official commissioning, is strongly recommended. Commissioning the system after installation is critical as this often reveals omissions, which later require another trip to the site. A final pre-commissioning check could save time and money.

- a) Test all basic functions of the system, such as the battery (normal charge/discharge behaviour), the loads (especially those at the furthest distance of a branched circuit), socket outlets (polarity, ...) and solar charge current.
- b) Check the protections and the status indicators of the charge regulator and the inverter.
- c) Test whether the voltage drops under full load conditions are acceptable.
- d) Retighten all electrical connections after at least one hour (settling of copper).
- e) Pull lightly at cables to make sure that the connections are sound.

#### **5.2.4 Training**

The Contractor should provide on site technical training in the daily operation and maintenance for the users of each PV system. The contractor shall explain to the user the system operating principles, load management requirements, impact of shading of the array and how to check and avoid it, user maintenance checks and how to conduct them.

Training shall be sufficient to ensure that the user can continue with ongoing daily operation and maintenance of the equipment.

To supplement and underpin the user-training a maintenance scheme consisting of regularly maintenance visits by trained and competent technicians should be established, e.g. as a long term contract with the contractor.

The Contractor shall provide plans documenting how all the training will be accomplished and how regular maintenance is proposed established.

#### **5.2.5 Maintenance kit & Spare parts**

The Contractor shall propose and offer appropriate maintenance kits and spare part sets reflecting the situation of the PV systems (reliability requirements, remoteness and accessibility) and availability of trained personnel.

#### **5.2.6 Documentation**

The Contractor should as minimum provide the following documentation:

##### **The User Guide Sheet**

The User Guide (single page (A4) laminated sheet) is used as a quick reference for the user. It is to be mounted near the charge regulator or the system status indicator. It should contain main information such as the meaning of various feedback indicators and specific hints on system operation (also referring to the implications of continued cloud cover, excessive energy use, etc), maintenance hints as well as safety instructions. The guide sheet shall be easy to understand and mostly to rely on graphical information (pictograms).

##### **The User Guide Manual**

The manual contains detailed information on the systems, explains the operating principles and basic maintenance, the system capabilities, the do's and don'ts and has a small section on troubleshooting guidelines.

The Contractor is requested to keep a record of all the serial numbers of PV modules, batteries, charge regulators and the inverters. This information is also to be filled into the manual (on the last page) with the specific system details.

##### **The detailed PV system specifications**

These specifications shall contain all the detailed technical information of the main components of the PV system or category of systems. This refers specifically to the complete list of components, main features, technical specifications and warranties.

Instruction manuals from the manufacturers are required for the charge regulator and the inverter, whereas data sheets are sufficient for PV module, battery and eventual other electrical accessories.

##### **O&M and troubleshooting manual**

A detailed manual on operation & maintenance and fault finding (i.e. beyond the User Guide Manual level) should be included in this catalogue.

This shall include repairs and diagnostic procedures to be carried out by the Contractor or a qualified third party.

##### **Installation guidelines**

A PV system specific installation guideline should accompany every PV system into the field in order to assist the installation personnel and to ensure consistent installation procedures and work. It will as a minimum contain the wiring and installation guidelines as given previously but will also make specific reference to the installers on the actual supplied components/technology. In addition the following diagrams are to be prepared:

- a) A **schematic layout** of each PV system, showing all the main components
- b) A **wiring diagram** of each PV system for the solar modules, the battery set (and its connecting points), the charge regulator and the inverter. This diagram(s) is also suited to indicate to the solar technicians the maximum length of cable and the required size of the conductor, as well as other useful tips.
- c) A **site layout** where the PV systems in question are to be installed.

### 5.3 Quality issues and international standards for PV technology

Quality is extremely important for photovoltaic systems, first of all because the investment costs are high compared with other energy sources, and the systems are commonly used in remote areas. Therefore, it is very important to keep running costs at a minimum, for example by avoiding repairs. Apart from economic reasons, quality is important for health care equipment or water pumps, where people’s lives are depending of the PV plant.

One way to keep a high technical standard for PV products is to recommend or demand specific standards for components or systems. Some organizations have practiced this for many years, for example WHO with their rules for PV driven refrigerators. In these years, the efforts to develop new standards for PV systems and equipment have increased, and this paper will describe some of this work.

Worldwide there exist a network of standards organisations to carry out the work of establishing new standards. Permanent workgroups or committees within each technological item most often do the job, but it may also be carried out by temporary workgroups. The groups typically include representatives from industry, researchers and professional users. As example some of the organizations involved in establishing and implementing standards are mentioned below:

- Non-electrical standards:*
- ISO - International Organization for Standardization
- CEN - Comité Européen de Normalisation
- Electrical standards:*
- IEC - International Electrotechnical Committee
- CENELEC - Comité Européen de Normalisation Electrotechnique
- Certification:*
- GAP - Global Accreditation Programme
- WHO - World Health Organization

The PV technology is endowed with a range of internationally recognized standards, the most important of which are listed below. When compiling a bill of quantities and in tendering of PV systems due reference should be made to the relevant standard in order to avoid/minimize the use of low quality components, impairing the overall reliability of the PV systems.

