Solar Technologies for Off-grid Rural Fishing Communities

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Abstract
This study describes a concept for the productive use of renewable energy to support the economic development in a rural area of the Philippines. As an example for productive use serves the application of cooling equipment based on electricity generation by solar technology. More precisely, the business case of an off-grid ice maker generating ice cubes for fishermen of a small island in the Philippines is analysed. The result is compared with the existing case, i. e. buying ice cubes from an ice cube producer using the island grid based on a large Diesel Genset. The business case is based on a series of interviews of important stakeholders included in the value chain of the fishery business in March 2018. These are the fishermen, the officials of the province level and the local level and further the fish traders being involved in the sale and distribution process. The result shows that the application of a pure off-grid ice making facility is economically feasible. The biggest challenge for a successful implementation of the concept is the lack of capital for the investment in the off-grid facility. The investment demand typically exceeds classical pay-as-you-schemes. Thus ways of developing alternative microfinance instruments have to be elaborated further for a successful implementation. The proposed concept of a foundation of a cooperative with fishermen as shareholders and a micro finance institution as a debtholder contributes to an increase of the income of the fishermen of roughly 14%.
Keywords: Decentralized Rural Electrification; Productive Use, Solar Freezer, Solar Cooler, Business Models

Introduction
Electricity is a vital factor underlying modern living standards (Groh, 2014). That is evident especially in rural areas of many developing countries, where a low living standard has to be constituted mainly due to missing or incomplete access to electricity (Bhattacharyya, 2018). As a result of a continuously widespread availability of renewable energy (RE), there is an improvement of possibilities enabling entrepreneurship by applying innovative technologies to use electricity for productive use (Alstone, Gershenson, & Kammen, 2015; Breyer, Gerlach, Gaudchau, Hlusiak, & Cader, 2013). This is a challenge for product developers who are responsible for the profitability of innovative products, but are limited in their decision making by budget boundaries. In order to meet this challenge, further knowledge about the demand of the local population in remote areas of developing countries is needed. Consequently, the purpose of this field study to the fishermen of the island Camiguin was first to realize the right product to meet the best demand and second to measure how

productive use can improve the income situation of rural population. To shed light on this problem, this study considers three research questions: Which products are appropriate to the users of electricity, what are possible business models based on productive use and what is the impact to the income of the rural population? Answers to these questions can enhance development strategies for product developers and microfinance institutions.

Solar cooling equipment in rural fishing communities

The rationale to evaluate the possibilities for productive use by applying off-grid solar electrification technology for fishery in remote islands of the Philippines is based on following considerations:

1) A large number of the fishermen live and work in off-grid, island-based fishing communities.
2) A common concern for these people is how to preserve catch freshness while waiting for the transport to the next stage of the value chain.
3) In most cases, these communities are isolated and far from regular transport networks.

Thus, the design, fabrication, and pilot testing of common service solar cooling equipment for fishing communities located in the Visayas and Mindanao shows up huge potential. The island of Camiguin fulfills the requirements of being selected as a representative case for the feasibility study due to following criteria:

1) The main income source of the population of Camiguin is fishery. 60% of the economic activities are directly related to fishery, the second important source of income is tourism with a share of 20%. The share of tourism is rising and will influence the importance of fishery additionally as a huge share of the fish catch is currently transported to the main spots of tourism located on the island of Bohol. As a result there is potential for further demand for the local fishery in Camiguin.
2) The fish catch is not restricted by natural conditions. It is limited by technical bottlenecks. Thus there will be no negative impact to the bio diversity of the marine biosphere by intensified fishing. The main obstacle to raise the size of the fish catch is given by the availability of cooling facilities to preserve the freshness of the catch. Currently the cooling is achieved by using ice cubes on the boats with two objectives: Cooling the fish as quick as possible and as flexible as possible. The amount of ice cubes taken on board is limited either by the high price of 5 PHP per kg as well by the limited supply based on the ice cube production by applying diesel gensets to feed the ice cube machines with electricity.
3) A typical feature for many remote Philippine islands: The quantity of the ice cubes produced limits the size of the fish catch. To expand the capacity of the Diesel genset is a cost expensive option which benefits few traders or local government enterprises, but does not improve the earning situation of the fishermen.
4) The island of Camiguin can be considered as a representative island, as the population as of roughly 100.000 inhabitants is typical for remote islands without a steady access to a powerful grid. Moreover, Camiguin is an ideal pilot area for RE due to the close distance between fishing communities around the island

Given that the objectives of this feasibility study are:

1) Demonstrate the economic sustainability of off-grid solar systems as a renewable source of energy;
2) Promote the use of cooling systems by fisherfolks to prevent spoilage and prolong the freshness of fishery and marine resources (FMR);
3) Strengthen business development services along the entire FMR value chain;
4) Encourage self-representation by fishing communities to protect their livelihood and the environment.
5) For local government units (LGUs) to advocate the use of RE in rural fishing communities.

