Data and Theory for Evaluating a PV-Project

By Mads Brix Nielsen & Mikkel Sørensen
Technical University of Denmark
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Rural electrification is an extremely complicated process due to the complexity of its nature. The challenges are crosscutting in social and institutional aspects; technology, economics and environment, and it became clear to us during six months intense studies - theoretical as well as practical - that no definite answer to the challenge exists. Careful considerations are imperative to every single case and by pointing out advantages and drawbacks in different approaches the report can serve as the basis of designing or evaluating projects in the context of rural electrification.

To us it served as the basis evaluating the Tonga Outer Island Solar Electrification Programme, an evaluation requested by the Tongan Energy Planning Unit (EPU) through the Secretariat of the Pacific Community (SPC) and carried out as a midterm study at the Technical University of Denmark entitled “An Evaluation of Tonga’s Outer Island Electrification Programme”.

This report is also submitted for approval at the University. It includes specific data on the Tongan programme but presented with special emphasis on the method used it could prove useful for similar evaluations.

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Mads Brix Nielsen
Mikkel Sørensen
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Data and Theory for Evaluating a PV-Project
1. Introduction

From August 2001 to January 2002 an evaluation of a PV programme, Tonga Outer Island Solar Electrification Programme, was carried out including a four weeks mission to the Kingdom of Tonga.

The objectives of the evaluation was to:

- Map out the benefits and impacts of the programme and compare these to the original objective.
- Access whether the programme is sustainable in its present form.
- Point out present and potential problems in the programme.
- Formulate recommendations in order to improve and develop the programme.

The evaluation is entitled “Evaluation of Tonga’s Outer Islands Solar Electrification Programme”

In order to do this a theoretical basis had to be established, as no specific guidelines exist. Further a large amount of project information had to be gathered. The data collected varied in form from interviews over visual observations to written project information. This complexity made it convenient to analyse the different sources separately before gathering the impressions in a data triangulating interception.

This report contains a thorough discussion of the conditions and challenges of setting up electrification in rural areas to some extent focusing on special conditions for Small Islands Developing States (SIDS). The choice of technology, financing scheme and institutional arrangements are aspects included but as careful considerations are imperative to every single case it does not give a definite answer to how rural electrification should be organised. However it presents a variety of possibilities considering their advantages and drawbacks.

Subsequently the photovoltaic (PV) technology will be more thoroughly described, as it was the very substance of the programme. Emphasis will be on small stand-alone systems especially in terms of determining a proper system dimensioning procedure.

Having presented the core theory of the evaluation, an interview survey conducted in Tonga will be presented. The methodology used will be outlined followed by a presentation of the main findings. The findings are presented as a description of what the users think of the programme followed by a description of the programme obtained through interviews with the Energy Planning Unit being the institution responsible for the programme.

The programme was funded by the European Union thus an introduction to their general policy in developing projects is included.

The final chapter is a cost-comparison between PV and a diesel-generator as the electricity-generating source in the islands using the simulation software HOMER will be presented. These two chapters might not gain full appreciation without the specific context of the evaluation, but should be considered a step-on-the-way - practical examples of the methodology.
2. Rural Electrification

Rural refers to *living in the country*.

Electrification means to *supply (a region, community, etc.) with electric power*.

Thus rural electrification is *supplying electric power to those living in the country*. [1]

2.1 BACKGROUND

Around two billion people, corresponding to 3-400 million households\(^1\), are living without access to electricity and the vast majority of these are living in rural areas with little immediate prospects of grid connection. Even though an estimate of 1.1 billion rural residents got electricity access between 1970 and 2000 the number of those without has stayed constant at about 2 billion due to growth in population. [2,3]

The lack of access to electricity is a significant barrier in terms of improving quality of life in developing countries as it is a hindrance to the provision of health services, community development, education and industrial activity. [4]

The low population density and consumption combined with limited accessibility of rural areas make it difficult and expensive to establish a functional infrastructure. Additionally a variety of institutional, economic and technical barriers need to be addressed to move towards a sustainable development including meeting the energy requirements of the population in rural areas of developing countries. This section will concentrate on the conditions and challenges of setting up electrification in rural areas - to some extent focusing on special conditions for Small Islands Developing States (SIDS).

Whether the rural area is a small mountain or desert village or a remote island, electrification is a problematic process. The technological, financial and institutional considerations are more or less the same but the context somehow differs. This makes the development of a universal planning tool an almost impossible task, careful considerations are imperative to every single case as the best choice of technology, financing scheme and institutional arrangements might vary. As a result of this complexity this report does not seek to give the definite answer to how rural electrification should be organised. The intention is just to present a variety of possibilities and considering their advantages and drawbacks pointing out those of interest to small island societies.

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\(^1\) A household is defined as *the people of a house collectively* [1]
2.2 SIDS

SIDS are usually identified as being geographically dispersed, isolated and small in size and characterized by high population densities; in most cases with over half of the population residing within 2 km from the coast. In many cases SIDS are environmentally vulnerable; being prone to ecological hazards and extremely damaging natural disasters and particularly vulnerable to global climate change even though they emit little GHG’s themselves. Often SIDS are economically vulnerable qua low levels of economic activity having small, limited financial reserves and being highly dependable on international trade and donor aid. Economic development is largely dependent on coastal and marine resources and increasingly on tourism. [5]

The Alliance of Small Island States (AOSIS) is a coalition of these small island-and low-lying coastal countries, most of which have a geography that makes them especially vulnerable to the adverse effects of global climate change. Acknowledging this has put extra emphasis on integrating renewable energy into the development of the energy sector coupled with the incipient industrialisation. [6]

2.2.1 The energy sector

Most SIDS are blessed with abundant renewable energy resources, but they depend overwhelmingly on petroleum imports for their electricity production, for transport and on biomass for the bulk of their energy consumption. Neither of these sources are about to be depleted completely, but access to both is limited, and the use of either has severe environmental and economic consequences. Transporting oil to SIDS can be environmentally risky, and it is almost always extremely expensive, diverting the usually scarce governmental funds away from important issues such as developing the health and education sector. The rather high population density is limiting the biomass potential per capita and a substantial increase in exploitation could lead to deforesting. On the other hand the use of biomass is as of today highly inefficient and introducing high-efficient technologies could step up the utility value. [5]

Apart from seeking to satisfy an increasing demand for energy from the industrial sectors in urban areas, many SIDS have put emphasis on improving the availability of energy services, including electricity, in the rural areas. The rural areas in a SIDS are characteristically small islands with one or a few villages in the waters encircling the main-islands, sometimes even hundreds of kilometres away. These very small island communities are generally referred to as “the outer islands”. In most outer islands almost no industrial activity is present and the people have relied on biomass for cooking and kerosene for lighting purposes. Having experienced a steady migration from the outer islands to the already densely populated main-islands the SIDS’ governments have attempted to initiate programs to improve the living standards, an element of this being access to electricity. [6,7]

The significant use of biomass mainly in the form of fuelwood states three potential drawbacks: The collection of fuelwood takes up a large amount of the women’s already stretched time, the burning of biomass is polluting the households leading to respiratory diseases and eye infections and lastly; since few islands have substantial vegetation and/or dedicated forestry plantations the use of fuelwood is seldom sustainable. In addition to this the utilisation of biomass is often inefficient because of the use of traditional stoves and other ineffective appliances. [5]

Since it is often the most economical option for power generation in urban areas petroleum will most likely remain the single most important commercial energy
source for the foreseeable future both in the electricity producing sector but also in the transport sector. In SIDS as it is the case in most developing countries grid distributed electricity is mainly available in cities and surrounding rural areas and hereby only satisfying the needs of existing solvent consumers, excluding a vast proportion of the population. In addition to this vast power losses are present in the distributing grids, which causes a further increase of the price and decreases the service. Contrary to many developing countries coal is used only to a small extent in the larger SIDS such as Fiji and Jamaica. This is due to the limited size of the energy systems hampering the financial feasibility of coal-fired power plants. [5]

The extensive dependency on imports of petroleum products is straining the economies of many developing countries including the SIDS, and is making them extremely vulnerable to price fluctuations. Additionally petroleum products in many SIDS are imported at some of the highest prices in the world. This is primarily due to large distributor to recipient distances and the small amounts shipped out results in prices that are 200-300% of international market values. [5]

Adding to this the cost of transport to outer islands the price increases even more. Furthermore jetties in the outer islands are seldom capable of landing the fuel, and in some cases not even present, thus the only possibility is to float the fuel ashore in drums often resulting in spills and environmental damage of the vulnerable reefs surrounding the islands. The result is a potential deterioration of the fishing possibilities further reducing the income possibilities. [8]

Another aspect of the energy sector in many SIDS is the lack of sustainable governmental development policies and the fact that a national energy plan is outlined only in few cases. The absence of a political environment and the urgency of other issues such as poverty and low economic growth are repressing the focus on energy supply, renewable energy and energy efficient technologies. [5]
2.3 **Social Aspects**

When faced with the challenge of setting up electrification in rural areas, a variety of potential problems need to be addressed. One aspect is general considerations recommended to be part of any development project, another the more practical choices to be made. Of the general considerations, emphasis is put on local participation and capacity development while the most important practical choices are concerning how to finance an electrification project and what technology to use. Further, the institutional arrangements, both local and national, seem crucial to the success of any given project.

These issues are crosscutting, but in the following they will be dealt with individually to gain a perspective.

### 2.3.1 Mapping out the needs

In order to elaborate a sustainable energy development, the required energy services of the population in rural areas need to be mapped out. It is critical to recognize that what societies want are the services that energy provides, not the fuel or electricity. For people living in poverty, the priority is to satisfy basic needs such as adequate food supply, shelter, availability of potable water and sanitation and access to health services and education. Additionally, when the agricultural and industrial needs are taken into account, it is obvious that the energy service requirements in the rural areas are extremely diverse.

[5]

This is illustrated by the answers from participants in a workshop in Uganda when asked to identify their energy requirements. Their responses were: Food processing, rural industry, household lightning, household cooking, water pumping, entertainment, refrigeration for clinics and hospitals, and transport. The priority of these may vary, but the answers are a very good indicator of the demands of people living in rural areas. Household services requiring electricity are in many cases basic needs such as light, water pumping, and refrigeration, which can be met by low voltage appliances. The net final energy requirement for satisfying all basic human needs in a household, in regions with no heating requirement, has been estimated to be about 8000 kJ daily per capita of which 20 percent is in the form of electricity. This corresponds to an average electrical power demand of less than 20 watt, which can be met by very small units. [3,5]

### 2.3.2 Participation and capacity building

A significant barrier to rural electrification is the lack of institutional and technical capacity. Job and education possibilities are often limited, which in many cases results in migration, especially concerning educated people. On the national level, the institutional framework is often bureaucratic and slow and the rural areas generally have low priority. Furthermore, norms, regulations and institutional environment are rarely established and functional in the energy sector and the concerned governmental bodies are in many cases understaffed and economically short-handed. [5]

In the rural areas there is often a lack of social security and thus an increased demand of generating food and money. This tendency of “living on the edge” means that the time for political engagement is limited and could affect the extension of local political participation negatively, but the major problem is often whether the locals are given the possibility. [9]

### 2.3.3 Local participation

In some projects the aim for electrification has been to develop the commercial sector
in the rural areas, thereby somewhat disregarding the basic needs of the population. In India the result of a national programme with this objective is that 80% of the rural villages have been electrified, but less than 50% of the households [3]. Nevertheless programmes approaching the commercial sector should not be disregarded as long as they are designed in accordance with the wishes of the population.

A potential obstacle to the local participation is the bureaucratic social conditions, which are present in many developing countries, meaning that the ones that actually are supposed to benefit from the programme are not invited to participate in the planning process. Things are implemented top-down from donors through government to the rural population. [10]

If the opinions of the end-users are disregarded in the planning process the participation of the users are limited to choosing whether they want to take part in the project (if they are given that choice). Based on experience from a variety of development projects it has been determined that a high level of local participation is of great importance to the sustainability of a project. [11]

This means that the local people should be invited to participate as early in the project as possible. Doing that it is important to involve people from all social groups. Special emphasis should be given to involving the women in the process. They are often the ones bearing the burden of the traditional energy system (especially in collecting firewood) and in the case of electrification they are likely to be the ones who will use the light the most.² [3]

² Some put it in the way that the women will be the major beneficiaries but it must be a matter of discussion whether weaving mats and cooking all night are benefits. [3, 8]

An electrification programme can mean big changes in the social conditions of a small village, i.e. meetings can be held in the evening instead of in daytime when other often income generating activities are prioritised. The essence is that an electrification programme could enable the rural population to increase their political involvement, improve their possibilities of educating themselves; thus giving them better chances of participating if invited.

Figure 2.1: The locals often are interested in taking part in discussion on solar electricity (here a group-meeting in Tonga)

2.3.4 Capacity development

The term capacity development or capacity building³ became an important part of donor projects throughout the nineties due to earlier projects' poor achievements in sustainable impacts, national ownership and relevance.

Even though there are many definitions it seems like there are several similarities and a common acceptance of the importance. The local and national institutions are supposed to have control of the continuing development in a sustainable matter and as mentioned the participation of the locals (stakeholders) and relationship among the actors is more or less included in all definitions. One of

³ In this report the two terms are considered as one as they somehow cover the same aspects.
the most comprehensive is the one given by the United Nations:

The process by which individuals, groups, organisations, institutions and societies increase their abilities to:
1) perform core functions, solve problems, define and achieve objectives; and
2) understand and deal with their development needs in a broad context and in a sustainable manner [12]

Especially when dealing with “technology transfer” many projects have failed because the recipients were not prepared to use the advanced technology that was introduced. It could be that no one had explained why this new technology was an improvement; that no one had taught them how to use it or maybe no one asked if they wanted the technology in the first place. [13]

Boesen et. al [14] is of the opinion that the participation of the stakeholders (locals, government etc.) is necessary to the capacity development and looking at different descriptions of capacity development and participation it is clear that the two things interact. [12,14,15, [16]

Figure 2.2 suggests how to describe five levels of the capacity to implement a new technology (NT):

The lowest step in capacity development is the knowledge of the existence of a certain technology. If the recipients are taught how to use the technology, and to some extent why, the capacity has developed to the 2nd step. In the 3rd step the recipients are completely aware of the advantages connected to the use of the technology. If they further gain the capability of adapting the technology to the situation present, they are at the 4th step. The last step contains all the basic knowledge, which will give the recipients the capability to initiate further implementation of the technology, without donor assistance. An additional step could be that a society obtained the ability to produce and develop the technology. [17]

A technology transfer’s chances of success will in our opinion increase dramatically if the capacity is developed to the 3rd step in all the recipient communities with the possibility to acquire services and expertise from at least an institution at the 4th step company/organisation. A technology transfer to communities on the 2nd step of the figure will barely be sustainable. [17]

The users’ capability to adapt the technology does not necessarily have to be present. This is supported by the use of personal computers; everybody in the industrialised world uses them, but only a very few know how to fix a more complex problem. In development terms this is referred to as a “black box” technology and can very well be used for electrification purposes as long as its functions are very well understood. [5]

The question of capacity development should be considered all the way from the project preparation to implementation and evaluation. A suggestion to how to do so can be found in Boesen, et. al., 1998. [14]
In conclusion capacity development is developing the ability to use a technology as well as the ability to participate, but being able to participate is not enough if not invited. Participation requires some kind of an invitation to do so.

2.4 CHOICE OF TECHNOLOGY

Having determined the needs of the population the possible technologies should be weighed against each other. The key question is: which technology is most appropriate for bringing the needed electricity services to a given population?

Of utmost importance are the costs due to the limited financial ability of the rural population and of financial reasons later to be discussed it might be wise to differ between initial costs and running costs. When evaluating the costs attention should be given to:

- The daily energy consumption of a household
- Total number of households served
- Household density
- Power requirements, including productive loads
- Expectations of load growth / population growth

Often the demand is overestimated and a cost-evaluation on a kWh-basis, not considering the efficiency of the appliances, could very well result in expenses beyond the reach of the poorest. The costs should be evaluated as the total costs of bringing the specific services in question to the users equivalent to the monthly expenses per household.

Further suggestions on how to evaluate the economics of a project will be put forward in the paragraph “The economic evaluation”.

Additionally the quantity and quality of the energy services provided by the feasible technologies might differ and it has to be considered how that will effect the users’ satisfaction; which benefits it gives and whether it will affect the demand for electricity and other energy sources.
The most obvious technologies for rural electrification are:

- Extension of the electricity grid
- Small generators
  - Diesel
  - Biomass
- Wind turbines
- Small-scale hydro power
- Solar home systems

Possibilities that according to the organisation later to be discussed can be categorized as:

- Medium-scale grid connected systems: Systems of 1-20 MW capacity operated by independent commercial companies
- Small- to medium-scale decentralised systems: Mini-grids or clusters of individual systems in many cases run by local operators
- Individual small systems: Primarily renewable energy technologies

It should be realised that a technology choice more often will be successful when it is carried out in accordance with the general energy policy of the country; the priorities and forms of economic development; the social, natural, environmental and cultural characteristic of the region approached; and the geographic and climatic conditions of the site. [5]

2.4.1 Extension of grid

Many electrification programmes have focused on extending existing electric grids. Often operated by a public utility the tendency has been to prioritise the connection of inhabited areas in order of the costs. The lowest cost is naturally connected with an extension to areas just outside a grid serving an urban area; the result could be a growing village and thus an urbanisation rather than a rural electrification.

No private utility will build an unprofitable line (unless compensated by subsidies) and the cost of extending a grid to a remote area with a small population can be exorbitant; this is due to:

- Inefficient use of power lines due to low population, demands and energy density.
- The demand profile of a village tends to be very peaky.
- The grid is often just incrementally extended not being optimised to the demand, and a change (grow) in demand will often raise the need of larger capacity in the grid.