The IEC and CENELEC committees have established four working groups each, covering the subjects listed below:

	<b>IEC TC 82</b>	<b>CENELEC BTTF 86-2</b>
<b>WG1</b>	Glossary	Solar Home Systems
<b>WG2</b>	PV Modules	Inverters(2A) & AC Modules(2B)
<b>WG3</b>	PV Systems	Building integrated PV
<b>WG4</b>	PV Energy Storage Systems	PV pumps

IEC has published Publicly Available Specification (PAS) IEC 62111 (1999): Specifications for the use of renewable energies in rural decentralized electrification.

With regard to modern renewable energy technologies such as mini/micro hydro power, solar photovoltaics, solar thermals, biomass (as fuel) and biogas standards have been compiled or are under work.

The IEC has published a number of standards on PV Module Testing and Measurements, Module Type Approval & Reliability, PV System Performance Measurement, Characteristics of PV Systems and System Safety:

### **Test standards**

IEC 60891 (1987) Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic (PV) devices. Amendment no.1: 1992

IEC 60904-1/-10 Photovoltaic devices (in 10 parts) (1987 / 1998)

### **Other Standards**

IEC 61215 (1993) Crystalline silicon terrestrial PV modules – Design qualification and type approval

IEC 61345 (1998) UV test for PV modules

IEC 61346 (1996) Thin film terrestrial PV modules – Design qualification and type approval

IEC 61701 (1995) Salt mist corrosion testing of PV modules

IEC 61721 (1995) Susceptibility of a PV module to accidental impact damage (resistance to impact test)

IEC 61683 (1999) Photovoltaic systems – Power conditioners – Procedure for measuring efficiency

IEC 61702 (1995) Rating of directly coupled PV pumping systems

IEC 61724 (1998) Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis

IEC 61725 (1997) Analytical expression for daily solar profile

IEC 61829 (1995) Crystalline silicon PV array – On-site measurement of I-V characteristics

IEC 61194 (1992) Characteristic parameters of stand-alone PV systems

IEC 61277 (1995) Terrestrial PV power generating systems – General and guide

IEC 61727 (1995) PV systems – Characteristics of the utility interface

IEC 61173 (1992)    Overvoltage protection for PV power generating systems guide

**Technical Reports**

IEC 61836 (1997)    Technical specifications – Solar PV energy systems – Terms and symbols

## 5.4 Environmental issues

PV technology is fundamentally environmentally benign. All processes in the manufacturing of the components and during operation through the system's economic life time are negligible. At the stage of decommissioning, or when replacing, the storage batteries will pose a threat to the environment unless adequately handled.

### 5.4.1 The situation

Photovoltaic (PV) stand-alone systems are often used for household electrification in off-grid areas. Such PV systems, provides a limited service of electricity without any environmental emissions during operation.

Main components of such PV systems include:

- PV modules
- Charge controller
- Battery
- Inverter (eventually)

The environmental impact cradle-to-grave of the PV modules and the power electronics (the charge controllers and the inverters) are easy to control and anyway very small.

Batteries used with PV systems are usually lead-acid types of various designs, but all including lead and various sulphuric compounds, that can have a severe negative impact on the environment if not taken care of properly.

The lead represents a market value of about US \$ 600 per ton making recycling of lead economically attractive, if a recycling scheme can be set up. The sulphuric compounds have to be disposed of in an environmental benign way and there is no build-in economic incentive.

There are two principle routes for recycling:

- the manufacturer and recycler vertically integrated
- a partnership not vertically integrated

In many countries the role of independent collectors is being legislated out of existence by onerous regulation costs and by increasing emphasis on a duty-to-collect on the battery manufacturers. Therefore the partnership model becomes closer to the vertically integrated model, but requiring partnership between smelter and battery manufacturer

Most industrialised countries have established rules, regulations and routines for battery recycling and disposal and the European Union has elaborated Directive 91/157 requiring member states "to draw up programmes to achieve the separate disposal of spent batteries and to reduce the amount of such batteries going to waste".

In many developing countries no such regulations are either found or enforced, and it will normally be beyond the scope of PV projects to institutionalize such regulations. Spent starting

batteries (SLI batteries) from the transport sector usually constitute an overwhelming factor in this context compared to PV systems.

#### **5.4.2 Problems to be Faced**

Battery recycling presents a number of challenges:

##### 5.4.2.1

The logistics of a reversed distribution chain: to bring spent batteries back in. This process maybe complicated by all sorts of regulations on special waste. Experience often shows unsatisfactory recovery rate using reversed distribution chain, but economic incentives are possible.

##### 5.4.2.2

The requirement for storage facilities for spent lead acid batteries - regional and central storage.

##### 5.4.2.3

The disposal of sulphuric compounds in particular  $\text{SO}_2$ . All spent batteries contain sulphuric acid and lead sulphate in the paste. This sulphur requires ultimate environmentally benign disposal as pure  $\text{H}_2\text{SO}_4$ , as crystallised  $\text{Na}_2\text{SO}_4$ , eventually as gypsum  $\text{CaSO}_4 (2\text{H}_2\text{O})$  or as leachable soda slag. The options of disposal of soda slag and  $\text{SO}_2$  up-the-chimney are disappearing, and effective  $\text{SO}_2$  disposal is costly.

##### 5.4.2.4

Smelters of spent battery lead must accept the challenge of continued environmental improvement with the associated capital cost and rising operating cost.

##### 5.4.2.5

The problem of controlling lead in air levels to ever-tightning standards (national & international) - both at workplace and at site boundaries.

##### 5.4.2.6

Long-term environmental clean-up costs at the end-of-life of the recycling plant (smelter) including possibly back-dated landfill liabilities.