Benefits of participative construction of autonomous PV installations in rural Benin

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Abstract. A maternity ward and a college in Zinvie, Benin, have been equipped with two modest PV installations of 600 and 300 watts peak respectively. This project was carried out using a participatory approach that encourages vocations for solar energy and PV installations in particular. It is also the starting point for a socio-economic analysis of willingness to pay. The collected information reveals that consumers have discovered the advantages of solar electricity and are expressing their desire to switch from the national monopoly service, which is more expensive compared to Switzerland, to autonomous PV installations. However, socio-economic data shows that the effectiveness of this transition is still confronted with the high cost of the initial investment, compared to the economic agents' annual electricity consumption budget on the one hand and their annual savings on the other. A draft model in terms of mutual investment is proposed in agreement with the stakeholders concerned for the reversal of mentalities in favour of solar PV energy.

Keywords autonomous PV systems, participatory work, willingness to pay, mutual investment company, waiting costs

1. Introduction

In the 1990s, an overview of the balance of electricity sources in Benin did not show PV installations as an energy source [1]. The new trend, 20 years later, shows that the country is currently dependent on imported electricity. In 2016, 1 billion kWh was consumed versus 0.3 billion produced by the country. While PV initiatives exist in West Africa on an embryonic scale, as the result of private initiatives or specific external financing [3], their real presence is unaccounted for in the official statistics [2]. The predominance of solar kits is also observed. These facts make it difficult to estimate the total installations deployed due to the lack of a unifying framework for counting private installations. According to the many solar mapping tools available, Benin is situated in one of the most favourably irradiated areas of planet Earth. This region is therefore well positioned for the development and multiplication of solar PV initiatives given the fact that improving access to electricity is a major concern for the socio-economic development of developing nations [4].

This interdisciplinary article reports on the experiences of installing two solar PV systems in Zinvie in the commune of Calavi in southern Benin. Technical information of the project will be briefly
presented. Then, the socio-economic nature of the project and the implications on a larger scale will be discussed more broadly.

2. Methodology
The village of Zinvie was selected from three candidate sites because of its lack of community solar initiatives. The public health center’s maternity ward and the general secondary school (CEG) were chosen as they were strategic points. There, the goal was to indirectly reach the inhabitants of the village in order to test the hypothesis of participatory work in exchange of receiving the electricity service.

The installation was carried out by a volunteer team consisting of experienced solar technicians and local people interested in the project. At the same time, the two places permitted to collect from the population primary socio-economic data and information on energy consumption patterns in the municipality of Abomey-Calavi, which is partly served by the State monopoly service. Semi-structured interviews were conducted with nine community representatives. They were chosen on the basis of two criteria: their official position in the community organization and their status of representatives of the different economic agents’ categories studied, at the rate of three per category. That choice allowed to collect accurate opinions and energy consumption data. Random discussions with more than ten other inhabitants who did not participate in the survey confirmed the findings.

The two PV installations were designed on the basis of the electricity requirements of the two sites. As the consumption data of the two selected buildings were not available, the estimate was based on the types, quantities, efficiencies and duration of use of the equipment. Thus, at the CEG, six lamps per classroom were installed, complemented by four exterior lamps. These new lights favour good study conditions compared to the preliminary design situation of two bulbs that provided poor lighting combined with power cuts that prevented students from studying. A standard 220V AC equipment was used to prevent the installation from being neglected due to the lack of replacement parts. For the sizing of the installations, reserves were added in order to anticipate cloudy days and to allow for the addition of future equipment. In the maternity ward, the sizing thus allowed the use of the elementary equipment necessary for urgent medical procedures.

All equipment used for the PV installation was purchased on-site. This choice provides clear information on deployed equipment and market prices, while providing analytical benchmarks in terms of budget. Thus, the investment costs to be borne by any economic agent wishing to make the transition could be modeled. The budget obtained on the technical heading at the end of the project was compared, on the one hand, with the annual costs currently incurred on the states’ network by 3 economic agents who consume electricity. They represent the key agents in southern countries for this type of need: Agent 1 (A1): A household with low electricity consumption; Agent 2 (A2): A household with higher electricity consumption including relatively high power consumers (freezer, electric iron, water heater etc.); Agent 3 (A3): the CEG Zinvie chosen as a public institution. The consumption data of each agent was obtained directly on site and studied over a one-year period, providing an average profile. Consumers were informed of their average consumption, which was confirmed by the agent’s invoices. To go beyond electricity consumption cost indicators, national wage grids for all categories of workers were studied [5]. The manipulated matrix simulated real purchasing power and annual household savings levels. 10 scenarios were selected, each scenario classifies a couple in a household with income levels ranging from average to maximum. The estimated gross domestic savings rate for Benin in 2017 is the reference used for the calculations [6]. Thus, the gross annual savings obtained for the 10 household scenarios were compared with the project's equipment purchase budget line at both sites.