[19]

It is obvious that grid electricity is convenient to the users; a high availability (though breakdowns are very common in developing countries) and the possibility of using high voltage appliances being valued characteristics. Nevertheless the further you get away from the grid the higher the costs, in many cases ruling out this possibility. [19]

If a high quality grid-extension is the cheapest opportunity (in life-cost terms) it should be chosen, but emphasis on energy efficiency should be considered as grid-availability tends to alter the use of non-efficient appliances (it makes it possible).

The costs of grid-extension in developing countries are generally 5-10,000 US$ per kilometre. In the example of a village with 50 households this correspond to 1-200 US$ per kilometre per household. This indicates that other possibilities should be considered for small villages more than a few kilometres of the grid, while grid-based power supply often is the least-cost option for large concentrations of households or productive loads. [18,19,20]

Dealing with isolated island communities the cost of connecting them to the main-island will be even higher and it seems obvious that whilst the price of electricity and the potential access to high quality
power may be attractive to users, the operating costs and overall economics are not likely to be viable in electrifying small outer islands.

2.4.2 Diesel

Diesel generators are common in many rural settlements, either for a single user/purpose or connected to a local grid. The initial costs of a diesel generator are low compared to the alternatives but high maintenance costs and the expenses of transporting diesel fuel and lubricating oil to remote locations add to the total costs of the generated electricity. Due to high running costs the generator is typically only operating a few hours a day thus the consumption must be adjusted to the supply. If the generator is to be run for a longer time the running costs will increase. [3,19]

Those living close to the generator could be bothered by the noise and another disadvantage is that fuel has to be supplied regularly. This can be difficult in remote areas especially when weather conditions are bad, and if the fuel supply fails the village is without power.

The operation and maintenance of a community generator will require comprehensive training of local labour, alternatively the stationing of a technician, which may be complicated but on the other hand, especially the former, contributing to the development by creating jobs

While the households often have to compromise on the comfort if a generator is chosen, though the capability to take advantage of load diversity allow smaller sized installations, it is often the obvious choice to industrial purposes, often characterized by a relatively predictable, constant demand [21]. This corresponds well with the operating characteristics of generators resulting in a higher efficiency.

2.4.3 Biomass

Small biogas plants have been installed in development countries with varying success. A number of SIDS installed such plants during the high oil prices of the 1970's however without success due to restricted feedstock. [5]

The main commercially viable possibility is to use biomass-derived produced gas to displace about 70% of the diesel-fuel in a generator. Using this technology the social considerations are similar to those of the diesel engine, though some extra work is connected to the gasification process. The main benefits are:

- The use of locally available biomass instead of imported oil products
- Lower operating costs compared to diesel

[3]

The initial costs are on the other hand higher but on a life-term-basis it is estimated that the technology is cost-effective compared to diesel if the diesel costs a higher than US$ 0.35-0.40 a litre. At lower costs the operation time must be high, e.g. about 3000 hours a year to level at a diesel cost of US$ 0.25. [3]

Other possibilities includes the spark-ignition engine which doesn't require diesel but need to be further developed, microturbines, also requiring research and development, and wood-fired power stations being more appropriate to larger-scale production [3] [5]. Further it is possible to use coconut oil as fuel in diesel engines. [5]

In conclusion biogas should be considered as a possible alternative to a pure diesel engine whenever the potential is present. It is reducing the net-emission of CO2 and can be cost-effective if oil-prices are high. On the other hand a more complex
technology can complicate the maintenance thereby increasing the costs.

2.4.4 Wind

There are two ways to exploit wind power, which seems feasible to meet rural energy needs. [3]

The first one is to implement wind in a wind-battery-diesel and possibly PV hybrid system; typically using wind turbines of 5-100 kW. In regions with high diesel costs, these hybrid systems can lead to lower operating costs and a decrease in air pollution is an obvious advantage. [3]

The disadvantages are a considerable increase in capital costs and also, qua the diversity in technologies, a complexity of operation and maintenance, which raises a need for skilled labour. The required maintenance for wind turbines is considerable especially on islands due to a humid and saline atmosphere. [5]

The other possibility is small household-scale wind turbines of about 100 W. The benefits are more or less similar to those of PV home systems presented in a later paragraph, and as with PV the initial costs are relative high but the running costs very low. [3]

Whether wind energy is a possible solution depends on site availability. In most SIDS wind resources are neither strong enough nor constant enough and periodic storms have the potential of seriously damaging the systems. Particularly on atolls the use of wind is problematic with turbulence caused by trees making it necessary to cut down a large number of trees around the site in order to provide a clear wind path; this could mean a decrease in agricultural resources and an increased risk of erosion. On top of this skilled labour is required to maintain and repair the systems. [5]

2.4.5 Small-scale hydropower

Small-scale hydropower is a possibility to rural electrification if the resource is locally available. Of specific interest is micro hydro defined as less than 100 kW and mini hydro ranging from 100-1000 kW. The electricity can be produced at very low costs (0.04-0.10$) but a potential drawback is that the systems often is situated in rivers that lack reservoir capacity leading to severe seasonal variations. In such cases the long-term viability depends on backup electricity provided by other sources. [3]

In SIDS the potential varies a lot, with some countries like Fiji and Samoa having potential even for larger scale hydropower and atolls having zero potential. [5]

2.4.6 Photovoltaics

Photovoltaics have proven to be a viable technology for bringing small amounts (typically less than 1 kW) to rural end users and up through the 1990’s more than 300,000 solar home systems were installed. [3]

Apart from the photovoltaic module the battery is an important part of the system as the energy is produced during the day and mostly used at night. The PV systems are rather expensive, but if the demand is low and/or the fuel prices are high the very low operating costs can very well make them the most cost-effective possibility in the long term. [3] Some further advantages are:

- No grid is required thus the location of hoses are not fixed by the grid
- Continuous availability of power (if dimensioned correctly)
- Each PV system is independent to failures in others: a breakdown in a generator results in loss of power for the entire community, failures in PV-systems affects only the individuals.
- It is fairly simple to repair and maintain a PV-system thus limited training is required.
- Systems are modular meaning that the size can be adjusted according to changing needs and the systems can be specifically sized to fit individual households.
- Health risks are negligible; the low voltage makes electric shock harmless and no local emissions appear. [21,22]

Experiences shows that the comfort of a PV system is very highly rated by the users but if the demand exceeds basic appliances such as lights and radio, the technology tends to be more expensive than the alternatives. [3]

The availability of solar light should also be taken in consideration. The larger distance from Equator the larger the seasonal variations, and the systems have to be dimensioned to satisfy the need all year (if used all year). Furthermore the installation can be difficult in areas with dense vegetation. [21]

On the environmental part the systems should be evaluated on a life-cycle basis. The energy production is small thus the saving in emissions limited, while the major risk to the local environment is connected to the disposal of batteries; batteries that typically are replaced every 5-8 years. [21]

In our opinion PV technology should be considered whenever the demand is low, but PV in rural electrification should be regarded only as electrification and social development (satisfying the basic needs) as the environmental and commercial benefits are small.

The initial costs of a solar home system vary from 8-40$ per installed watt [3]. With the typical size being about 50 Wp the initial costs thus is at least 400$ per system/household [3]. Including installation and some training in the budget Eduardo Villagran [19] estimates the “photovoltaic ceiling” to be 650$ per user, a price that could be lowered to about 450$ for a 55 Wp system if better practice in system design was adapted [19]. The reason why special considerations should be given to the system design is that a dimensioning above the necessary gives an unnecessary increase in the initial costs while a too conservative dimensioning could reduce the lifetime of components (especially the battery) and thereby an increase in the maintenance costs.

The PV technology and the considerations connected to the design of stand-alone systems are more thoroughly described in an independent chapter of the report.

### 2.4.7 Future possibilities

An enormous amount of research is to be done in assessing the end-use efficiencies, cleaner technologies, renewable resources, and the market for these renewable energy and efficiency technologies. [5]

Having presented most obvious possibilities for rural electrification it should further be noted that development of other technologies could make them able to compete. In the SIDS wave energy could become a possibility and others include fuel cells e.g. combined with gasification of biomass [23], though both technologies have some way to go before a possible commercialisation.

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4 The price of other possibilities, e.g. grid or diesel, which will make PV the obvious choice.
2.5 Responsibilities of the Stakeholders

It is of great significance to lay down the role and responsibilities of all stakeholders; government, aid organisations, energy service companies (ESC)\(^5\), financial institutions and users; in order to obtain sustainable project implementation.

Rural electrification tends to be synonymous to very high capital costs and as the rural population in developing countries in general have low incomes financial arrangements are necessary in order to pay/finance these costs. Further it has to be decided who is going to introduce, operate and maintain the scheme and how the costs of the institutions and technologies for service provision are to be repaid.

Although several organisational models and sustainable financing schemes have been tried out a definitive solution have not been designed. Acknowledging the significance of the case-by-case approach and having the diverse conditions (social, technological, institutional etc.) in mind, a definitive solution is unlikely to be profitable. It is therefore useful to have a variety of approaches at every level of the project implementation. In the following some possible solutions will be given concerning the organisation of the consumers, the structure of financing schemes and the role of the government and aid organisations in order to address the barriers.

2.5.1 Financing

It is appropriate to split up the financing of rural electrification into two parts; the first being the payment of the initial costs the latter being the payment of operation and maintenance. In development projects the initial costs are often supported in form of a grant and a financial sustainability is then an object of the project. This means that the users have to pay for the operation and maintenance possibly through government subsidies.

Subsidies to make a service available to users should not be long-term support, as dependencies tend to perpetuate themselves. The most common practice for allocating subsidies is the minimum subsidy per user criterion, which promotes both least cost and maximum leverage. [19]

As mentioned different financial models are possible, some of them being:

- Financing through a grant
  - A single initial grant
  - Continuously financial assistance
- Loan aggregation via cooperatives
- Promotion of energy service companies
- Revolving funds

[5]

When financing through a grant the key aspect is to find the balance between reaching as many consumers as possible and attain economic sustainability. Focus should also be on capacity building and a development away from a donor dependency frame of mind.

To avoid the high cost of many small loans and to generate a start-up capital community cooperatives can be set up.

Subsidizing energy service companies, enabling them to present a payment scheme to the consumer, which is compatible to their income, obliges the

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\(^5\) Energy service companies are vendors specialised in supplying services, maintaining and running energy projects and in many cases provide financing schemes appropriate for rural consumers. These energy service companies could play a significant role in the dissemination of rural electrification.
consumers who otherwise would not be able to meet the installation fee. This is especially practicable in the case of medium-scale grid connected systems, but could also be used in terms of small individual systems.

In the case of revolving funds a bank takes on the risk of the loan usually with start-up capital provided by a grant.

Combining one or more of these schemes can be appropriate, but whatever is used financial sustainability is top priority and essential if the development is to expand and reach the rural population.

[5,24,25]

2.5.2 Organisation of the consumers

The low economic and political capacity of the rural consumers in developing countries combined with the high establishing costs and in many cases low political priority of rural electrification, necessitates the organisation of individual rural consumers in formal forums. Both in terms of empowering the individual consumers and to facilitate the implementation and running of the electrification village, committees and community cooperatives are commonly used approaches.

Village committees

The organising of the consumers in village committees representing all households involved in an electrification project is inexpensive to set up and tends to be legitimate representatives of their communities. This model is often appropriate when either government or aid organisations finance the utility and it is especially suitable in projects involving small individual systems. In most cases a secretary of the committee and one or more local technicians are elected in order to undertake the services of the committee; usually maintenance of the systems and collection of payments or replacement charges. Often the technical capacity is not sufficient thus professional technical assistance is necessary in case of complicated problems. [5,19]

The drawbacks of the village committees are that they are rarely formal in terms of legal framework and since they represent the in most cases poor, rural consumers, their financial support is limited. The informal decision-making can result in a few powerful users neglecting the majority of the users needs. Another aspect is that the success of the committee, and thereby to a large extent the project, is determined by the commitment and capacity of the responsible persons, the secretary and the technician(s). Furthermore collection of fees or replacement charges and the effectuation of consequences in case of non-payment (i.e. disconnection of systems) can be ineffective because of the close, often familiar relationships in the small communities. [5,19]

If the need for skilled labour assistance and spare parts is frequent the village committee approach is rarely the appropriate organisation form. In this case the running costs will increase significantly and/or the periods of system breakdown will tend to be long and frequent. [5,19]

Rural cooperatives

Cooperatives, which require a willing attitude among most of the users and intensive organisational development training, are a way of facilitating rural consumers buying the electrification utilities or obtaining a loan despite limited economic capacity. It applies especially to the implementation of small- to medium-scale decentralised systems where the cooperation owns the utility, however financial assistance is in many cases needed anyhow. [5]
The financial structure is quite rigid and not necessarily reflecting the users’ willingness and capability of contributing thus limiting the dissemination of the provided services. On the other hand they provide a formal legal structure and a well-defined administrative and decision-making procedure. An energy service company hired and paid by the donor through the local government could do the service and maintenance and form the financial assistance. [5]

2.5.3 User fees

Whether the approach of the electrification is commercial or donor-funded a user payment or a replacement charge is always involved to secure sustainability or at least some extent of local participation.

These fees have to be determined in relation to the income level to secure affordability. A classic approach is to estimate the amount used on the former energy source but it should be recognised that people, especially in middle-income countries, in general are willing to pay more in return for the improved comfort. [19]

The fee necessary to obtain financial sustainability should always be calculated; and this calculation should be used if within the affordability of the users. If not arrangements for linear subsidies (often governmental) should be considered.

Depending on the organisation of the users, and who is collecting the fees, close and familiar relations in the small communities can make it difficult and having someone outside the community collecting it would in many cases enhance the effectiveness of the fee collection. [7]

Most often the fees are paid on a monthly basis, which could be a reason to low collection rates as rural population in development countries rarely think in terms of a “monthly budget”. The economy is mainly subsistence and the availability of money can vary drastically with seasons, either due to varying possibilities of income or expenses like school fees and church contributions often paid once or twice a year. That means that the monthly fee is not necessarily the most appropriate to rural areas; the specific economic situation should always be considered. [9]

In Africa Shell and Conlog has introduced a payment concept of consumers inserting pay-as-you-go cards into a sealed battery box - the concept being similar to what is known from mobile phones [26]. The service included on a card could either be related to the net-energy use or be restricted to a limited period (e.g. one month). This technology could be a possibility to adjust the payment of the PV service to the habits/capability of the population and is an easy way to effect consequences towards users not paying the fee.

Apart from the payment cards the Shell/Conlog system includes two microchips in the battery respectively the panel and these components will not function without the associated control system. This makes the panels unattractive to thieves. [27] The major drawback is that every extra component involves a risk of breakdown.

2.5.4 Moving towards a market

The energy service company is somehow a step towards a commercial market, which could represent a major step forward. To make a business commercial viable however, it is estimated that funding is needed to expand until a number of 1500 systems [22]. Furthermore low customer density in a given service territory makes
sales, installation service and payment collection expensive and difficult, resulting in transaction costs that are about 30% of the total system costs. This reduces affordability, undermines sustainability of systems and reduces the market impact of even dramatic cost reductions in PV modules. [26]

Even before reaching the critical number the programmes could benefit from a competitive selection of suppliers. If the contribution instead of being channelled directly to the users were used for the promotion of the energy service companies, it could contribute to an emerging commercialisation thus reducing costs. [5]

However it is important to secure that even the poorest families in an area can afford the services offered. A possibility that not often has been practised is to offer different options to the users. In a programme introducing PV through an energy service company in Sri Lanka four different systems, and prices, were offered. [28]

Another market approach is to lease the equipment to a cooperative, which would give the investor a larger security and thereby reduce the overheads of the cooperative – and the individual consumer. [5] [24]

**Opening the market**

If aiming for a commercialisation it is important to make the market approachable. Historically, energy price subsidies have been used to promote wider use of modern energy carriers. This approach could however be problematic because you end up with tariffs lower than real producing costs resulting in “closed market” and no gain for private companies in entering the market. In addition you have a disproportionate exploitation of the subsidies by the more affluent that can afford to pay the unsubsidised price while it do not reach the rural and often poorest consumers. [3]

In many SIDS duties and taxes discriminate against RE energy efficiency technologies, however, as they only apply to conventional solutions; a fact that hinders the reduction of the start-up costs and thereby reduces the dissemination of RE and energy efficiency technologies. In addition the projects are often quite small which increases the relative costs even further. To comply with this bundling of individual projects are an obvious approach, but a reduction of costs in terms of favourable tax incentives and power purchase agreements could also contribute to the promotion of rural electrification. [5]

A market driven electrification has the potential of moving faster than the somehow bureaucratic aid organisation approach, but as pointed out it contains the risk of leaving out the poorest. Further it will not be successful if the governments do not involve themselves by educating the masses on the benefits and advantages of a given technology. [24]

### 2.5.5 Co-ordination

In many developing countries rural energy planning is still in its childhood. The single most important task for the governments in these countries is to lay down a comprehensive strategy on the highest level for the energy sector. This should include a transparent, supportive institutional and regulatory framework supporting and promoting sustainable development and capacity building. Financing schemes compatible with the rural population’s financial capacity should be provided and energy service companies should be promoted. [25]

Further lowered duties and tax exemptions on RE and energy efficiency technologies and phasing out the subsidies to grid distributed power channelling these funds
to more effective use would enhance the availability of these technologies for the rural consumer. [5]

International donor organisations also have an important role to play in a careful selection and implementation of projects, but also in encouraging the local governments to act towards sustainable development. In addition the donor organisations should promote capacity building in terms of supporting local energy service companies and by providing adequate information dissemination on RE and energy efficient technologies. [3]

While international donors and financing agencies like the World Bank, UNDP, UNESCO and EC are best suited for large-scale promotion and arrangements for financing and technology transfer, the smaller NGO’s could be an important factor in the implementation and coordination of the projects. [25]

Evaluations should be carried out in any step of planning and implementation of every project and experiences should be shared actively between governments, donor organisations and consumers. This step is of great importance to the success of existing as well as future electrification programmes. [5]

2.6 THE ECONOMIC EVALUATION

In our opinion the choice between the market approach and the traditional aid funding is not to be seen as a definitive choice, the two can very well work parallel in different programmes. When it comes down to it the important thing is not how but that the rural population gains access to electricity.