The aim of the qualitative evaluation was to achieve that all stakeholders involved in the FMR value chain were covered: LGU officials, representatives from government line agencies and fishermen. It has to be pointed out that more emphasis is placed on the fishermen as end-users rather than policy makers.
The availability of an ice making facility is a critical factor every time a fishermen goes out to sea to catch FMR. There is a need to explain further to fishermen the technical aspects of solar technologies as applied in the context of current fish catch practices. The growing demand for FMR both within the island as well as to the neighboring islands Mindanao and Bohol augur well for the introduction of improved fish catch systems using solar technologies.

Evidence of the interviews

The island of Camiguin consists of the five municipalities Mambajao, Mahinog, Guinsiliban, Sagay and Catarman. Interesting to note is that these municipalities show up significant differences in economic activites resulting in corresponding differences in the average income per head (Tab. 1).

Table 1 Population and income and fish output characteristics of the island Camiguin

as of 2017	Mambajao	Mahinog	Guinsiliban	Sagay	Catarman	total
Population	39.913	14.852	6.700	12.623	17.589	91.677
Per capita income per month (PHP)	3.267	3.487	1.959	2.850	3.912	3.273
Per capita income per month (USD)	65	70	39	57	78	65

The municipalities of Mambajao, Mahinog and Catarman are located in the northern part of the island and show up the highest per capita income - this is given by the fact that tourism contributes significantly to the local economy over there and as a result the achieved price per kg is clearly higher than in the Southern provinces of Sagay and Guinsiliban. Guinsiliban displays the most underdeveloped shape of the economy especially compared to the neighboring municipality of Sagay. Sagay can offsetting the missing access to the tourism business partly by a scope to catch squid which is sold further as a dried snack to other parts of the Visayas and Mindanao.

Figure 1 Interviews of the fisherfolks in Guinsiliban, Camiguin Island

The data evaluation process (Fig. 1) contained stakeholders from all 5 municipalities of Camiguin. The main findings were:
1) A common concern for fisherfolks is the importance of the supply of ice cubes every time they go out into the sea to catch fishery and marine resources (FMR);
2) At the fisherfolks level, the prevalent practice is to buy 12-15 pieces of ice in plastic bags from small retailers or households at 3 PHP per plastic bag or 5 PHP per kg ice.
3) Floating fish carriers, on the other hand, buy crushed ice from Mindanao-based ice plants at 470 PHP per block or 100 kg needing 30-32 blocks every time the carrier receives fish catch and then distribute it along coastal towns of Mindanao and sometimes as far away as Jagna in Bohol.
4) In the case of truck fish carriers, crushed ice requirements is at an average of 24-28 blocks per trip. These are then distributed within Camiguin, particularly Mambajao, as well as ferried across to Mindanao for distribution to upland communities of Bukidnon and Misamis Oriental.
5) When it comes to select possible solutions for the cooling equipment there is a clear and overwhelming response of all municipalities to prefer an ice making facility instead of alternatives as a solar freezer or solar cooler. The rationale for this preference is a convincing one: Ice cubes can be manufactured on-shore and can be transported easily on the boats in small cube boxes (Fig. 2). This process has the considerable advantage, that the cold medium does not depend on any sources for electricity on board. The possible alternatives solar freezer and solar cooler depend on an access to electricity on board and are typically not resistant against corrosion on sea when installed on a boat. That is a decisive argument against the usage of mobile solar cooler or solar freezer on board.


Figure 2 Fisherboat with ice cube boxes

The following statements during the interviews underline this evaluation (Cubillas, 2018):
Mambajao: "Solar is imperfect because you need batteries to operate in the evenings. Sustainability means enjoying the fruits of solar after Project ends, especially the funding…".
The FGD conducted deals mainly with policy issues especially the cause-effect relationship

between the fishing sector and wastewater generated by point sources (e.g. Resorts, Hotels and Restaurants)
Mahinog: "Solar seems to be useful to us. However, the pay-as-you-go scheme needs further elaboration. I need to fully understand what is it before i will talk to my association members". The social preparation of this group is very cohesive. The 7 fishing associations are organized into a federation. In addition to their main livelihood of fishing, the federation ventured into poultry raising/dressing as well as bangus culture to mitigate the effects of typhoons.
Guinsiliban: "Magamit ba namo ang solar to charge our batteries? Solar is more useful sa mananagat than for fish carrier." The main interest of these fisherfolks is assistance in having their own fishing boat (16 HP outboard motor) instead of the current practice of renting these boats.
Sagay: "Our association should secure a permanent site first before we will consider solar". Member housewives of the fishing association earn income from the processing and drying of their husbands' squid catch.
Catarman: "With solar, fisherfolks will not be at the mercy of comprador anymore. We can now dictate the price on a take-it-or-leave- it basis".