3. Results
3.1. Technical point: Sizing and costs of on-site equipment
Estimates have shown that a maternity has modest basic needs of 1.8 kWh per day and the CEG building requires 0.6 kWh per day for lighting. Table 1 below shows the different components that were used. Production simulations, based on the sizing of the two installations and the solar irradiation of Benin,
show that the production of these two installations should cover the daily consumption needs throughout
the year [7].

| Table 1. Characteristics of the installed equipment |
|-----------------------------------------------|
| Hardware characteristics | Maternity | College |
|----------------------------|-----------|---------|
| Solar panels (150Wp)      | 4         | 2       |
| Load regulator (A)        | 1*40      | 1*30    |
| Solar gel battery (12V 100Ah) | 4       | 3       |
| DC/AC voltage converter (W) | 1*1500 | 1*500   |

The cost of the two installations was CHF 1430 for the maternity ward and CHF 1380 for the CEG. This includes all the necessary equipment: panels, charge controller, batteries, converter, solar cables, structure for panels and battery cabinet, electrical equipment such as cables, switches, LED bulbs, accessories. The most expensive parts were the batteries (30% of the material cost), then panels (20%). The DC-AC converter accounted for 7% of the costs, while the price of the charge controller was only 2% of the installation cost. The remaining 41% is distributed among the other multiple components.

3.2. Social issues
At the end of the work, 15 deserving volunteers were thanked and officially recommended for maintaining the facilities under the guidance of the on-site technician. Their commitment was irreproachable throughout the duration of the project. The hypothetical model tested in the field has thus proved effective. It is summarized in a participatory approach condensed into 5 steps summarized in Table 2. The model provides a safety value for long-term monitoring of installations, also as an effective awareness-raising process for reversing behaviour in favour of solar energy.

The beneficiaries interviewed at the village level stated that they would be willing to pay the initial investment to switch from their current systems to stand-alone PV installations. This socio-psychological result, certainly favoured by the interesting result obtained, once subjected to the socio-economic data collected, highlights the potential obstacles.

| Table 2. Participatory working model. |
|-------------------------------------|
| Steps | Stakeholders involved | Questions | Attendance |
|-------|-----------------------|------------|------------|
| Information / Awareness raising     | Beneficiaries         | Why PV installations? | Estimated at 500 participants |
| Opening / Participation             | Voluntary beneficiaries | Why understanding the system? | Estimated at 20% of the sensitized mass |
| Learning / Motivation               | Committed volunteers   | Can one go in depth? | Estimated at 10% of the sensitized mass |
| Training / Explanations             | Highly committed participants | Can one leave a technical hand? | Estimated at 8% of the sensitized mass |
| Synthesis                           | Unconditional candidates | Is the donation in good hands? | 15 recommended participants |
|                                    |                       | • Ensure continuity and have the right intervention reflexes | |
3.3. Finance and Microeconomics

The summary of the interviews showed that the small consumers have consumption needs ranging from 250 to 3500 kWh per year for annual amounts ranging from CHF 70 to 1000. These orders of magnitude were confirmed by the electricity bills collected. Prices are between 23 and 30 cts CHF/kWh, depending on the power level. On the basis of an annual electricity consumption, Figure 1 shows the costs in Swiss francs incurred annually by the three categories of economic agents.

![Figure 1. Annual costs borne by 3 economic agents VS costs of both installations](image)

Table 3 shows estimated solar installation sizes, related prices and payback periods for each category. Smallest consumers would have high payback periods, while big consumers would require huge storage capacity and probably need other sources for investment.

|                      | Mini. (A1:A2) | A1    | A2    | Maxi. (A1:A2) | A3    |
|----------------------|---------------|-------|-------|---------------|-------|
| Annual costs (CHF/year) |               | 57.5  | 150   | 441           | 1050  | 2212 |
| Electricity consumption (kWh/year) |           | 250   | 584   | 1679          | 3500  | 8459 |
| Estimated solar panel sizing (kWp) |            | 0.3   | 0.6   | 1.5           | 2.4   | 5.1  |
| Estimated storage capacity (kWh) |             | 3.6   | 7     | 17            | 29    | 60   |
| Estimated price (CHF)     |               | 850   | 1400  | 2700          | 4300  | 8400 |
| Estimated payback period (years) |           | 15    | 9     | 6             | 4.1   | 3.8  |