However the two approaches can differ in the most cost-effective choice of technology. This is due to the market paradigm; that a private investor will evaluate things from a financial perspective while a public institution should be evaluated on an economic perspective. [25]

A financial analysis will be based on the real financial cost, i.e. market prices, including local taxes, national taxes and possible subsidies, import duties and the cost of borrowing the necessary capital. [25]

As most banks regard the investment risk in the area as high, the overheads and other lending costs are pushed up, which is an obvious disadvantage to RE qua the high initial costs. [5,19]

Further the lifetime of RE installations (e.g. >20 years for PV panels) is often longer than the depreciation period used in cost analysis, and most private investors do not want to use a longer depreciation period due to larger unreliability. [19]

While private investors always uses the financial approach the approach chosen by institutions varies a lot, though the economic approach seems the obvious choice.

An economic analysis will consider the economy of the project as a hole. Transfer payments, e.g., taxes, duties, and

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6 Somehow similar to a profit respectively non-profit approach
subsidies, should be excluded from the economic evaluation, since these payments simply transfer resources (from taxpayers through government to beneficiaries) without reducing the real resources available to the economy as a whole. [25]

The economic analysis should also recognise that the initial cost often is paid for (at least part of it) by a grant thus will have no influence on the long-term sustainability. In addition a public institution often has a tendency towards calculating costs with a longer depreciation period. Unfortunately many economic feasibility cost evaluations use a ten years timeframe based on the lifetime of e.g. a diesel generator. [25]

It is possible to shadow-price externalities (both detriments and benefits) to reflect the true value to the overall economy of resources employed. In some cases a consequence of a programme may have no financial cost but a real economic cost, e.g. if water is polluted by diesel oil it should be an additional cost in economic analysis. Especially the environmental shadow-prices are a matter of discussion and no universal accepted guidelines exists, mostly due to reluctance in industrial countries towards imposing expenses on industry.

Whether the economics are evaluated from the users point of view or from a general standpoint it should be based on life-cycle costing. Life-cycle costing examines all the costs incurred over the lifetime of different systems. These costs are converted into today’s money, a method known as discounted life-cycle analysis, and the analysis period is chosen as the lifetime of the installation, the longest lifetime in a comparison; giving somewhat more credit to long-lasting technologies. [25]

Further it makes it possible to calculate the annuity necessary to cover the expenses over a period of time, thus determining the necessary fee to financial sustainability.

It should be noted that the estimation of the lifetime should consider the expected lifetime of the programme. It makes little sense to calculate the economy of a windmill in a twenty years period if it is certain that it will only be used for ten.

Financial considerations should not be the only parameter influencing the decision of technology, other aspects like ease of maintenance, reliability, flexibility and environmental consequences should also be included.

The environmental aspect could turn out to get more attention in the future. For one the Clean Development Mechanism in the Kyoto/Bonn agreement allows industrial countries to implement RE projects in development countries and credit the savings in CO₂ on their own accounts.
3. PV Theory

The principle of Photovoltaics is the direct conversion of light into electricity. Some materials exhibit a property, known as the photoelectric effect that causes them to absorb photons of light and release electrons.

The incident energy of the light allows mobile electrically charged particles to become excited. These particles are then able to move in the presence of an electric field; e.g. generated by a p-n junction in a silicon-based semiconductor, and the resulting electric current can be used as electricity.

[29]
This chapter presents the basics of the PV technology with emphasis on stand-alone systems.

3.1 Introduction

The French physicist, Edmund Bequerel, discovered in 1839 that certain materials could produce small amounts of electric current when exposed to light. In 1904, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, a paper that later, in 1921, gained him a Nobel Prize in physics.

In 1954 Bell Laboratories made the first photovoltaic module, though it was too expensive to gain widespread use. Later in the 1950s PV-cells provided power to earth-orbiting satellites. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline.

During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications to power remote, off-grid critical electrical requirements such as railway signals and telecommunications. In the 1980s PV became popular in consumer electronic devices, and today PV is a well-proven technology used in a range of applications including those for water pumping, transportation safety systems and for electrification of rural residential.

[30, 31, 32]

Figure 3.1: A PV module powering a weather station in Tenerife
3.2 Insolation – The Solar Potential

The energy production from a PV module depends largely on available sunlight at the location. The power density of sunlight on Earth is about 1000 W per m² irrespective of location, while the energy available per unit of time (day, month or year), the insolation, varies a lot: from 800 kWh/m²/year up to 2500 kWh/m²/year in dry desert areas. Of great importance to system design are the differences in the average monthly insolation: the variation close to equator is about 25% and goes up to a factor of 10 in very northern and southern areas.

3.3 The PV System

A PV system is defined as the active PV module plus all components required for taking the photo-generated electricity to the point of use including energy storage in off-grid systems. [33]

As this report focus solely on off-grid/stand-alone systems this is the only type described. A stand-alone system is characterized by providing electric power to applications independently of a grid and requires, when used for residential lighting, energy storage most often in a battery.

The components included in a typical system are:

- The PV module / panel
- Batteries
- Regulators
- Module array frame support
- Electrical cables
- Switch gear
- Safety equipment
- Mounting equipment
- Land or roof/facade space
- Parallel connection box, if more than one panel
- DC-AC inverters, if AC appliances are present

[33]

In designing a stand-alone system the type of loads should be considered as well, the most common being lighting and radio.

3.3.1 The PV Cell

The solar cell is a semi-conductor that converts sunlight into DC electricity. Most common is the Silicon PV cell, a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. The basics of the process is as follows:
1. An electrical field is created near the top surface of the cell where the two differently doped sections are meeting (this area is referred to as the P-N junction).

2. Sunlight strikes the surface of the cell and the internal electrical field in the P-N junction provides momentum and direction to light-stimulated electrons.

3. When the cell is connected to a load the result is a flow of electric current.

This effect is due to that the conductivity of a semi-conductor varies much with temperature. By inserting (dotting) impurities in silicon crystals the structure allows for conduction. Positive charged atoms, e.g. Phosphor, respectively negative charged, e.g. Boron. [29] (Illustrated in figure 3.4)  

The open circuit voltage of a silicon cell is typically around 0.59 volt with a working peak voltage 0.44-0.49 volt. The voltage varies with temperature (approx. 0.4%/C - Open Circuit – and –2.2mV/C - Peak) but only little with irradiation.

The current output of a PV cell depends on

a) Size / surface area
b) Efficiency
c) Intensity of sunlight striking the cell [31]

Cell types

Today the crystalline Silicon Technologies accounts for more than 90% of the world PV-market, shared equally between Monocrystalline Silicon Wafers and Multicrystalline Silicon Wafers. [35]

Monocrystalline Silicon Wafers were used for the first commercial cells. Apart from PV modules it is used in microelectronics. It has a relatively high efficiency, but it is also the most expensive type.

Production: Boron doped p-type monocrystalline silicon is produced by the Czochralski process: a cylindrical single crystal is slowly pulled from molten silicon
held in a quartz crucible in an argon atmosphere. The silicon used is typically low-spec polysilicon rejected by microelectronics and recycling. The result is a round substrate, diameter approx. 150mm sawn to a wafer thickness of 300um.

To improve the performance and reduce costs producers try to increase the substrate diameter and to further decrease the wafer thickness (Silicon wafer accounts for up to 40% of the total module costs.) It is predicted that a wafer thickness of 150um will become the industrial standard within 5 years. [35]

**Multicrystalline Silicon Wafers** have a lower efficiency but are cheaper; and as they are square they give a better utilisation of the module area, reducing the final module cost. The technology is exclusively used for PV-cells.

*Production:* molten silicon is solidified in rectangular quartz crucibles and the cooling rate is controlled to produce large-grain material. This gives a wafer of lower cost compared to the monocrystalline but the electrical quality (minority carrier lifetime and grain boundary recombination) is inferior meaning lower cell performance. In addition, there is a higher sunlight reflection loss at the cell surface due to inability to texture the surface by proven low-cost chemical etch process.

To improve the efficiency different etching processes are being researched in order to decrease the reflection loss. To reduce costs the size of the silicon ingots is increased and the wafer thickness reduced. Today the ingots weigh more than 250kg and the wafer thickness is 250um (It is not clear whether thinner wafers are suitable to a high-yield cost-effective process) [35]

Different technologies are being developed aiming to further improve the efficiency of silicon cells. [35]

**Thin Film Technologies** offer promise of lower cost PV devices by significantly reducing the quantity of semiconductor material used to make a solar cell; this is done by using transparent conducting oxides as one electrical contact. A range of different types exist all known on material used for the semi-conductors. [35]

The efficiency of thin film cells tends to be

![Table 3.1: Solar cell efficiencies](image)
somewhat lower than that of the monocrystalline silicon cells. This is due to the materials band gap, which renders any incident photon with lower energy useless for electricity generation. The semiconductor is unable to utilise energy contained in the incident spectrum beyond this wavelength. The thin-film conductors have a higher band gap compared to the monocrystalline, but on the other hand the materials used suffer less from thermal effects (see “Losses”).

Another possibility is Photo Electro Chemical cell (PEC) also known as the Grätzel cell. The principle of the PEC cell is analogous to that of the photosynthesis of plants, and the technology has the potential of cells with very low production costs. [37]

Other attempts to lower production costs include concentrators. Simply concentrating solar energy onto PV-material enables reduction in the system cost if the cost of the concentrator is less than that of the displaced PV-material. [38]

Table 3.1 contains the record efficiencies respectively the commercial module efficiencies of most approved cell technologies.

The efficiency of commercial modules is expected to increase steadily over the next decades, irrespective of technology. In 2010 the efficiency is likely to be about 12-20 percent, and beyond 2020 possibly 30% or more. It should be noted that the high efficiencies are not expected obtained by simple extrapolation of today’s commercial technologies; and it is not very likely that the modules with the highest efficiency will be the ones with the lowest manufacturing cost per watt. [3]

### 3.3.2 The PV module:

In order to obtain relevant voltages a number of cells are connected in serial. A typical module consists of 36 cells resulting in an open-circuit voltage of approximately 21.8V, peak-voltage of 16,5-17V and peak current of 3-4A.

The module structure protects the solar cells from the environment, and photovoltaic modules have proven to be very durable and reliable. They typically have ten-year manufacturer’s warranties and much longer expected lifetimes in practice. Some manufacturers are even beginning to guarantee an 80% output after 25 years. [30, 31]

The nominal output of a module is given in Watt-peak (Wp), which is the output under a given light spectrum with an intensity of 1 kW per square meter at a junction temperature of 25 degrees Celsius. [25]

There have been barely any changes in design and fabrication method of modules for 15 years [40]. The modules are usually flat and rectangular [41]. The cells are protected by:
3.3.3 The PV panel

The terms module and panel are often used interchangeably. In this report a panel refers to a few modules connected together. [30]

A PV-array is all the PV-panels connected to a system. In a stand alone system the total array is often only one panel. [42]

In stand-alone systems the modules are usually connected in parallel with the peak voltage of 16.5-17V being suitable to the common used battery voltage of 12 volts. (It is possible to connect modules in serial if a higher voltage is required.) [41]

3.3.4 The battery

As premature battery failure is among the most common problems in a stand-alone PV system special emphasis will be given to this subject. Although they are a rather limited part of the initial costs, the battery, in some PV systems, accounts for more than 40 % of the life cycle costs. [43]

Three different types of batteries are used in stand-alone PV-systems, all of them being the lead-acid type.

The cheapest one is the Flooded Lead-Acid Battery. This type of battery requires maintenance in the form of regular water filling. Further they suffer from high water-loss and self-discharge rate but perform, when properly maintained, well under a range of critical conditions including high temperatures, low discharge-rates and deep discharge conditions. The nominal specific gravity of the electrolyte is 1.28, but should be up to 1.30 in cold climates and down to 1.19 in warm climates.

The Gelled Electrolyte and the Absorbing Glass Mat (AGM) are commonly referred to as VRLA Batteries (valve-regulated lead-acid). Both are designed not to need any maintenance over the lifetime, with valves installed to prevent gas build up in the cells. They are more expensive than the Flooded ones but good performance combined with no maintenance has made the VRLA batteries the most popular choice for PV systems. The use of calcium results in lower gassing and self-discharge rate, but the VRLAs do not perform well under high temperature and deep discharge conditions. The gelled electrolyte batteries tend to show a somewhat better performance than the AGMs. [44]

In general avoiding critical operating conditions such as overcharging and deep discharge can extend the life of these
batteries. For instance a low state of charge for extended periods will cause increased sulphation, which severely reduces the life of the battery, while overcharging results in loss of water requiring more maintenance. The shortened battery life contributes significantly to the life costs of a PV system. [43]

If handled properly and with proper system design the lifetime of a battery should be 5-8 years. [41]

### 3.3.5 The Charge Controller

The regulator, or the charge controller, plays a key role in prolonging the lifetime of the battery. It is not only providing overcharge protection for the battery but in addition contains load control functions in order to avoid over-discharge of the battery.

Most regulators use battery voltage for regulating the charge and discharge, though a few regulators use ampere-hour tracking with the most advanced having a microprocessor included allowing more complex algorithms.

The voltage can be regulated by e.g. simple on-off (interrupting), linear constant voltage and high-frequency pulse with modification (PWM). The switching element is typically MOSFETs. Since PV arrays are current limited the battery charge can be regulated by either short-circuiting the panel (shunt) or by open-circuiting the array connection to the battery (series).

The regulator is set to a voltage regulation point (VR), which is the highest voltage the battery is allowed. In a simple on-off regulator the battery remains disconnected from the array until the voltage drops to array reconnect voltage (ARC). In constant-voltage and PWMs the VR is maintained by limiting the current.

To prevent the battery from being over-discharged the regulator cuts off the loads when the battery voltage has declined to low voltage disconnect (LWD) set point. The loads are allowed to draw power from the battery when it reaches the load reconnect voltage (LRV).

[44]

The regulator should be dimensioned according to the maximum current, and all loads, batteries and panels should be connected through the regulator. [41]

### 3.3.6 Set Points for optimal battery performance

In the following common guidelines for the adjustment of the regulators set points are outlined. All values refer to 12 volts batteries, with differences between the various types included.

**VR:** To maintain battery state-of-charge a certain amount of overcharge is required. Thus for flooded lead-acid batteries the VR should be set at 120-130% of full capacity respectively 105-110% for VRLAs. A higher VR results in most cases of flooded lead-acid batteries in a higher charge acceptance, but also higher water loss – and a too high VR accelerates the corrosion rate decreasing the lifetime. For VRLAs a higher VR do not improve the time of recharging. [44]

**ARC:** For an on-off regulator the ARC point secures a continuous on-off switching to secure that the battery is fully recharged. Tests indicate that the difference between VR and ARC should be 5-9% of the nominal voltage. The recharge-no-charge process replaces the “float” period known from the other mentioned regulators. The “float” period is required because the battery is not fully recharged when the VR is reached and it is notably longer for VRLA batteries.

Experiments show that at least 90% of the initial capacity is maintained after a year with VR set at 14.7 volts and ARC=13.7 volts. This result is similar to those of
experiments with a constant voltage of 14.4 volts. [44]

LVD: This set point is to protect the battery from over-discharge. A lower LVD results in short terms in a higher load availability while a higher LVD helps maintain battery state-of-charge. Typical LVD set points in small systems vary from 10.8 to 12.0 volts, but tests indicate that this does not guarantee a high state-of-charge. Especially in the case of VRLA batteries the lower settings of the LVD is not recommendable. [44]

LRV: This setting should be high enough to have the battery recharged enough after a LVD cut-off such that it is not drawn directly back down to LVD. Typical values vary from 12 to 13 volts. Again the VRLAs should have a higher LVD, but this will not have a negative effect on the time from LVD to LRV as the VRLA recharge is characterised by a rapid increase in voltage. [44]

Some regulators contain a power point conditioner, referred to as a maximum power point tracker (MPPT). This device operates the PV-array at the voltage providing maximum power and converts this to the output voltage required by the battery. This can help to reduce the energy losses. [25]

![Figure 3.6: The battery should be given special attention in a PV system. Here a flood-acid battery (108Ah)](image)

<table>
<thead>
<tr>
<th>Type of Battery</th>
<th>flooded lead-acid</th>
<th>VRLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR</td>
<td>120-130% of battery capacity</td>
<td>105-110% of battery capacity</td>
</tr>
<tr>
<td>ARC</td>
<td>Depending on regulator</td>
<td>Depending on regulator</td>
</tr>
<tr>
<td>LVD</td>
<td>10,8-12,0 V</td>
<td>10,8-12,0 V</td>
</tr>
<tr>
<td>LRV</td>
<td>12-13 V</td>
<td>12-13 V</td>
</tr>
</tbody>
</table>

Table 3.2: Recommendable regulator set points for optimal battery performance

### 3.3.7 Power point conditioner
3.4 Losses

Mismatch
A mismatch loss is defined as the power available from a combination of cells or modules being less than the sum of power of the individual cells or modules. Mismatch losses in PV is caused by electrical output differences in cells and/or modules. It occurs from the fact that power from modules or cells connected in series, is limited by the current flowing through the lowest performing part. If modules are connected in parallel they must operate at the same voltage and could cause voltage mismatch, but this effect is rarely significant. [45]

Heat loss
Most solar energy incident on PV panels is converted to heat reducing the solar-to-electrical conversion efficiency. [46] The manufacturers Standard Test Condition (STC) is given for a temperature of 25C / 1000W/m² but the solar-to-electrical conversion efficiency of mono and poly crystalline silicon PV conversion efficiency of PV cells decreases with increasing cell temperature; e.g. 0,4-0,5%/K for crystalline silicon solar cells [45, 46]. This is because an increasing temperature reduces the available potential difference across the junctions, thus the available voltage from the unit decreases. [33] Improvements in operational performance are achieved if the thermal energy accumulating in the material can be effectively dissipated. [33]

In addition, a higher temperature increases the number of minority carriers generated in the semi-conductor. These carriers carry the dark current through the junction. The dark current flows in opposite direction to the required forward/output current. [33]

Problem solving concerning heat loss
The method of installation impacts on airflow. Individual frames tend to intrude the flow path, making the prediction of flow conditions problematic. Improvements by fins give an extended surface area but increases pressure losses and add to the overall weight of the collector. [33]

Ohmic cable losses (copper losses)
The connecting DC cable can lead to an induced voltage loss (longer cable – larger loss). [45] It is important that the system is designed with a proper cable size:

Cables to battery should be 4-6 mm²
Cables to module should be 1,5 to 2,5 mm² depending on the length of the cables
More than 10 metres of cable could cause unnecessary losses [41]

PV module aging
The performance of the panel can degrade with age. In general the supplier will guarantee 90% of initial performance after 10 years and 80% after 25 years. [8] In newer panels even better guarantee is provided.

Battery losses
The losses in the battery will also affect the performance of the system. The battery degrades with age and as mentioned the design should allow for some overcharging. [44]

External losses
The external losses cover those arising from the installation angle (the angle is seldom optimal to the angle of incidence of the sunlight), dirt on the module (which could decrease the amount of sunlight to the cells) and shading from e.g. trees.

Inverter losses (if present)
The total AC energy produced by the inverters depends on the PV array input power and the inverter terminal and inverter losses. Inverter losses are the minimum power needed for the inverter to switch on. [45] As Stand Alone Systems seldom operates with AC appliances an
inverter is not present, thus no inverter loss appears.

### 3.5 Performance Ratio:

As the perfect system conditions do not exist, it is common practise to estimate a performance ratio being simply the ratio of delivered energy to the nominal output of the array. For state-of-the-art standalone systems the typical performance ratio is estimated to about 60% [3] while experiences from the past 15 years suggest that typical performance ratios for small systems vary from 30-55% [8]. This indicates that some improvements have been accomplished, though some of the empirical losses also could indicate the importance of proper installation.

In the table the different losses in a PV-system is estimated and the resulting performance ratio calculated:

Table 3.3: Performance ratio

<table>
<thead>
<tr>
<th>Loss</th>
<th>Typical effective efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV-module power loss (usually guaranteed by the supplier 15-25 years)</td>
<td>10-20% 90%</td>
</tr>
<tr>
<td>Mismatch and heat losses</td>
<td>5-20% 90%</td>
</tr>
<tr>
<td>Battery losses (increasing with age)</td>
<td>10-20% 85%</td>
</tr>
<tr>
<td>Cable losses*</td>
<td>2-15% 95%</td>
</tr>
<tr>
<td>Angle effects**</td>
<td>2-10% 95%</td>
</tr>
<tr>
<td>Others (e.g. shading/dirt on panel)**</td>
<td>0-20% 95%</td>
</tr>
<tr>
<td>Performance ratio</td>
<td>26-69% 0,59</td>
</tr>
</tbody>
</table>

* mostly due to poor dimensioning
** influence more in tropical conditions
*** Could be avoided by proper installation and maintenance

### 3.6 System Design:

The first step in properly designing a PV stand-alone system is to determine the loads to be supplied. As the initial cost of a PV system increases more or less proportional with the size of panel and battery it is important to keep the necessary system size to a minimum. Due to this only highly energy efficient appliances should be used. The energy service in question should be considered carefully e.g. an outdoor light could be of lower quality than an indoor without affecting the benefits to the user. Low voltage diode light can be used outdoor while energy saving fluorescent tubes is the preferable choice indoor.

Any additional loads e.g. a radio should also be chosen from a criteria of energy efficiency.

When having determined the energy necessary the nominal panel size can be evaluated using the array to load energy ratio (A:L). It represents the average daily amount of energy output from the panel divided with the average daily load usage in the critical period (typical the month with the lowest solar-irradiation to load ratio is used). An A:L ratio of minimum 1.3 is recommended. The importance is indicated by tests showing that batteries cycled with an A:L of 1.1 yield less than half of the cycles obtained with those operated with an A:L of 1.3 or higher.

If the daily energy requirement is $E_d$ [Wh], the minimum monthly solar irradiation is $S_{min}$ and the performance ratio, $X_p$, the nominal PV panel $[W/1000W/m^2=W_p]$ rating, PV, is found as:

$$\frac{E_d \cdot (A:L)}{S_{min} \cdot X_p} = PV$$

The required battery capacity, $E_{batt}$, can subsequently be determined. To secure
power availability in periods of bad weather the batteries are usually dimensioned with 5 days of autonomy, \( a_d \). In addition, an extra capacity factor, \( Y_c \), allows for overcharging, typically 1.3 is used. [41]

\[
\frac{E_d \cdot a_d}{V_{batt}} \cdot Y_c = E_{batt}
\]

With \( V_{batt} \) being the nominal voltage. [41]

If extreme climate or operating conditions are present those must be considered carefully, e.g. by dimensioning to a longer autonomy period. [44]

### 3.7 COSTS

The PV technology is expensive. The initial costs of a system require some kind of donor contribution to make it available to the poorest developing countries. The limited maintenance giving very low running costs result in lifecycle costs comparable to the alternatives when it comes to rural electrification and in providing power to remote applications such as communication or weather stations the PV technology is outstanding.

The price of the modules still represents a major part of the total costs, but as the market has an annual growth of 26%, hopes are that the price will continue to go down. [33]

The production cost of a crystalline silicon module was above 3 ECU/Wp in 1994, but predicted to decline to 1.8 ECU/Wp in the short term and around 1 ECU/Wp in the longer term. [47]

In 2001 projections through 2004 indicated a steady decline to an average module manufacturing cost of 1.4 ECU/Wp (US$1,25). This was based on data from 10 1998 industrial participants in the US Manufacturing R&D Program. [48]

The market prices on modules were ECU 3-6 a watt, depending on supplier, type and significantly ordered quantity. [3]

<table>
<thead>
<tr>
<th>Nr</th>
<th>Supplier</th>
<th>Brand Name</th>
<th>Wp</th>
<th>$/Wp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SolarSense.com</td>
<td>ASE</td>
<td>300</td>
<td>3.50</td>
</tr>
<tr>
<td>2</td>
<td>PV BULK BUY</td>
<td>Photowatt</td>
<td>95</td>
<td>3.82</td>
</tr>
<tr>
<td>3</td>
<td>Altenergystore</td>
<td>Photowatt</td>
<td>100</td>
<td>3.99</td>
</tr>
<tr>
<td>4</td>
<td>Altenergystore</td>
<td>BP Solar</td>
<td>120</td>
<td>4.08</td>
</tr>
<tr>
<td>5</td>
<td>MHS-Solar</td>
<td>Photowatt</td>
<td>100</td>
<td>4.39</td>
</tr>
<tr>
<td>6</td>
<td>Altenergystore</td>
<td>BP Solar SX-65</td>
<td>65</td>
<td>4.44</td>
</tr>
<tr>
<td>7</td>
<td>Solar Electric</td>
<td>Unisolar</td>
<td>64</td>
<td>4.52</td>
</tr>
<tr>
<td>8</td>
<td>MHS-Solar</td>
<td>Photowatt</td>
<td>75</td>
<td>4.59</td>
</tr>
<tr>
<td>9</td>
<td>Altenergystore</td>
<td>BP Solar 275</td>
<td>75</td>
<td>4.65</td>
</tr>
<tr>
<td>10</td>
<td>Altenergystore</td>
<td>BP Solar</td>
<td>85</td>
<td>4.66</td>
</tr>
</tbody>
</table>

Table 3.4: Cheapest modules sold on the internet [54]
Breakthroughs in low-cost technologies such as Thin Film cells could mean a dramatic decline in module prices. Already thin film modules are expected to cost 1-1.5 ECU/Wp in the short term and 0.5-1 ECU/Wp in the longer term [21], but they have lower efficiencies thus requiring more space, which could be a problem for some purposes, though space is seldom a limitation when it comes to rural electrification.

Other components than the module and the installation costs (labour) are referred to as balance-of-system components (BOS). BOS-costs are typically at least 50% of the system cost. [40] The BOS-costs brings the total price of a stand-alone system up to ECU 8-40. Attempts to reduce the total costs include:

- Simplification of installation process – minimising labour
- Standardisation of components – reducing inventory and training complexity
- Increasing cell efficiency – reducing e.g. installation area, support structure and cabling

[40]

A typical breakdown of system costs of a stand-alone system is presented in table 3.5

<table>
<thead>
<tr>
<th>System component</th>
<th>Typical lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel</td>
<td>20-35 years</td>
</tr>
<tr>
<td>Battery</td>
<td>3-8 years</td>
</tr>
<tr>
<td>Controller</td>
<td>5-15 years</td>
</tr>
<tr>
<td>Lamp socket</td>
<td>5-25 years</td>
</tr>
<tr>
<td>Light tubes</td>
<td>5000 hours</td>
</tr>
<tr>
<td>Switches</td>
<td>5-15 years</td>
</tr>
<tr>
<td>Connection Boxes</td>
<td>10-25 years</td>
</tr>
</tbody>
</table>

Table 3.6: Component lifetimes

Savings in the initial costs at the expense of quality and a proper system design will inevitable result in higher running costs and often the resulting life cycle costs would increase as well.

[44]

The criteria of cost evaluations are further discussed in the chapter "Rural Electrification".

<table>
<thead>
<tr>
<th></th>
<th>Cost (ECU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>Per unit</td>
</tr>
<tr>
<td>Module</td>
<td>270</td>
</tr>
<tr>
<td>Battery</td>
<td>150</td>
</tr>
<tr>
<td>Charge controller</td>
<td>96</td>
</tr>
<tr>
<td>DC/DC converter</td>
<td>24</td>
</tr>
<tr>
<td>Additional hardware</td>
<td>60</td>
</tr>
<tr>
<td>Light</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>915</strong></td>
</tr>
</tbody>
</table>

Table 3.5: Costs of a PV system [8]
3.8 **ENVIRONMENTAL CONSIDERATIONS**

The PV system does not cause emissions during operation and the battery is usually the only subject to environmental discussions when the importance in recycling it is pointed out (e.g. due to the lead and acid contained). In spite of this romantic conception the actual environmental benefit seems to be limited though increasing as life-cycle analysis of systems and components have led to the development of different materials and processes in the manufacturing of PV-systems.

Early PV systems were net consumers of energy: the energy produced in the lifetime of the system was smaller than the energy required for manufacturing. In other terms: the energy payback time\(^9\) was longer than the lifetime. The situation for grid-connected systems is already favourable. For standalone systems the energy payback time is estimated to 7-10 years at an insolation of 2000 kWh/m\(^2\)/year, with the potential to go down to six years. In these calculations the battery accounts for about five years, very close to its lifetime. \[3\]

This encore emphasizes the importance of proper use of the battery as well as the need of further developing the energy-storing element of the system. A breakthrough in the fuel cell technology could prove the solution to the problem.

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\(9\) The energy payback time is the time it takes to produce the energy used for manufacturing the system.
Data and Theory for Evaluating a PV-Project

4. Research Interviews

4.1 METHODOLOGY

During our visit to Tonga October to November 2001 we carried out a total of 20 interviews. The persons interviewed included employees in the ministry, in aid organisations and development offices, people who had been involved in the installation of the systems and some of the people actually using them.

The interviews were all semi-structured interviews in accordance to the qualitative research methodology. This section is to explain our choice of methodology and present the process of planning, carrying out and analysing these interviews. It is more a description of our procedure than a theoretical review. 10

Our methodology is to a large extent inspired by Steinar Kvale, who has thoroughly described the qualitative interview [49]. Some additional literature was included as well, but it must be recognized that flair is an important part of the process.

The information gathered through the interviews was to support data from other sources (literature, technical assessments etc.). Systemising and analysing the interviews made the data useful for this purpose.

Information from the people running or supporting the project provided valuable knowledge on the institutional matters (the interviewed in this group are considered key informants), while information from the users further provided knowledge on the social aspects of the programme.

4.1.1 Why choosing the Qualitative Interview?

Handing out questionnaires can give the researcher a lot of clear quantitative answers to certain questions (the quantitative interview), but the context of the answer is missing [49]. To get as many aspects of the project as possible covered we chose to use the semi-structured interview.

Further the fact that almost all written information (not much) on the programme was quantitative data made the qualitative interviews an obvious choice.

The semi-structured research interview should be an “inter view” - an interchange of views on a certain subject [49]. The interviewer has not mapped out the entire interview, but has decided on which topics that should be discussed. He/she remains open-minded to inputs from the interviewed, possibly considering supplementary sub-topics but keeping focus on the relevance to the main objective of the interview.

Dealing with a complex socio-techno-economic subject this process offers the opportunity of discovering problems or opportunities to the subject, which has not yet been considered. [49]

Another advantage of using a less structured method is that it is minimising the risk of the researcher attributing opinions to the interviewed. [50]

4.1.2 The interview-guide

Before conducting an interview an interview guide should be prepared, to insure that the dialogue remains on the relevant subjects. The typical interview

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10 For more theory on the qualitative interview we recommend: Steinar Kvale 1996 [49]
guide contains a list of main-subjects with underlying questions, which seem relevant to the objective of the interview. The literature on the subject offers lots of suggestions on how to formulate questions. Most general is that the questions should be simple (avoid having two questions in one sentence) and that they should not be leading towards a certain answer. [49, 50, 51, 52]

Three interview guides were prepared: One for managers (e.g. in governmental bodies) one for the local organisers (town officers and technicians) and one for the users.

Main subjects included in all guides were the fee collection/payment and the service of the systems. In the user guide special emphasis was on the satisfaction/benefits of the programme.

The interview guides are included in appendix 1.

It is desirable to test the guide before conducting the interviews [50]. We chose to discuss it with others having knowledge of PV-programmes and/or interviewing in development country environments [53]. According to these discussions the guides were adjusted. Further we were aware that the first interview possibly would have to be considered as a test interview if the guide needed further adjustments (this was not necessary).

4.1.3 Who to interview?

A typical mistake when performing a qualitative research task is to gather an extensive amount of information, almost impossible to analyse in a meaningful way. Focus should not be on the quantity but on the quality, but having said that it is important to get enough information to validate the findings. [49]

As mentioned we were interested in getting information from three different groups involved in the projects, two of those somehow overlapping.

On the organisational plan we wanted to talk to employees from the Ministry of Foreign Affairs, people having been involved in the process of planning and implementing the project as well as having specific knowledge of the islands in question. We wanted to talk with at least two persons from this group to get to see things from different perspectives. We ended up interviewing four people; one interview was very brief, while two persons were re-interviewed.

Unfortunately we did not get to talk with the government technician, who is looking after the systems. He was out of the office during the four weeks we were there.

With respect to the users and local organisation we wanted to interview at least four people plus at least two local technicians and Town officers (also being users). We ended up with a total of nine of which three were Town Officers and two local technicians.

On top of this we wanted to conduct at least one group-interview as literature suggests that the outcome might differ due to interaction in the group and an often more relaxed atmosphere. We conducted two group-interviews and they both gave us a lot of information. Our impression was that we got the same information as if we had separately interviewed each of the persons, maybe with a tendency towards an improved exactness.

Regarding the users we tried to cover different criteria (sex, age, social position) and with three women included (all town officers and technicians were men) and a representative variation in age we were fairly successful in doing so. In addition we interviewed one who did not have a system and had at least four represented in a group interview.

In addition to these interviews our contact person had arranged interviews with representatives from donor organisations and we also had informal conversations with some electricians. These
interviews/conversations were interesting but not particularly relevant to the project although they helped in putting things into perspective.

A complete list of the interviews is included in appendix 2.

4.1.4 The Interview

When conducting the interviews we tried to appear objective letting the interviewed do as much of the talking as possible. We intended the interviewed to feel comfortable and we did not determine a specific order of the subjects. Nevertheless we did tend to keep the conversation within the objective, and if interesting statements were made we followed up on those.

Every interview began with a briefing explaining the objective and ended with a debriefing leaving room for possible questions or reflections.

Further guidelines of the qualitative interview and the role/behaviour of the interviewer are given by Kvale [49].

All interviews were more or less successful. We covered all subjects in the interview guide, (some better than others mostly due to the knowledge/interests of the interviewed), the atmosphere was pleasant and the translation (if necessary) was in all cases but one satisfactory.

4.1.5 Evaluating the interview

After each interview we wrote down our immediate impressions of the interview; especially considering the atmosphere and the credibility of the statements made, as suggested by Kvale [49]. These notes were a great help in the analysing process whenever contradictions appeared.

4.1.6 Taping / notes

Most of the interviews were recorded to make sure that we did not miss important points and so that we could fully concentrate on the interview. Nevertheless the setting of some interviews made a useful recording impossible and instead notes were taken during the interview.

4.1.7 Organising the data

Most interviews were transcribed completely, but a few were found to contain so little valuable information that only a summary was made. The transcriptions and the summaries then became the object of our analysis although we tried to keep the complex impressions of the interview in mind by looking at our post-interview notes.

4.1.8 Analysing the data

Several methods exist for analysing interviews. The objective is to uncover the essential information and make it suitable for presentation. When dealing with a fairly large amount of text it is desirable to condensate this. Inspired by Kvale’s description of condensation [49], a variant of this by Launsø & Rieper [50] and further including elements of Kvale’s Categorising method [49] we have put together a method for our analyses, somehow being a kind of ad hoc analyse as described by Kvale [49].

Our method is visualised in figure 4.2
The last step was to gather the different views, prevalence of these, and quotations on the chosen categories and sub-categories to a summarised description of the situation; our findings. In this last step we to some extent included our own knowledge on the subject to look critical on the statements of the informants. By putting the statements into context we intended to give a more balanced description of the matter. This is known as a common sense interpretation. [49, 50, 55] When incorporating the interviews in the final evaluation it will be done as a data triangulation as described by Mikkelsen [56].

Some software designed to ease the process of categorizing data exists, but the limited amount of collected data made it possible to handle the analysing process without.