Figure 2 presents the results of the annual savings analysis for 10 household scenarios. These savings were related to the installation budget of the two sites in order to highlight the investment power of households. "Mini." (250) and "Maxi." (3500) represent the extreme values of consumption needs per year (KWh/year) of small consumers A1 and A2.
4. Analyses and discussion

The project has generated great interest among the villagers. Several residents requested assistance during and after the project to design their future installations or to improve old installations in other areas. Two officials wanted urgent action to estimate and install their solar home equipment. The students of the CEG, in particular, voluntarily invested themselves on the site and learned how to design, build, use and maintain a solar installation. The feedback from the first months of use shows that the facilities are operating under the established conditions that users turn off the lights as soon as natural light is sufficient. This condition is necessary in view of the fact that the sizing is done with the clear intention of encouraging rational consumption and therefore responsible ecological behavior.

It appears that the equipment on site is cheap compared to Switzerland. However, this notion of low cost is relative because it remains expensive for indigenous people. Batteries, which also have a significantly shorter life span than panels, are the most expensive equipment. The very affordable regulator is an essential element for the proper functioning of an installation and a good battery life. Their prices show that the installation of a regulator is worthwhile unlike solar kits, which do not provide it. From the will of the candidates to the effectiveness of the installation, many parameters are involved that raise crucial questions. Responding favorably to each of them would be a key to facilitating the advancement of photovoltaic electricity in disadvantaged areas.

In a geographical area without global incentive mechanisms, a first model that promotes a change in mentalities in favor of solar energy is the example in a participatory form in several phases. However, Table 2 presents a relative insufficiency in the possibilities for beneficiaries to decide and plan for themselves. This model of organization by participative stages was conceived upstream. Thus, candidates should be trained more so that they can size their installation independently, or consult technicians or experienced people.

The idea of mutual investment seems to complement the experience on the ground. It could help getting away from third-party financing and realize direct financing with the result that the project is replicated for all members of the mutual. Indeed, the mutual insurance system is known and applied in Benin by circles of friends for the financing of events or personal projects such as the purchase of goods and investments. The notion of mutual also strengthens the financial power of economic agents in relation to the results in Figure 1 and Figure 2. In the case of Figure 1, the CEG that consumes enough would have the means to invest in one year but this possibility remains linked to the goodwill of the State. It appears that large consumers of this size will be willing to pay for an energy transition if additional waiting costs do not hinder the process. On the other hand, A1 and A2 agents representing typical households in the macroeconomic environment of countries in sub-Saharan Africa will save at least three to ten years to be able to invest in a facility similar to those of the project. In addition, the return time of their installations is at least 2 years depending on the sizing. In the second case, where real savings are analyzed, it appears that only households whose spouses have an above-average income

![Figure 2](image.png)

**Figure 2.** Annual savings levels for 10 scenarios of household VS costs of both installations

- Rmo : Average income
- RE : High income
- RAE : Quite high income
- Rmax : Maximum income
- IPV : Photovoltaic installation
can imagine investing in a year. These two cases give weight to the notion of mutual already practiced informally in many sectors in Benin and West Africa.

5. Conclusion
This study uses data from the project to provide an overview of the challenges of solar energy diffusion in rural areas of Benin in response to the economic and financial realities of potential agents. However, it is absolutely necessary to work towards sustainable lifestyles by finding appropriate solutions to obstacles. Monitoring and proper evaluation of this project over time is a necessity in order to complete the analyses from the point of view of precision dimensioning models [8]. This is the way to design integrated models that graft socio-economic realities onto market prices and energy policies [9], models that can be used by people committed to solar energy in the future of rural areas of Benin. The effectiveness of this approach also requires sustained political will to establish mechanisms and support actors on the ground. This is all the more interesting because PV electricity is extremely well suited to strong decentralization by directly exploiting the roof surfaces of buildings.

Given that solar energy is likely to be the most promising and powerful source of energy among renewable energies and that the development and appropriation of renewable energies is a major concern of our time, this paper was written to highlight the possibilities for action in favour of solar initiatives in rural areas in Benin and report on a project that could be reproduced in other areas of similar conditions. While in urban areas the electricity grid could be extended if political and economic conditions are fulfilled, the technical possibilities in rural areas for public grid connections are limited, and the costs high. Therefore, autonomous PV installations are best suited. That is still reality, ten years after the conclusion that “Solar Home Systems are an interesting option for dispersed settlements in most South Sahara African countries, where grid electricity is not likely to be available for the next decades.” [10]

The initiatives use the rotating model of mutual finance and integrated participatory workcamps through the rotating cycle of self-financing, self-construction, capacity building for old members and training for new members, and empowerment of the entire team for the long-term operation of the facilities.

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