4.1.9 Presentation

We have chosen to present the findings from two interviews with the head of the Energy Planning Unit, 'Apasaki Sokai respectively the findings from the eleven interviews with users (including Town officers and local technicians). The reason for presenting these is that they provide a good understanding of the programme seen from respectively the EPU’s and the users’ point of view.

The remaining interviews are used as references in this report as well as in “Evaluation of Tonga’s Outer Islands Electrification Programme”.

While the findings from the interviews with the users are presented with a lot of comments and impressions as to how we understood the situation, we have chosen to present the interviews with 'Apasaki Sokai mainly in the form of her own lines. Of course our opinion will to some extend be present qua the quotations we have chosen to include. Further some editing has been necessary (mostly to transform the lines to written language) and some statements include elements from both interviews.
The anonymity of the users is upheld although we have included the name of the actual islands wherever the collected information shows differences between islands.

4.1.10 Reservations

We are aware of possible biases in the findings, which might only be part of the truth.

- We only spend a limited period of time in Tonga and even shorter time on the respectively islands; seasonal variations could appear (e.g. less sun or less food).

- Coming with a western culture we might not fully comprehend the more complex aspects of rural life, with a possible risk of misinterpreting observations.

- The interviewed might answer with ulterior motives. In one interview it seemed like the interviewed at some point got the idea that we might have come to give him something being “rich white people” and this was reflected in his answers throughout the rest of the interview.

Nevertheless we have tried to be very critical to our own interpretations and whenever we had doubts we have left out the quotation or finding in question.
4.2 The Programme as Seen by the Users

This section presents the findings from the interviews with the users.

4.2.1 The PV experience

The PV systems were installed 5 ½ years before our visit. During this period they have become a part of the daily life in the island.

Satisfaction

All 11 persons in our interview survey responded positively with remarks like “the solar is good” and “everybody in the village are happy about the solar systems”. Further all 48 owners of the systems we inspected were pleased with them. Further supporting the impression is the fact that those who have not got a system really want one: “they didn’t want but they do now”.

New demand

Back when the system was installed there was some scepticism towards the new technology, but even during the installation about 30 extra houses were added to the programme. The result is that most villages have systems installed in all houses but a few, though in some villages like Hunga a large number of the islanders still uses other sources of light. Those without a system chose not to join the programme to begin with but experiencing the neighbours’ solar powered lights apparently have changed their minds. Other factors like a marriage could also force a change in priorities though: “I married last year and now I want a solar system”.

PV vs. Kerosene

Before having the solar systems installed the light came from kerosene lamps. According to the users the improvement in light quality, safety and comfort is remarkable. It is a common opinion that “The light from solar is better than that from kerosene” and a lot of the other improvements are mentioned in these statements: “If the (kerosene) lamp falls down when everyone is asleep the house could burn off; Plus the smoke from the lamps: it is dirty” and “on a windy day the boat cannot go to Neiafu and then the people without solar have no kerosene and the shop has no kerosene. Then they have to use candles and torches.” Further a nurse once has treated “a child who drank the kerosene”.

PV vs. Grid

Even compared to grid-electricity (though only few had experienced it) the solar power was preferred. Most notable; a nurse who had previously worked in the main-island says: “Sometimes all the light in Neiafu went off, but the solar system is always working, it is better than the electricity (grid) because with the solar system only one light is broken at a time”.

Figure 4.3: Satisfied PV users
Expenses
While it is obvious that the PV-light is an improvement compared to kerosene, it is not clear from our interviews whether the expenses to light have increased or decreased. Those with PV have difficulties remembering how much they spent on kerosene and the answers from those without differ as well. Nevertheless it seems like the expenses to kerosene approximately equal those of PV.

Fees
The monthly fee of 6$ is an acceptable amount to the users. Some said that "6$ is not much" others that "it is a fair price, everybody is happy it is no problem to pay". Also the initial cost of 50$ seemed acceptable. The general impression was that the islanders could afford to pay a higher fee which is supported by the fact that non-users spontaneously declared themselves willing to pay 10$ a month to get a system.

Finances
Most of the islanders earned their money by selling agricultural products; fish or mats weaved by the women on the market in Neiafu. Some have regular jobs in the islands as a teacher or nurse or in the main-island as e.g. taxi-driver or working in a shop/restaurant. Further it seems like a fairly large amount is being send from relatives living abroad: "When they are getting money they are sending it to the family". It is obvious that the islands mainly have a subsistence economy with e.g. agriculture products being exchanged for fish, although money is used in the local shop to buy things like dry-cell batteries, biscuits and cigarettes.

Benefits
The light is used for a wide range of activities: The women are weaving, people are reading books or prayers and the light is also used when "eating, cooking, talking, when having a Tongan cava party and in the school". Some mentioned that they do not have to paint as often as they used to and in terms of health services the light as earlier mentioned is an important help to the nurse: "I have delivered three children in the night time - the solar system helped to deliver three children". Further systems are installed in most churches and Town Halls, being used for different community activities.

Use
It seems like the usage of the light is carefully considered as the users "only use the light at night time" and "When we are in the living room we use the light in the living room - not all the lights" though "some leave one on. When they have kids they got to have light". Also we didn’t experience that direct connection of loads to the battery was a big problem: A few radios had been connected but we were told that they were only used in daytime and the users were very well aware that they "are not allowed to put radios on the battery".

Other needs
On the face of it the users didn’t have any further needs, but on seconds thoughts a community freezer so that they "can eat some of the fish and put the rest in the freezer for the next day" and "then we will have more fish and we can go to the town and sell it" was a prevalent request. In the health clinics a refrigerator could be an improvement because "you must keep the injection in the refrigerator we have to send the children all the way to Neiafu to get an injection". Further things like; "people want to put a light outside" and "some people have a house with 5 rooms, but the rule is only 4 lights" and "when we load the net into the boat and on-load it on the jetty we got to have light" are mentioned. Apart from that dry-cell batteries are being used in radios, which could be run by a PV-system, and in torches.

Higher fees
The people are well aware that an extension of the systems will have to be
paid for and are willing to do so, but they have no idea of how much it would/should cost.

4.2.2 The organisation of the programme as experienced by the users

In the villages the programme is in principle run by Solar Committees representing all the users. In reality however, the active parties are the Town Officer, the Secretary of the Committee and a local technician; in some villages one person has more than one function.

Preparations

The project started in ’96: “All the town officers went to meet with the government, who told about the project. They said that everyone could have a solar system” Then all the islanders were presented to the idea either by “the Town Officer who came back and had a meeting with the community” or by a representative from the EPU “who came and asked us if we wanted a system”.

Next the EPU arranged a workshop for two people from each island about which a Town Officer tells “They told us about the monthly payment which should be reported to the planning unit. If something is not working well we have to send a message to the planning unit and ask them to give the necessary information to the local technician, and if the technician still cannot fix it an officer will come and see to it.”

The local technicians have their knowledge from the same workshop: “we had a workshop in Neiafu with the people from Land and Survey; they taught me how to do” Since that the technicians have not received any further training though all we talked to seemed eager to learn more: “I would like to learn more about the systems” and “I want to learn how to fix it” were common remarks.

The fees

Concerning who should be responsible for the money collection, a meeting was held in October 2001 where they “talked about the 6 dollars, there is a problem with the collection of the money” and “the target is that every island here in Vava’u have to pay 80% to the treasury”

Collection

The Secretary, who in most villages is identical to the Town Officer, collects the monthly fees. In some villages he goes around and collects the money, in some he expect the users to come to him and in some users pay at a monthly meeting. There is no significant connection between the method of collection and the collection rate. Most villages seems to have a decreasing commitment towards collecting the fee but then again this was highly necessary especially for the smallest community Lape, of which the Town Officer tells: “They did not collect, the committee did not work - they slept. I just started this year, and a secretary and one more – we are three people in the committee. I choose two new people the old were no good; and now the money is being collected.”

Deposit

Once the money has been collected it should be paid into the treasury. The procedure is described by one of the Town Officers: “We have to go to the treasury and put our money there and send a receipt about the monthly payment to them. I have a photocopy of the receipt. I keep it here, if something happens”.

Bank accounts

It seems like all the Town Officers are aware of this procedure, but nevertheless a lot of them choose to put at least part of the money in a village bank account. Some says that “He collects the last week of the month and then he goes to the “Bank of Tonga” and put it in an account of the Solar Committee” while other states that “We have money in the bank and money in
the treasury.” In one village (Ofu) we actually saw proof of a bank account holding 8749.70$.

It is a fact that the amount of money going into the treasury is far from comparable with the expected, and even if the private accounts are taken into consideration it seems like a fairly large amount is missing.

Consequences
A possible reason is that the users do not experience any consequences if they do not pay: “some people don’t pay for three months. The Town Officer asks them every time but he never cuts of the power”. In some villages some form of consequence has been reinforced “if I have a broken light and I have not paid I cannot get a new one”, but the procedure introduced by the EPU, which says that “if they don’t pay for two months we give them a warning and if they still don’t pay the following month we cut off the light, until they pay and then they have to pay another ten dollars to reconnect” has apparently only been used sporadically in one village (Ofu).

Awareness
Another aspect is that the users often have no idea of what the money is for. They know it is to have the light and often that service is identified with the replacement of bulbs. They have not considered that the battery might has to be changed resulting in a belief that “we don’t think we are spending that much money in buying repairs” which is perfectly true at the moment but will not stay true for long time qua the batteries are beginning to be worn- out.

Local service
Even more critical in terms of collection rate than the users commitment, is probably the limited service activities.

Procedure
The local technician is responsible for the daily maintenance. Apart from assisting the users whenever they have a problem with the systems, in most villages he does a monthly routine check. As one of the Town Officers tells: “The technical officer goes around to the 42 houses every month to check if there are any problems and then he makes a report for me”.

The things they check somehow ranges; one of the most thorough stating: “I clean the panels and check if any trees are coming up around it, then I check the water level in the battery, the regulator and if any lights has come of, and if so I go back to town officer to get a new bulb”.

It seems that most villages have incorporated these regular services, but one village, Hunga, differed by apparently not having a technician: “No one comes to refill the water my husband refills the water.”

Figure 4.4: Town Officer showing the prove of the private account
Training
The quality of the local technician’s job, somehow reflected by the condition of the systems, depends largely on his skills and knowledge; all technicians have received the same training, but some just pickup easier while others have experience from working in electrician companies in Niafu. Regardless of this they all seems happy with the job and the payment which differs from 10$ a month to the suggested 10% corresponding about 25$ in the specific case. Further they are all eager to learn more about the systems. Desires like “I would like to learn more about the systems” and “I want to learn how to fix it but I don’t know how” are present with any local technician we have met with.

Panels
It seems meaningless to teach them anything about fixing a panel, but giving them some information on the apparently harmless nature of white spots which have appeared on the panels lately, would take some worries of their shoulders. Worries arising from ”some guys who came from Tongatapu and surveyed the panels, because of all the white spots on the panels and they said it will cause problems with lights”

Bypasses
In terms of the charge controller and the battery, the limited knowledge can easily lead to misjudgements fatally reducing the lifetime of the battery. One of the technicians tells: "I have a test tube I can put inside the rooms of the battery, it has three words: charge, fair and good. If the water goes up to fair I think: ok, if it reads: good, I think: good battery. If I put in the test tube and the water goes to charge, I think: there is a problem with the charge regulator”.

Even though this technician has learnt a procedure of checking the charge level of the battery his conclusion is clearly wrong, but unfortunately common. Some of the batteries are beginning to show significant signs of reduced capacity resulting in more frequent low-voltage cut-offs by the charge controller. But the technicians have experienced that they can by-pass the charge controller and thereby avoid the cut-offs, thus making them think that the problem is with the charge controller. They might realise when the battery breaks down completely, but it seems like a rather expensive lesson to teach them, completely ruining the battery. Nevertheless it appears that the practise has been enforced by the EPU technician telling “the technical officer that he should connect it directly.”

The direct connection could pull the last resources out of an old battery, but it could also make technicians accustomed to malpractice. Further it brings about a danger of explosion if the battery is drastically overcharged. One of the technicians says, “The final decision is to replace the battery”, and batteries working without a charge controller will have to be replaced in the near future.

Environment
When this replacement begins some information on the environmental consequences of dumping batteries should be included. The only information given so far is that “When the battery is not working we have to dig a hole and put it down there” and the general opinion is that “the old battery is rubbish.”

EPU services
Survey visits
To take care of the maintenance beyond the skills of the local technician the EPU occasionally sends out a senior technician. “When they come they fix whatever the problem is, but they only come once every year for survey. In the meantime when we have a problem, we call them to come in but they don’t come in, they only come in on survey time.”
Hotline
In the meantime the local technicians are supposed to call them on the phone: "I call the guy in Nokualofa in the Land and Survey and he tells me how to fix it". In one village the interviews indicated that the EPU sometimes visit more frequently: "We are sending them a letter and approximately one month later they come and see the problem." But all the interviewed put forward a wish of a more regular service, as one said: "They should come at least three or four times a year. We would be very happy if they came 3 or 4 times a year."

Spare parts
Anyway the process is slow an even when the locals know how to solve a problem they can be hindered in doing so, because they lack the necessary spare parts. Until recently it seems like all the parts have been stocked up in Nokualofa. "Before I had to send a message and then there could be one month before we had a new bulb" but recently some bulbs has been handed out to the Town Officers "we had a seminar here and we asked them for 20 lights and when we finished the seminar they gave me the bulbs" and that is highly appreciated.

Satisfaction
Still the islanders are not satisfied with the service provided by the EPU: "Really what they need is to get an office up in Vava’u, so that all the equipments and all the parts could be here in Neiafu instead of getting it down from Tongatapu." And the EPU has promised to improve things: "They told me there will be a man that we could tell next year" being 2002.

In the meantime the systems in general are performing very well. The aging batteries are just about the only urgent problem and most users can still say: "the solar system is always working".
4.3 The Programme Seen from The EPU

The Energy Planning Unit is part of the Ministry of Land, Survey and Natural Resources and is presented in the following way by the officer in charge:

“The unit is only a small section under a big ministry. We are belonging to the Natural Resource Division. We are focusing on the politics and project management, public awareness and energy conservation as well as any kind of capacity building regarding training and related activities. At the moment we are largely looking after the RE projects, which is mainly the solar electrification of the remote islands. We also liaise with the donors and the community and if a private company is involved we also liaise with them.”

“We further arrange school competitions in writing essays and drawing pictures with a energy promoting–energy conservation theme.”

“We are working with hardware supplying, capacity building and training. We used to run workshops on some of the island groups on diesel engine operation and maintenance – refrigeration and air-condition maintenance and tree planting. We had a national program for women teaching about energy conservation, power, diesel, driving, cooking, reading etc. Actually we have covered quite a lot.”

“At the moment we are only three working full time: the Officer in charge and two energy technicians. One of our employees is in Australia doing a masters degree in RE and he is expected to start February 2002. We used to have a driver, a technician trainee and an assistant looking after our library and our database, but we lost her. So we do not have many people her.”

“We were very active from ’92 to ’96. At that time we had seven or eight employees including Solomone Fifita, but things really slowed down in the late nineties and we are slowly loosing our staff”

It is obvious by this presentation that the EPU is currently having a hard time due to lack of manpower. The intentions are good but the resources limited. Still some new projects are being prepared:

“We are currently working with SPC on the proposed Ha’apai solar electrification, which involves electrifying seven islands. We have implemented other projects including a wind data collection, a resource analysis. That project involved the Japanese International Corporation Agency, the funding agency for Japan. Previously the Foreign Secretary funded a project of a wind study that was looking at the potential for wind power. We have had another project, which we have not really implemented because we had problems identifying a supplier. That project involved purchasing rechargeable dry cell batteries for things like radios and torches. But we have not implemented that project because we do not have the staff to do so and it is difficult to find a supplier.

Budget cuts have had their influence on the declining staff in the EPU, but a limited availability of skilled people is part of the explanation too.

“Not very many skilled people are available and we do not have many people expressing interest in this particularly sector meaning that there are a limited number of people, who would be able to fill in a position like energy officer. We can always get technicians because young people can be trained easily, but for graduates and people with higher degrees, i.e. masters there is a limited number.”

Earlier the entire EPU were located in Nokualofa but a decentralisation process is being initiated:
"We only have the Ha’apai office at the moment and that is part of our agreement with SPC, to have someone in Ha’apai that manages the project. We have experienced – from Vava’u – that there should be someone out there, if there is any sort of technical problems and the financial side of it: Collecting the fees and things like that should be done by a technician. Just to respond to the need of the customers is also very important and we have not been able to do that very well.”

Thus the EPU has acknowledged that the organisation of the Vava’u project is not ideal. Actually the EPU’s contribution seems rather limited:

"At the moment we just make sure that we supply the spare parts. We also look after the systems in general and makes sure that the operation is continuous and if there is any complex problems we send someone out. We also look after the community in terms of managing and provide some training to new technicians."

"We always plan for two visits annually, but this year we have had problems with travel arrangements and transferring funds. So this year has been problematic but otherwise it has been pretty much on schedule."

Only one service visit was carried out in 2001. The service visits are carried out by a EPU employee:

“Senior technicians do the service. One of the technicians covers Vava’u and the Niua’s and the other goes out to Ha’apai and the islands of the coast. Those visits are very technical and they attend to the details of the batteries and the panels. So they do a thorough check of the systems.”

“They bring in a report. I believe that one of the technicians designed a new form for his next visit. He has a standard form including the household and the family name and all the different parts of the system.”

In the islands local technicians take care of the daily maintenance:

"He is responsible for looking after minor things: Changing light bulbs, checking the water in the batteries and cleaning the panels."

The people in the village nominate this technician who receives some training arranged by the EPU:

“Sometimes we bring them into a group and do awareness training so they can pull a wire out, plug in something or be able to recharge the battery.”

Also the users have received some information on the systems albeit limited:

“We have not done much of that. We have only done a briefing about what the function of the PV system is and how they should look after it. Just some general guidelines: How to look after it and things they should avoid doing to the battery and things like that. Just to make sure that there is not any kind of complications due to people tempering with it. Because we have had cases where people plug in a guitar or a radio.”

Having them sign a contract agreeing on certain terms should ensure that the guidelines are followed:

“After the installation there is a contract signed and there is a number of rules lay out. Off course most of them are not observed.”

One of the terms is to pay a monthly fee of 6 pa’anga A part of the monthly fee paid by the users has originally been dedicated to the payment of the technician:

“Our standard practice has been that 10% of what have been collected should be paid to the technician, but we are aware that most of the villages do not practice this.
They do not pay their technicians. That is what we have been told. I think Falevai does pay theirs but others do not.”

Confronted with the technicians wish to have more training an interesting dilemma arose:

“They would like to learn a bit more detailed on how the systems really operate, so that if something happens they can fix it straight away and our training gave them just a general awareness about just the main functions of the system. At the same time we have reservations about giving them the full training, because that is when they start tempering with the system, and we are not there the full time to supervise. So having the full knowledge would increase the opportunity for them to temper with the system and hook up any appliances that they would like to. So that would also represent a lot of problems for us.”

This caution towards giving the technician an adequate level of knowledge having them fiddling tempering with the systems without realising the consequences necessitated a demand for a more complicated procedure of solving problems:

“If there is problems with a system it is reported to the island technician and then the island technician contacts the town officer or us directly. If it is something he can fix our technician just gives him instructions on how to do it and if it is something complicated then we have to send someone out from here.”

One of the problems could be that the needed spare parts are not present, only light bulbs are stocked on the islands:

“They have light bulbs now because we usually send out a few extras, but we do not send out spare batteries.”

And the process of getting supplies is slow:

“We sometimes order supplies from a local company – PES and Funua Electric – other times we order directly from the supplier in New Zealand and sometimes we order from Australia or Kiribati.”

“It takes us usually three months to get something. That is quite a while so we try most of the time to order in advance – to anticipate the demand.”

Nevertheless the stocks are limited:

“I think we have about two batteries, probably about one panel and lots of lights – tubes. Controllers we order only when it is required, because it is very rare that controllers brake down as with batteries and panels. The request for tubes is higher than for the rest of spare parts.”

Figure 4.5: The EPU officer in charge shares her experiences from the programme
Having been installed more than 5 years ago a vital part of the systems, the batteries, are beginning to be worn-out. This means that the lights tend to cut off late in the evening in some houses. This problem is dealt with by bypassing the charge controller so that it will not cut off the power when the battery voltage is getting below the minimum recommended. Confronted with this the Officer in Charge responded:

"I am not really sure what goes on out there, but in principle we do not advise any tempering with the system, which in the long term will affect the entire operation of the system. So this is the first time for me to know, that our technician does give that sort of advise (bypassing) to individual households. That is something that I have to sort out later."

The local management group, the Solar/Lighting Committee, is apart from the technician’s maintenance responsible for the fee collection:

"We work closely with the town officers and we also work closely with the members of the committee whether it is the treasurer or the island technician or the secretary of the committee."

"Sometimes one person can hold different responsibilities."

"And the leadership plays a major role. It makes a big difference if a village leader is very active and the effectiveness really depend on the town officer."

The collection of the fees is one of the biggest problems in the programme, with a collection rate well below 50 percent:

"We think the monthly fee is affordable and they do not seem to think so."

"I think the payment rate is 42% or 48%"

This could seem peculiar, as the PV should be saving the islanders money when compared to the previous use of kerosene:

"It is a lot cheaper than kerosene. Diesel goes up all the time and kerosene goes up too. "I think previous surveys found that one family spend 10-15 pa’anga a month on kerosene for lighting."

One problem however, is the subsistence economy:

"The fact that the islanders do not have a monthly income does create a problem for the monthly fees."

"There is nothing regularly coming in. It depends on catches – they men are going out fishing. They are able to cash in some money. Maybe something like 200 or 300 and they will be able to survive on it three to four months and then another opportunity comes up. Other times they depend on their family, who live overseas: Relatives who migrated to New Zealand, Australia or America. A substantial amount of money comes from Tongans abroad supporting their families here. The opportunities for generating money in the communities are very, very slim."

And still the fee for the PV system has to compete with other expenses:

"Sometimes we feel that one of the problems is that electricity or power is not equally a priority as something like education or church. In a family lights could be competing with for example children’s education or the annual contribution to the church."

Compared to which the fee is marginal:

"The level of church contribution varies from ten pa’anga to a couple of thousands. But in the islands we are probably looking at an average of 100-200 pa’anga that is paid once a year. There is one big donation and I think it is this time of the year."

"School fees are about 80 pa’anga a term in average. So it will be just over a
hundred – under 200 per year for one child.”

“Hospital services are almost free and dental care is free. Medications are also free. If you are in the hospital for a week then you pay for the bed. It is something like ten pa’anga per night.”

In conclusion a monthly fee of 6 pa’anga seems easily affordable and the real problem is to be found elsewhere:

“In my opinion the major problem is the expectations. Sometimes the communities’ expectations are a lot higher than what they receive. So we are trying to close that gap which is very, very difficult.”

“The high expectations are not necessarily due to the preliminary information given to the communities. I think it emerges from the culture, which is prevalent in any rural community: That they are totally depending on the government or any sort of aid program to improve conditions and lifestyle. That sort of mindset is one of the biggest barriers that we encounter. People are somewhat reluctant to take their own initiatives and to be confident in them selves that they can do this and they can really develop their own community by their own initiatives. But that is not our experience in working with projects that deals mainly with small communities. So it is quite a battle and we are probably just spinning around the same issues. I think it is just down to people’s beliefs: Government should give us power and water and that sort of mindset is difficult...”

“At the moment we are trying to encourage people to take the initiative and not to depend on us, or a donor to give them things. Just get them into a frame of mind where they feel that they can approach anyone and look after them selves and really do not have to depend on someone. We are trying to take away that dependency culture.”

Clearly encouraging and empowering the people to commit to the projects and act by themselves is an important part of any development project, but apart from the high expectations and the give-me-for-free attitude the consequences of not paying the fee should be considered:

“The ideal situation is that they should be disconnected, but usually the committee is very careful in doing so. Because they live in such a small village there is a very close social relationship and it is difficult to maintain a good relationship if for example your uncle disconnects your power.”

A possible solution to this conflict of interests will be incorporated in the next Tongan PV programme:

“What we are looking at now in Ha’apai is to avoid the problems we encountered in Vava’u. We will employ people on the island but they are not to be accountable to the local committee but to the regional solar committee as well as the EPU.”

Users not paying the fees might not be the biggest problem. Some of the collected money just never gets to the treasury accounts. The EPU knows for a fact that some of the villages have deposited part of the fees in a private bank account of which they say:

“We really do not support the fact that their money is put into a bank account and they and they operate it independently, because we learned about problems in other projects where the funds for the specific projects are used for other activities in the village. If they intend to use the fund mainly for solar we really do not mind, but if the fund is used for other activities on the island then we do not really support it, because they are utilizing the fund, that should have gone into the electrification programme for other purposes. So when the time comes for a replacement of hardware and things like that: services, there is no money, because
they spend it on the feast, the church and the school, which are fine in itself, but it is not our concern. Our concern is the electrification of the islands.”

A fairly large amount seems to be hidden in these private accounts:

“I am sure that if all the money in the private bank accounts is put in the central account or if they at least give us the specific numbers we can always put those in the financial account, which will make a big difference. That would probably push up the average to like at least 50%. So I am sure that in some ways the project is satisfactory. It is just the way we do things and they do things. We seem to running sort of against each other.”

“Hunga, Kapa, Matamaka, probably Noapapu and a few others have got bank accounts. I think, that Hunga has got about 9000 in the bank. Falevai is about the only island that does not have a bank account.”

The motive from the villages is to stay in control of the money and to generate interests:

“I think the main idea is that they generate some sort of interest on whatever amounts that they collect, which is a very good principle and we support that.

The problem is the lack of control, which goes with the principle:

“We had a case, where a village officer used the money without the village knowing about it. They found out some years down the track just before the guy past away and now they cannot recover the money. So that 5000 is gone.”

Some improvements have been experienced lately:

“I recall looking at the financial report we made that there were improvement in some islands. I think Matamaka was the best performer of all the islands. They were still under the 50% of what they should have collected, but during a short period of time they collected more than 100%. The amount they collected actually doubled the normal amount that they should collect…”

But the improvements made are difficult to monitor because the EPU accounts are not up-to-date:

“There are still some numbers, which need to be re-finalised, because after the report some payments came in, which we have not updated. But that should only be the numbers for January through to November 2001, but there will be no major difference.”

On top of the poor collection rate the government has compromised between the fees necessary to make the programme financial sustainable and what the users are willing to pay in the planning process:

“The monthly fee may go up from six pa’anga to about ten in connection with an upgrade – some sort of realistic number. You cannot do much with six pa’anga that is about half of what they should collect per month. So we really have to improve on the fee collection. Not just the collection side of it, but also how much they should collect. The actual fee it self should be able to cover at least half of the costs. If we were in real business we were bankrupt!”

The EPU is looking into possibilities of restructuring the fees; a differentiation could be a possibility, having those with four lights pay more than those with two:

“The costing that we use now is based on the cost on the equipment over a certain number of years. The calculation is taken into consideration in terms of number of years for batteries and the panels. But we have not looked closely at the costing in terms of per kW. You know how many kW
is consumed by every household. That could give us some accurate costing figures."

"The standard costs for the batteries, controllers and the panels are very much the same. The only difference in the costs is the number of tubes they have in the house. Some have three and some have two so it might just be a difference of a few pa'anga – a few cents."

It is quite obvious that something has to be done on the financial part to keep the programme running and to keep it contributing to the original objective being:

"... mainly to improve the standard of living in the remote islands."

As long as the systems are working the EPU finds that they comply with the objective:

"There is no doubt that the quality of life really has improved in the islands, because they have gotten electricity. Even though it is only lighting it is a beginning, there is a great opportunity for expansion. I think that Tonga has got a very good program going for the rural areas in terms of electrification. We have had a lot of ups and downs with the program, but I think in general it has made a very good contribution to life in the rural areas and also to the economy."

The improved quality of life due to the project has helped slow down the migration:

"In certain islands the PV projects has helped for people to prefer to go back to the islands for Christmas. Most of the families who migrate to Nokualofa they still pay a monthly fee for their house back there so they go back for Christmas, New Year and the prayer week. So it does encourage people to return to their home islands, but at the same time there are people who need to migrate for obvious reasons and just does it. There are a quite limited number of them, who leave the island for good and at the same time a significant number of people are returning to the islands for reunion with families."

It is aspects like education facilities and job opportunities that make people migrate to the main islands. Especially for the women the possibilities on the small islands are limited:

"The situation for women in the islands is not very good. In terms of employment opportunities they are not many opportunities in the islands and their participation in the project is not very extensive. So what we are trying to do now is to encourage them to participate whether they are involved in the committees or fundraising or teaching their children how to look after the systems. So we are trying to pull in the women. Before it used to be mainly men, which ran the committees in the village."

"The occupation opportunities in the islands for women are mainly weaving and handicraft working; the women do not go out fishing and to the bush"

Ironically women are often more educated, but the real concern in this problem is rather the priorities in the school system:

"In general I think that girls have got a better academic record than boys. But I think one of the problems is that in the school curriculum focus is on academic achievement rather than looking at the vocational side of education. So there is not much vocational schooling here. It is mostly academic driven. Everyone should go to the university and come out with a degree. The vocational need is neglected. But I think the Ministry of Education is trying to rectify that problem. They are setting up institutes and sending boys and girls to them."

The EPU has not given up on the Vava'u programme, but are intending to adjust the organisation. In terms of the deposit of
the fees the money is to be moved from the treasury to a bank account controlled by the EPU:

“We agreed in Neiafu at our last meeting that we will take all the money out of the Treasury and put it into a bank account with trustees. We have consulted with the Ministry of Finance and we can do that what our plans are now is to start processing it in the beginning of the next financial year. Maybe that is much more convenient arrangement and structure for the project.”

A hinder to this might be that the villages have to share an account:

“All the monthly payments will go into just one account so it is much easier for monitoring purposes and also overall to have just one account. I picked during the meeting that there are certain islands there are a bit reluctant to merge with they other into just one account, because they would prefer to have some sort of control of their money, but I still think that having just one account is much more beneficial for the islanders than having different accounts.”

Eventually a senior technician will be located in Vava’u on a permanent basis:

“We are planning to send someone out to Neiafu, hopefully by the next financial year.”

“The Financial year officially starts in July. July 1st, June 30th. So hopefully by then everything is all arranged and organised and will start in Neiafu on July 1st.”

Another technician will be located in Ha’apai and both will be people currently working in the office thus further reducing that staff:

“The demand is more for the outer islands for the technical support than in the office. I need to find someone. I have got someone under training at the moment so that is all right. We try to establish him as a permanent staff.”

In the islands the demand is obvious and the technicians will have enough to do:

“The technicians will be there mainly just to manage the island group’s electrification. So they will look into managing their finances, look after all the technical assistance that they require, ordering equipment and any training requirement they also need to look after – basically everything.”

Along with the technicians the establishment of decentralised stocks for spare parts is intended:

“It will it be combined with a stock of spare parts on the islands. We will take most of the spare parts, and send them to Vava’u and we will also try to get spare parts to Ha’apai, because when Ha’apai’s project starts next year they will require their own spare parts. So we will have to ship them out to the islands.”

The hopes are that the villages will follow the example of Falevai – that has the best collection rate. The fact that the town officer has been chosen district officer could help to push that forward;

“Falevai is like the role model of Vava’u and fortunately this year the village officer is now the district officer, which means he is in charge of the entire district of the outer islands of Vava’u. In the last meeting we had one of the main points he raised was that others can learn from his village and also they would be more than happy to help out in other villages in terms of fundraising or organising a committee. I think that Falevai is a good role model for Vava’u and also for the rest of the villages in Tongatapu.”

To make the other villages realise the purpose of doing things like Falavai, it
might be necessary to award Falavai, a possibility that has been considered:

“It is possible to give something new to Falevai to show that if you know how to look after it you can get funds to the next step of the project. However Falevai has not formulised their request yet, we have just discussed the concepts with them. It is possible for us to process a request and a proposal from Falevai to a donor.”

“I think others would feel let down and they would probably resent the fact that Falevai has got a freezer and they do not have, but I also think it is a good signal for others to see: The best performer; He gets what he wants because he looks after his systems”

Due to the lack of finances the EPU is considering to apply for additional financing:

“The monthly fee is mildly put not sufficient to keep the project going. I think that in terms of fee collection and the fund available for replacement of more expensive parts. Where it is now it cannot be done, so the only option is to propose for an upgrade for further assistance.”

A proposal for an up-grade could very well liaise with the users expectations of getting further improved access to electricity services:

“After the meeting in Vava’u it appeared that there is a lot of breakdowns in the systems. So what we are planning to do is that we will probably have to propose an upgrade for Vava’u. Definitely what is in the account now will not be able to support any replacement of more than about ten households. So our only alternative is to propose another upgrade, which allow anyone out there to upgrade the system: Have a new battery and maybe increase the capacity. We really have to sit down with the islanders and look at their own requirements during the design process for another proposal. That is our only alternative now, because definitely the amount of money collected so far is just not sufficient. That may be enough to replace the tubes, light bulbs and stuff, but as far as batteries and panels and controllers – they are a bit more expensive – so they definitely will not be able to cover the replacement of more than ten households.”

“I think that most users now would like to see a refrigerator, a radio, a video and all the other electrical appliances they would like to run. But the capacity that is available does not allow so what we have done is to encourage them. If they want to increase the capacity they can very well do that and they can cover the costs. But no one has done that. But then the expenses regarding adding another panel or replacing the battery: we are looking at hundreds of pa’anga, and off course the average family cannot afford it.”

“To this date we have not really designed a program for upgrading. I think it is a matter of we having the time to sit down and design the proposal, because that is all that is required: To do the system sizing and the consultation.”
"But we would need more funds."

The most logic donor for an up-grade would be the EU who financed the programme in the first place and is working in Vava’u, but the money is not to be given without signs of local participation:

"Apparently EU will be willing to fund an upgrading program provided that the current program is satisfactory. That people are able to pay the monthly fees and that they look after the systems and also if households are able to make a small contribution, if the communities can make a contribution of 20% of the project as an initial fee. Then EU will be willing to fund an upgrading program."

Recently the policies of donors have changed and donors are now expecting a higher degree of commitment from the recipients:

"I think the donors now are very tough. They are not so willing to give grants to villages that do not commit to the project, because there has to be some sort of sense of ownership in the village for people to take responsibility. So the donors are very particular about contribution from the recipient just to demonstrate that they are responsible and capable of looking after what they are given, because you do not just hand cash for nothing. You want to see some sustainability."

Apart from the economic aspect the significance of proper maintenance is underlined:

"The donors have emphasised a lot the fact that the community should be able to look after what they are given, whether it is electricity, whether it is water, education or some sort of facility on the island. To demonstrate that the community is capable of looking after what they are given is one of the main contributing factors to a second grant."

Usually the commitment is through labour but there are projects by the Canadian government where 40% in cash has to be raised by the villagers and Japan and EU enforces the same procedure. This cash-requiring practise is received with some reservations:

"I think it is a good idea in principle if what we are trying to achieve is a sense of ownership and responsibility in the community. If it is for any other reason I do not really support it, because there are certain villages that just do not have the money and there are families that depend on money being sent from relatives overseas. There are families out there that cannot find 200 pa’anga for a water tank."

An up-grade could give the users the possibility to have some extra electrical appliances:

"At least there should be extra capacity for small appliances to be hooked in. A radio, TV or VCR, but a refrigerator is totally out of the question. It is just uneconomical for them to run their own refrigerator."

It is of great importance only to use highly energy efficient appliances, as the energy available from the system is limited. In respect of the demand for a refrigerator or a freezer the most obvious solution is to install one freezer in each village. Nevertheless improvements in the current project must be proven in order to have a proposal accepted:

"Falevai is most likely the only island, which would have no problem in approaching a donor and get some sort of grant, because they have been consistent in collecting the fees and the village itself is very effective in terms of running its own committee. For the remaining villages it is difficult. So what we have been trying to do is to since last year is to try to emphasise the fact that their fee collection should improve above the 50% margin. At
least that would give them something to justify on their own limits to the donors if they wish to request for a refrigerator or some sort of ice making facility or what ever it is that they wish to ask for in terms of electricity and appliances.”

The explanation as to why the Vava’u programme has been causing more problems than other programs might be found in the culture:

“I think culturally Vava’u it is a bit different than everywhere else. They have a stronger regionally solidarity I suppose. That makes them a bit more difficult.”

“There has been a lot of politics going on too. That is one of the problems we had. One of the people’s representative has been stirring things up in the outer islands. That did not help. It pulled the program down, because the local politicians were advocating that households should not pay for the maintenance of the systems, because it was a grant. That really affected the fee collection.”

“I think it was in ’96. It was taken up in the parliament and we stopped our services for a while. We did not want to take the risk of sending out the boys. Maybe someone would beat them up! They can get really bad. We have experienced abuses from people. So that sort of thinking was prevalent in Vava’u for a while, which made it even more difficult.”

“I think Vava’u want to be independent. There have some kind of proposal in parliament and also a public demand that Vava’u should have an independent government. Whether that is a good idea I am not very sure. But it was that kind of thinking that really discouraged people from pay the monthly fee. And also loosing the real sense of the project and it really affected the sustainability. I think the villages now have realised that they really need to look after their own systems, because otherwise no one is going to help them. Now they have also realised that the donors are not willing to give them something else if have not looked after what they were given initially. So that is it the things that encourage the villages in Vava’u to be more active in collecting the fees and also maintaining the systems. It has a bit of a history: Vava’u.”

The close and sometimes even familiar relations considered; a different approach could possibly improve the low payment rates:

“Long term I think that a private company running the maintenance and collecting the fees is what we would like to see, so that people could pay directly for the services that they want rather than having us to do all the services.”

“Ha’apai has got another 150 systems coming and the Niua’s are proposing for solar. If that happens that would be another 200-300 systems. So that really would push up the number towards 1.000. But at the moment the privatisation scheme would be a struggle”

Even in the islands of Vava’u a demand for additional systems exists:

“There is definitely a demand for more systems, because there are some new families that have moved to the islands and there are also families that did not participate in the program. So we have got groups of people who would like a system, but cannot afford to pay for it individually. And the existing users would like to see more capacity so they can use a lot more electrical appliances in the household. So we have three groups of people with different demands.”
5. EU Development Policy

This chapter will give an outline of the European Union (EU) development policy and a presentation of the ACP-EU cooperation.

5.1 INTRODUCTION

The EU provides approximately half of all public aid to the developing countries and is their main trading partner in many cases. Its activity covers all the regions of the world and it is cooperating with a large and increasing number of external partners. [57]

Cooperation between the European Union (at that time the Community) and countries in Subsaharian Africa, the Caribbean and the Pacific started in 1957 with the signature of the Treaty of Rome, which gave life to the European Common Market. [58]

In part 4 the Treaty provided for the creation of European Development Fund (EDF), aimed at giving technical and financial aid to African countries still colonised at the time and with which some States of the Community had historical links. [58]

The current main objectives of the development policy of the EU are outlined in the Amsterdam Treaty of 1997. The Treaty Establishing the European Union of 10.11.97 reads:

Article 177 (ex Article 130u)

*Community policy in the sphere of development cooperation, which shall be complementary to the politics pursued by the Member States, shall foster:*

- the sustainable economic and social development of the developing countries, more particularly the most disadvantaged among them;
- the smooth and gradual integration of the developing countries into the world economy;
- the campaign against poverty in the developing countries.

*In addition to this Community policy in this area shall contribute to the general objective of developing and consolidating democracy and the rule of law, and to that of respecting human rights and fundamental freedoms.*

*The Community and the Member States shall comply with the commitments and take account of the objectives they have approved in the context of the United Nations and other competent international organisations.* [59]

The EU’s development policy’s strategy is formed on the basis of:

- The international development aims, as defined in particular in the Development Assistance Committee (DAC) and the Organisation for Economic Cooperation and Development (OECD)
- The results of major international conferences
- The principles enshrined in the Treaty establishing the EU

The strategy is designed to cover all developing countries, which have
cooperation and partnership links with the EU. The EU’s development policy concerns all developing countries. Regarding the allocation of resources, the least developed countries and low-income countries are given priority. [57]

5.1.1 Objectives

The development policy of the EU is grounded on the principle of sustainable, equitable and participatory human and social development. Promotion of human rights, democracy, the rule of law and good governance are an integral part of it. The main objective is to reduce poverty in the sense lack of capacity. Poverty is defined not simply as the lack of income and financial resources but also as encompassing the notion of vulnerability and such factors as no access to adequate food supplies, education and health, natural resources and drinking water, land, employment and credit facilities, information and political involvement, services and infrastructure. [57]

In this context the EU supports a strategy that embraces linking trade and development; support for regional integration and cooperation; support for macro-economic policies; transport; food security and sustainable rural development; institutional capacity building, particularly in the area of good governance and the rule of law. [57]

In order to meet the challenge of poverty reduction through sustainable development cooperation priority is to help improve the supply, distribution and use of energy in developing countries. Particular emphasis is put on energy programming, operations for saving and making efficient use of energy, reconnaissance of energy potential and the economically and technically appropriate promotion of new and renewable energy. [58]

5.2 Funding and Structure

In the Community’s Infofinance 1999 it was found that the expenditure of the European Union had considerably increased to reach an amount in 1999 of 91 billion EURO in commitments (decisions), of which 6.5 billion EURO (7.25%) was spent on external cooperation activities, including development aid. [60]

Development aid managed by the European Union is financed through the general Community budget and the European Development Fund (EDF). The EDF awards grants for aid programmes for the signatory countries of the Lomé Convention. The Convention covers the 71 ACP States (Africa, Caribbean and Pacific) and 20 OCTs (Overseas countries and territories). The OCTs are countries and territories, mainly in the Pacific and Caribbean, associated with four EU member states (UK, France, Netherlands and Denmark) with whom, they enjoy varying degrees of autonomy. Additional loans from the European Investment Bank (EIB), largely for infrastructure, have become a feature of cooperation too. The Lomé Convention will be described more thoroughly later. [60]

The aid financed by the Community budget was distributed on geographical and sectoral programmes. The geographical programmes was set up in the 1990s aiming to help countries from the former Soviet block and the sectoral programmes support humanitarian aid, local investments in Asia, Latin America, the Mediterranean and South Africa. In addition to this the sectoral programmes are co-financing decentralised players, in particular NGOs, operations in developing countries or their public information campaigns in Europe and environmental, food aid and food security operations. In 1999 the total amount of grants financed by the Community budget was 6.571,78 MEURO. [60]
5.2.1 The Lomé Convention

ACP-EC Cooperation dates back to the birth of the European Treaty of Rome establishing the European Economic Community 1957, which expressed solidarity with the colonies and overseas countries and territories and a commitment to contribute to their prosperity. [59]

In 1975, the nine Member States of the European Community (the Federal Republic of Germany, Belgium, Denmark, France, Ireland, Italy, Luxembourg, the Netherlands and the United Kingdom) and the 46 countries of the ACP area signed the first Lomé Convention in Lomé, the capital of Togo. The Convention now links 15 Member States of the European Union and 71 ACP countries and 20 OCTs representing a total of some 500 million people. Its main characteristics are:

- The partnership principle,
- The contractual nature of the relationship,
- The combination of aid, trade and political aspects, together with its long-term perspective.

The long-term perspective is stressed by the duration of the Conventions: five years for Lomé I, II, and III, and ten for Lomé IV. [59, 61]

The EDF operates according to the priorities negotiated with the beneficiary countries and only at their request. These countries' development policies therefore determine what type of aid the EDF provides. The beneficiary countries' priorities are negotiated with the European Commission on a country-by-country basis. These negotiations culminate in the signing of a five-year "national indicative programme" (NIP). Without this programme, cooperation cannot begin and no financing can be provided. In practice, during both the negotiation of the five-year programme and the consideration of projects to be financed, a dialogue is established between the beneficiary country and the Commission with the aim of reconciling the priorities of the country's government with the Commission's conditions and preferences. The Commission has the option; even after the "national indicative programme" has been signed, of blocking any project submitted by a partner country. [61]

At the conclusion of Lomé IV in 2000 about 9.9 billion EURO of previous EDF resources were uncommitted. The Community is committed to mobilising these remaining balances plus the new EDF (the 9th EDF) resources of 13.5 billion EURO over a seven-year period, before the entry into force of the next financial protocol. Including the 9th EDF the total contribution to the EDF has been 42.064,5 MEURO. [59]

Lomé I signed in 1975 focused on trade agreements and infrastructure; road building, bridges, hospitals and schools and sustainable agriculture. These priorities continued under Lomé II in 1980-85. Under Lomé III (1985-1990), whilst infrastructure funding was still required, people were still dying of hunger and rural development projects became a focus of funds for the 6th EDF to promote food security and combat desertification and drought. With the signing of the ten year Lomé IV (1990-2000) the Community embarked on dialogue with the World Bank and International Monetary Fund (IMF) on how best to support structural adjustments as a means to economic growth. [59]

Several ACP and EU nations agreed on balance of payments support in their NIPs and sectoral and general import programmes which raised money for health and education projects by the sale of goods in short supply on the local market were financed with Lomé IV's initial five year financial protocol. The EU now provides 10-30 percent of total adjustment
aid to ACP economies, notably to education and health programmes. Other key changes under Lome IV included the banning of toxic waste movements between ACPs and EC member states and more EDF monies for decentralised cooperation and diversification of the economy. [59]

In the most recent ACP-EU cooperation agreement (the Cotonou agreement, which was signed June 23rd 2000 in Cotonou, Benin) the timeframe was extended to twenty years, with a clause allowing for revision every five years, and a financial protocol for each five-year period. Furthermore focus on poverty reduction will be strengthened through an integrated strategy embracing three focal areas for support:

- Economic development;
- Social and human development;
- Regional cooperation and integration.

At the same time focus will be on three horizontal issues:

- Gender equality;
- Environmental sustainability;
- Institutional development and capacity building.

The new Agreement promotes participatory approaches to ensure the involvement of civil society and provides a framework for supporting the mutually reinforcing effects of trade cooperation and development aid.[62]

### Table 5.1: EU support to Tonga [62]

<table>
<thead>
<tr>
<th>National indicative programme</th>
<th></th>
<th></th>
<th></th>
<th>EU aid to Tonga</th>
<th>Allocations in million Euro</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIB loans—risk capital</td>
<td>2,3</td>
<td>3,8</td>
<td>3,7</td>
<td>1,5</td>
<td>11,3</td>
</tr>
<tr>
<td>Slabex</td>
<td>1,2</td>
<td>4,0</td>
<td>4,0</td>
<td>2,0</td>
<td>0,4</td>
</tr>
<tr>
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<td>1,4</td>
<td>0,1</td>
<td>0,1</td>
<td>1,6</td>
</tr>
<tr>
<td>Total</td>
<td>4,5</td>
<td>11,8</td>
<td>14,3</td>
<td>10,0</td>
<td>9,0</td>
</tr>
</tbody>
</table>

5.3 EU-TONGA COOPERATION

EU-Tonga cooperation began in 1975 with the signing of the first Lomé Convention. Including the second financial protocol of Lomé IV a grant total of 26,8 MEURO has been allocated to Tonga. [62]

Under Lomé I, funds (4th EDF) were directed principally towards two main projects, i.e. the construction of wharfs at Neiafu and the Ministry of Works to procure road maintenance equipment, build schools, rural health centres and small wharves at Ha’apai and Vava’u. Lomé II funds (5th EDF) focussed on the fisheries sector, and on initiating works related to the upgrading of the Vava’u airport. [62]

Since the mid-‘80s (and the signing of the Lomé III) the EU-Tonga cooperation has focussed on the Vava’u Group, with a bulk of both the 6th and 7th EDF resources (6,5 and 6 MEURO respectively) going to two phases of an integrated rural development programme aimed at improving the island group’s basic infrastructure. In addition some 1,3 MEURO was allocated from the 6th EDF funds to improving the Vava’u’s airport and a further 340.000 EURO from the 7th EDF was approved in 1997 for the upgrading of the airport on Tongatapu. [63]

The main 7th EDF project – Phase 2 of the Vava’u Development Project (4,5 MEURO) approved in 1997 - involves the upgrading of a number of roads in Neiafu, the
improvement of urban water supply and waste management and the upgrading of Neiafu’s harbour. [63]

Progress was made in 1998 in the implementation of all project components. However, project approval came six years after the NIP was signed, and overall rates of commitment and disbursement for Tonga’s EU cooperation programmes remain significantly slower than the great majority of ACP States. [63]

The 8th EDF NIP (7 MEURO) was signed in April 1997 and focuses on stimulating export-led growth in the private sector. Again it concentrates on the Vava’u Region (65-70% of the 7 MEURO is to be allocated to projects in the Vava’u Region), with agriculture, fisheries and tourism as the sectors on which a future Vava’u Development Programme (Phase 3) will focus. I.e. the wharfs will be improved in the outer islands and the harbour of Neiafu will be improved: A marina for yachts will be constructed including a 1 1/2 km. lighted walkway. [9, 63]
6.1 The Hybrid Optimization Model for Electric Renewables (HOMER)

HOMER is a computer model that simulates and optimises hybrid power systems. We did not consider hybrid systems a possibility due to an increased complexity, however we found the model useful to the PV possibility with a community diesel generator.

Were no other is stated the information for this paragraph originated from the help function of the software or the software website [66].

HOMER can simulate over 1000 different hybrid system configurations per minute (on a 200 MHz Pentium), making it possible to consider a large number of possibilities. Compared to a simple spreadsheet model HOMER also considers the temporal patterns of loads and resources and simulates their effect on the lifetime of system components (estimated in the spreadsheet model). Sensitivity analyses are also easy to perform.

Whether the approach of the cost evaluation is financial or economic HOMER is usable as the user input is all component prices and the calculation method is a discounted analysis with a calculation period set by the user making it possible to perform life-cycle analysis. HOMER also considers possible scrap-values, which could have considerable influence, especially on the Renewable possibilities.

6.1.1 Input data and assumptions

It is a drawback that you cannot directly compare a fixed number of PV-systems (individual solar home systems) with e.g. one community generator, as this was our main purpose. However by dividing all the expenses connected to the installation of a generator equally on the households in a village, we compared the situation of one single household being representative of the village.

The calculations were done choosing a village of 40 households. Assuming that a smaller village only would favour PV further calculations would only be done if diesel turned out the preferable solution.

Subsequently our choice of values and sensitivity parameters are discussed.

Inputs

Loads: We estimated the average hourly power requirement of the four lights systems in a village to be:

![Figure 6.1: Village Load Profile](image)

The two and three lights systems were assumed to have similar patterns in scale.
This was based on what we experienced visiting the villages. Diverse use of loads was accounted for with a 10% noise factor.

Resources: We used the solar irradiation data obtained from NASA [64]. On this basis HOMER generates hourly solar data using only the monthly averages (radiation or clearness index) and the latitude using an algorithm published by V.A. Graham [65].

For Vava’u the resources is using the minimum monthly averages was found to be:

Components: Basic cost and performance data are specified for each possible component of the hybrid system. HOMER only allows specifying data for the panel, the generator and the battery. Other costs can be accounted for as a general overhead, but we assumed the amounts to be similar in either system.

The PV panel used is similar to the one installed in the programme with a nominal output of 55Wp and a price of TOP 416. The lifetime was set to be 25 years and the maintenance costs considered negligible. A panel size of 0, 55, 110 and 165 Wp was included in the simulation.\(^\text{11}\)

The battery was also chosen according to the existing system with a capacity of 108 Ah a lifetime estimate of 1000 full cycles or a float life of 6,5 years and the price being TOP 475, a price assumed proportional with capacity. Battery capacity of 0, 54, 108, and 162 Ah was considered.

A 2 kW Honda generator set was available at Pacific EnergySources at a price of approx. TOP 2000 [7], which is used in the calculation. The estimated lifetime was 10000 operating hours. Further estimating the initial costs of establishing a local grid to be TOP 4000, the total initial costs became TOP 6000 with replacement costs being TOP 2000. The operating and maintenance costs were estimated to TOP 0.3 per hour.

The output per household considered was 0; 0,1 and 0,2 kWh.

Additional optimisation parameters: As described it is possible to enter which sizes of components you want to consider. This was not complicated due to our simplified example.

It can also be specified to what extent an unserved demand is acceptable. We chose to use five percent as basis including zero and ten percent in the sensitivity analysis.

The interest rate, (often being a calculation rate in financial approaches), is also determined by the user. We chose to use 0 percent and included 3,6 and 12% to test the sensitivity of this parameter.

The fuel price was set to TOP 1 including sensitivity parameters 0,8 and 1,2.

\(^\text{11}\) You can perform a sensitivity (or parametric) analysis on any numerical input variable in HOMER. To do sensitivity, multiple values for a particular variable are specified, and HOMER performs its design procedure for each value.
6.1.2 Simulations

Several simulations were run varying the parameters. The two of most interest is one including all costs, a life-cycle analyses, and one considering the initial costs negligible as they was paid for by a donor. The first simulation presented considers the economy of the electrification as a whole, while the last simulation consider the economy from the users’ point of view.

6.1.3 Results

Every simulation performed by HOMER results in several dozen summary outputs (like the annual fuel usage and the total capital cost) plus about a dozen arrays of hourly data (like the hourly output of the wind turbine).

We have chosen to present the categorized rankings list which shows the best of each category of hybrid system (PV/battery, Diesel, PV/diesel/battery, diesel/battery and PV/diesel), ranked in order of increasing net present cost.

Further it is possible to graph any output variable versus any sensitivity variable or to graph versus two sensitivity variables. The sensitivity to fuel prices and demand is visualised in figure 6.4.

![Figure 6.3: Result of cost simulation with initial costs, showing most cost-effective system as a function of fuel price and primary load. Note that a single diesel generator is not competable at any point. Further the yearly operating time of the generator is as low as 300 hours. The simulation without initial costs gave an almost identical result and is not included.](image-url)
6.2 CONCLUDING REMARKS

PV came out more cost-effective than the solution solely based on a diesel generator in almost every calculation, though in many cases a hybrid system was the most cost-effective. Nevertheless a hybrid system would complicate the operation unnecessarily and the generator was only to be run approx. 300 hours a year. This would probably reduce the number of operational hours, a fact that has not been included in the HOMER analysis. Further considering that the advantage was marginal it leads us to the allegation that PV probably will turn out significantly cheaper compared to the diesel engine in a thorough life cycle cost analysis.

Additionally those living close to the generator could be bothered by the noise, regular fuel supply to the islands can be interrupted when whether conditions are bad, and the risk of oil leakage during transport is an environmental threat. In conclusion the diesel possibility turns out the inferior.

A complete list of the assumptions and analysis made are included in appendix 3.
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Appendix I

Managers - check-list

Intro:
- We are students from Denmark doing an independent study of the PV electrification programme... - Study energy - 4 weeks in Tonga - pleased to be here etc.
- We would like to tape this interview - only for our self to use - not possible to write everything down.
- Would you like do introduce yourself
- In what way are you connected to the PV-programme

Commercial parameters
- What is PV competing with
- Compared to these what is the positive/negatives sides of PV
- What is the market for PV (costumers, products)

System data
- Type
- Price
- Warranty

Monitoring/service
- Frequency
- What is done?
- What are the typical malfunctions?
- What is the normal timeframe from a malfunction appears to it is fixed?
  - Can this be decreased?
- How often are the batteries maintained?
- What happens to malfunctioning batteries?
- How often are the panels cleaned? - And controlled for shading from trees?

Monthly fees
- Who collects the monthly fees? And how?
- Are they paid on time?
  - Why not
- In case of users failing to pay the monthly fee what happens?
  - A) What are the rules (fines, removal of system, etc)?
  - B) Are these followed?
  - C) How?

Accounts
- Realistic?
- How is the money deposited? (Interest?)

Spare parts
- Stocks
- Prices
- Delivery time
- Battery recycling (if not what happens to the used batteries?)

Education/training
- Who?
  - Users + technicians
- How?
- How often?
Appendix I

**Typical problems**
- Past/present/future
- What should be done? / Solutions?

**About the users**
- How do they feel about PV?
- What are their needs (what kind of loads), expectations (disappointed/satisfied and are they realistic) and future plans/wishes (more/less loads, i.e. TV, refrigerator, etc.)?
- How is the contact to the users? (direct, indirect; discussion, information)
- Can the users afford to pay the monthly fee?
- How does PV affect on the migration?

**Other**
- Personal experiences
- Are the users satisfied/disappointed?
  - Why/ why not?

“Outro”:
- Thanks, that’s all
- Do you have any comments or questions
- Do you think we have left out something important?

**Supplementary Questions:**
- Can you elaborate?
  - How?
- Other examples?
- How?
- Why?
- By what means?
- What is/was the intention?
Appendix I

Technicians - check-list

Intro:
- We are students from Denmark doing an independent study of the PV electrification programme... Study energy - 4 weeks in Tonga - pleased to be here etc.
- We would like to tape this interview - only for our self to use - not possible to write everything down.
- Would you like do introduce yourself (education, role in the programme, etc)
- In what way are you connected to the PV-programme

Monitoring/service
- How do the systems work?
  - Frequency
  - What is done?
  - What are the typical malfunctions?
  - What is the normal timeframe from a malfunction appears to it is fixed? - What is the largest? Can this be decreased?
- How often are the batteries maintained? Is this adequate?
- What happens to malfunctioning batteries?
- How often are the panels cleaned! And controlled for shading from trees? Is this adequate?
- System abuse i.e. battery misuse - to what extent?
- Theft/vandalism

Procedure
- How do you get information about malfunction of a system?
  - Could it be done better?
- For what kinds of malfunction is it necessary for you to call for assistance?
- What malfunctions cannot be fixed without waiting for spare parts?

Monthly fees
- Who collects the monthly fees? And how?
  - Are they paid on time?
    - Why not
- In case of users failing to pay the monthly fee what happens?
  - A) What are the rules (fines, removal of system, etc)?
  - B) Are these followed?
  - C) How?

Alternatives
- Advantages/disadvantages of alternatives - KEROSENE
  - Expenses
  - Safety
  - Convenience
  - Stability

Spare parts
- Stocks
- (Prices)
- Delivery time
- Battery recycling (if not what happens to the used batteries?)

Education/training
- Who?
  - Users + technicians
- How?
- How often?
Appendix I

Typical problems
- Past/present/future
- What should be done? / Solutions?

About the users
- How do they feel about PV?
- What are their needs (what kind of loads), expectations (disappointed/satisfied and are they realistic) and future plans/wishes (more/less loads, i.e. TV, refrigerator, etc.)?
- How is the contact to the users? (direct, indirect; discussion, information)

Other
- Has getting PV changed your view on moving to a different area (main-island, other country)?
- Personal experiences
- Are the users satisfied/disappointed?
  - Why/ why not?

“Outro”:
- Do you think we have left out something important?
- Thanks, that’s all
- Do you have any comments or questions

Supplementary Questions:
- Can you elaborate?
  - How?
- Other examples?
- How?
- Why?
- By what means?
- What is/was the intention?
Appendix I

Users - check-list

Intro:
- We are students from Denmark doing an independent study of the PV electrification programme... - Study energy - 4 weeks in Tonga - pleased to be here etc.
- We would like to tape this interview - only for our self to use - not possible to write everything down.
- Would you like do introduce yourself
- What is your opinion on the PV-programme

Family structure
- Number of family members
- Distribution of work in the household
- Jobs
- Income

Program
- How did you learn about the program?
- Why PV?
- Former energy supply

Electrical equipment
- Number of
- Type

A typical day
- Before/after PV
- Changes

Monitoring/service
- Frequency
- What is done?
- What are the typical malfunctions?
- What is the normal timeframe from a malfunction appears to it is fixed?
- What happens to malfunctioning batteries?

Installation:
- Installation procedure
- Initial costs too high/low

Monthly fees
- Who collects the monthly fees? And how?
- Do you pay on time?
  o Why not
- In case of users failing to pay the monthly fee what happens?
- Willingness to pay higher fees because of A) better maintenance or B) larger system to supply more loads C) other
- How would you prefer to pay

Spare parts
- Availability of spare parts, i.e. energy saver bulbs
- Price
- Procedure

Education/training
- Experience with training/workshops
- How?
Appendix I

- How often?

**Typical problems**
- Past/present/future
- What should be done? / Solutions?

**About the users**
- How do you feel about PV?
- Are you satisfied/disappointed?
  - Why/ why not?
- What are your needs (what kind of loads), expectations (disappointed/satisfied and are they realistic) and future plans/wishes (more/less loads, i.e. TV, refrigerator, etc.)?
- How is the contact to the technicians/managers? (direct, indirect; discussion, information)

**Other**
- Personal experiences with PV
- Attitude towards battery recycling
- Has getting PV changed your view on moving to a different area (main-island, other country)?

**“Outro”:**
- Thanks, that’s all
- Do you have any comments or questions
- Do you think we have left out something important?

**Supplementary Questions:**
- Can you elaborate?
  - How?
- Other examples?
- How?
- Why?
- By what means?
- What is/was the intention?
List of interviews

26/10: Mr Solomone Fifita, Secretariat of the Pacific Community
29/10: Mrs Fekita Utoikamanu, EU Program Manager, Ministry of Foreign Affairs
30/10: Mrs Rosamond Bing and Doug Melvin, Australian High Commission
30/10: Mrs Balwyn Fa’otusia, Acting Director, Central Planning Department
31/10: Owner, Pacific Energy Supply Ltd.
31/10: Mrs Apisake Sokai, Officer in Charge, Energy Planning Unit
1/11: Mr Tevita Vaea, Officer in Charge, Vava’u Development Unit
6/11: Users, group interview, Hunga
7/11: User, Hunga
7/11: User, Hunga
8/11: Town officer and Secretary of Solar Committee, Falevai
8/11: Technical Officer, Falevai
8/11: User, Kapa
10/10: Local technician, Ofu
12/11: Town Officer, Secretary of the Solar Committee, local technician and user, group interview, Olo’ua
12/11: Town Officer and Secretary of the Solar Committee, Ofu
13/11: Mr Tevita Vaea, Officer in Charge, Vava’u Development Unit
14/11: Town Officer and Secretary of the Solar Committee, Lape
14/11: User, Nuapapu
16/11: Mrs Apisake Sokai, Officer in Charge, Energy Planning Unit
Appendix III

HOMER solutions file

Inputs:

Primary Load Data Source Generated from monthly profiles

Primary Load 1 Rescale Average (kWh/d) 0.176 0.088 0.132 0.352

Primary Load 2 Data Source Generated from monthly profiles

Primary Load 2 Rescale Average (kWh/d) 0.000

Peak Deferrable Load (kW) 20.000

Deferrable Load Storage Capacity (kWh) 400.000

Average Deferrable Load 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000 0.00000000

Deferrable Load Rescale Average (kWh/d) 0.176

Deferrable Load Anxiety Threshold (%) 30

Deferrable Load Panic Threshold (%) 0

Max. Unserved Energy (%) 0.0 5.0 10.0

Solar Data Source vavau.sol

Solar Data Rescale Average (kWh/m2/d) 5.730

Wind Speed Data Source Generated from monthly averages

Wind Data Rescale Average (m/s) 3.500

Latitude 18 deg. 40 min. S

PV Capacity (kW) 0.055

PV Capital Cost ($) 416

PV Replacement Cost ($) 416

PV O&M Cost ($/yr) 0

PV Capital Cost Multiplier 1.00

PV Replacement Cost Multiplier 1.00

PV O&M Cost Multiplier 1.00

PV Derating Factor (%) 80

PV Lifetime (yr) 25

PV Slope (deg) 20.0

PV Azimuth (deg) 180.0

Albedo (%) 20

PV Tracking System No Tracking

Number of Type 1 Turbines

Turbine 1 Capital Cost ($)

Turbine 1 Replacement Cost ($)

Turbine 1 O&M Cost ($/yr)

Turbine 1 Capital Cost Multiplier 1.00

Turbine 1 Replacement Cost Multiplier 1.00

Turbine 1 O&M Cost Multiplier 1.00

Turbine 1 Power Curve File Generic 10kW.tpc

Turbine 1 Power Curve Scaling Factor 1.00

Turbine 1 Wind Speed Scaling Factor 1.10

Turbine 1 Lifetime (yr) 10
Number of Type 2 Turbines
Turbine 2 Capital Cost ($) 10,000
Turbine 2 Replacement Cost ($) 0
Turbine 2 O&M Cost ($/yr) 0
Turbine 2 Capital Cost Multiplier 1.00
Turbine 2 Replacement Cost Multiplier 1.00
Turbine 2 O&M Cost Multiplier 1.00
Turbine 2 Power Curve File Generic 3kW.tpc
Turbine 2 Power Curve Scaling Factor 1.00
Turbine 2 Wind Speed Scaling Factor 1.10
Turbine 2 Lifetime (yr) 10
Genset Capacity (kW) 2.000
Genset Capital Cost ($) 6000
Genset Replacement Cost ($) 2000
Genset O&M Cost ($/hr) 0.30
Genset Capital Cost Multiplier 1.00
Genset Replacement Cost Multiplier 1.00
Genset O&M Cost Multiplier 1.00
Genset Lifetime (hrs) 10000
Genset Minimum Load (%) 0
Genset Fuel Curve Intercept Coefficient (L/hr/kW) 0
Genset Fuel Curve Slope (L/hr/kW) 0.250
Fuel Price ($/L) 0.80 1.00 1.20
Fuel Carbon Content (kg/L) 0.200
Battery Capacity (kWh) 1.320
Battery Capital Cost ($) 475
Battery Replacement Cost ($) 475
Battery O&M Cost ($/yr) 0
Battery Capital Cost Multiplier 1.00
Battery Replacement Cost Multiplier 1.00
Battery O&M Cost Multiplier 1.00
Battery Description Basic Battery
Battery Cycle Life (full cycles) 150 1000
Battery Float Life (yr) 7
Battery Max. Charge Rate (A/Ah) 0.10
Battery Nominal Capacity (kWh) 1.000
Battery Theoretical Capacity (kWh) 1.000
Battery Capacity Ratio 1.0000
Battery Rate Constant 1.0000
Battery Min. State Of Charge (%) 40
Battery Roundtrip Efficiency (%) 80.0
Inverter Capacity (kW) 10.000
Inverter Capital Cost ($) 0
Inverter Replacement Cost ($) 0
Inverter O&M Cost ($/yr) 0
Inverter Capital Cost Multiplier 1.00
Inverter Replacement Cost Multiplier 1.00
Inverter O&M Cost Multiplier 1.00
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| Number of Type 2 Turbines | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
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Note: Table values are presented in units of dollars.
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### Appendix III

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<td>897</td>
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<td>Battery Throughput</td>
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<td>0.0</td>
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<tr>
<td>Battery Life</td>
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<td>Fuel Usage</td>
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<tr>
<td>Genset Hours</td>
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| Unserved Energy | 0.0 | 0.0 | 0.0 | 0.0 |
| Battery Throughput | 17.3 | 0.0 | 70.3 | 31.8 |
| Battery Life | 3.1 | 4.6 | 6.2 | 6.5 |
| Fuel Usage | 34.9 | 98.9 | 0.0 | 36.7 |
| Genset Hours | 77 | 1598 | 871 | 1443 |
| Genset Starts | 366 | 366 | 366 | 366 |
| Genset Life | 5.6 | 6.9 | 11.1 | 9.9 |
## Appendix III

1.5  2.2  
**Genset Min. Load (kW)**  0.015  0.014  0.015  0.015  0  
  0.015  0.015  0.015  0.029  0.028  0.008  0.028  0  
  0.015  0.030  0.030  0.015  0.007  0.000  0.030  0  
  0.030  0.007  
**Genset Max. Load (kW)**  0.100  0.100  0.058  0.100  0  
  0.100  0.058  0.058  0.200  0.200  0.100  0.200  0  
  0.200  0.200  0.058  0.058  0.100  0.000  0.200  0  
  0.058  0.100  
**Genset Cycle Charge Ratio**  0.023  0.217  0.000  0  
  0.004  0.192  0.000  0.096  0.154  0.000  0  
  0.338  0.005  0.483  0.000  0.000  0.000  0  
  0.005  0.000  0.000  
**Genset Critical Charge Load (kW)**  0.014  0.014  0  
  0.014  0.014  0.014  0.014  0.028  0.028  0  
  0.756  0.028  0.028  0.028  0.028  0.014  0.756  0  
  0.000  0.028  0.028  0.756  
**Genset Critical Discharge Load (kW)**  0.015  0.015  0  
  0.015  0.015  0.015  0.015  0.030  0.030  0  
  0.189  0.030  0.030  0.030  0.030  0.015  -0.189  0  
  0.000  0.030  0.030  -0.189
Appendix III

HOMER solutions file

Inputs:

Primary Load Data Source  
Generated from monthly profiles

Primary Load 1 Rescale Average (kWh/d)  
0.176  0.088  0.132  0.352

Primary Load 2 Data Source  
Generated from monthly profiles

Primary Load 2 Rescale Average (kWh/d)  
0.000

Peak Deferrable Load (kW) 
20.000

Deferrable Load Storage Capacity (kWh) 
400.000

Average Deferrable Load 
0.00000000  0.00000000  0.00000000

Deferrable Load Rescale Average (kWh/d) 
0.176

Deferrable Load Anxiety Threshold (%) 
30

Deferrable Load Panic Threshold (%) 
0

Max. Unserved Energy (%) 
0.0  5.0  10.0

Solar Data Source vavau.sol

Solar Data Rescale Average (kWh/m2/d) 
5.730

Wind Speed Data Source  
Generated from monthly averages

Wind Data Rescale Average (m/s) 
3.500

Latitude 18 deg. 40 min. S

PV Capacity (kW) 
0.055

PV Capital Cost ($) 
0

PV Replacement Cost ($) 
416

PV O&M Cost ($/yr) 
0

PV Capital Cost Multiplier 1.00

PV Replacement Cost Multiplier 1.00

PV O&M Cost Multiplier 1.00

PV Derating Factor (%) 
80

PV Lifetime (yr) 
25

PV Slope (deg) 
20.0

PV Azimuth (deg) 
180.0

Albedo (%) 
20

PV Tracking System 
No Tracking

Number of Type 1 Turbines

Turbine 1 Capital Cost ($)

Turbine 1 Replacement Cost ($)

Turbine 1 O&M Cost ($/yr)

Turbine 1 Capital Cost Multiplier 1.00

Turbine 1 Replacement Cost Multiplier 1.00

Turbine 1 O&M Cost Multiplier 1.00

Turbine 1 Power Curve File Generic 10kW.tpc

Turbine 1 Power Curve Scaling Factor 1.00

Turbine 1 Wind Speed Scaling Factor 1.10

Turbine 1 Lifetime (yr) 10
### Appendix III

**Number of Type 2 Turbines**

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<tr>
<td>Turbine 2 Replacement Cost ($)</td>
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<td>Turbine 2 O&amp;M Cost ($/yr)</td>
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<tr>
<td>Turbine 2 Capital Cost Multiplier</td>
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<tr>
<td>Turbine 2 Replacement Cost Multiplier</td>
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<tr>
<td>Turbine 2 O&amp;M Cost Multiplier</td>
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<td>Turbine 2 Power Curve File</td>
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<td>Turbine 2 Power Curve Scaling Factor</td>
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<td>Turbine 2 Wind Speed Scaling Factor</td>
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## Appendix III

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