Business Case for an off-grid ice making facility

The volume of the fishcatch shows similar characteristics for the Northern municipalities Mambajao, Mahinog and Catarman. Larger deviations can be registered in the case of Guinsiliban with a significant reduced volume and Sagay with a tremendous large volume in the case of squid with 80 tons per year representing 26% of the complete volume of the island Camiguin as of 306 tons per year (Table 2). Assuming 200 working days per year a daily fish catch constitutes of 1.5 tons. As the fishermen use approximately 10 kg ice per boat for a catch of 20 kg fish, an ice demand of 0.75 tons per day can be assessed.

Table 2 Fish output characteristics of the island Camiguin

Volume (kgs) of catch p.a. as of 2017	**Mambajao**	**Mahinog**	**Guinsiliban**	**Sagay**	**Catarman**	**total**
Barils	8.000	2.150	700	5.000	5.000	
Budlisan	2.000	3.650	3.500		1.000	
Budloy	3.000	8.300	2.500	25.000	1.300	
Nokos	500	800	5.500	80.000	3.500	
Tamban	5.000	700	400	50.000	25.000	
Tulingan	5.000	5.330	2.000	25.000	5.000	
Others	-	21.990				
Total	23.500	42.920	14.600	185.000	40.800	306.820
Total per day (200 days p.a.)	118	215	73	925	204	1.534

The daily requirement of 750 kg ice leads to the following design of the ice making facility (Table 3). A typical serial 5.5 kW ice making facility produces 860 kg ice daily by a time length of one shift of 7 hours. The energy need for one month is determined by 1,155 kWh based on an energy efficiency of 45 Wh/kg equivalent to an output of 22.3 kg/kWh. Given an irradiation of 2,000 kWh/sqm for Camiguin equivalent of 1,500 kWh/kW peak a solar power site of 10 kW is required for to provide the electrical energy needed for the ice production. To bridge supply/demand deviations a battery bank is necessary to store the electrical energy.

With a typical autonomy of 1.5 days and a battery voltage of 48 V in total 10 batteries are necessary to achieve a capacity of 2500 Ah with the capability to provide the energy of 120 kWh aimed for.
The costs for the ice making facility can be outlined as follows (Table 4). The 5.5 kW ice maker costs 7,000 USD. Assuming current costs of 1,800 USD per kWp for the solar panels and 2,000 USD for one inverter the investment need for the PV site of 10 kW amounts to 20,000 USD: Based on a battery price of 400 USD/kWh the installment of the 120 kWh battery bank leads to an investment of 48,000 USD. Thus in total an investment size of 75,000 USD can be assessed, whereas the energy system covers 68,000 USD.
Usage terms of 10 years for the ice maker and of 22 years for the PV energy system constitute depreciation rates of 10% and 4.6%. Thus, machinery costs of 700 USD p. a. and power costs of 3,128 USD p.a. have to be taken into account. Assuming four workers for maintenance and servicing the ice making facility with a monthly salary of 9000 PHP or 180 USD per head lead to labour costs of 8,640 USD per year. In summary, based on a monthly output of 25,800 kg and monthly total production costs of 1,039 USD production costs of 4 USD-ct per kg or 2.0 PHP per kg were achieved. By taking the power costs of 261 USD per month and the energy demand of 1,155 kWh per month into account the costs for electricity result in 0.23 USD/kWh and 11 PHP/kWh. When comparing this result with the existing situation the important outcome is: The PV off-grid ice making facility produces produces cheaper and is more efficient than the local electrical utility Camelco with costs of 2.12 PHP/kg and 14 PHP/kWh.

Table 3 PV Off-Grid Ice Making facility

Ice Maker kW	5.5
Output ice kg per shift	860
Ice Maker Time per shift hours	7.0
Energy demand monthly kWh	1,155
Energy per kg ice Wh/kg	45
Required power kW total cal.	9,2
Solar Power kWp installed	10
Irradiation kWh p.a. /kWpeak	1,500
Energy kWh monthly	1,250
Battery bank days autonomy	1.5
Battery Voltage V	48
Battery bank capacity Ah	2,553
Number of Batteries 48V	10
Battery bank Energy kWh	120

The benign cost profile leads to a sound profitability of the ice-making facility as a business model. Assuming a sales price of 5 PHP/kg for an average sales amount of 770 kg ice daily revenues of 2,304 USD per month or 27,647 USD p.a. are achieved. Taken the total costs of 12,468 USD p.a. into account a yearly profit of roughly 15,180 USD can be expected attaining a sound return on investment (ROI) of 20% and a payback of the ice making facility by 4.9 years or 59 months.

Table 4 PV Off-Grid Ice Making facility - Profitabiltiy calculation

Costs	**USD**	**PHP**
Ice Maker price	7,000	
Price module USD/KWp	1,800	
Price Inverter SMA Sunny Island 9 kW	2,000	
Invest Solar total USD	20,000	1,000,000
Price Battery Lead Acid USD / kWh	400	
Invest Battery total	48,000	2,400,000
Invest Energy system	68,000	3,400,000
Invest Ice Maker system total	**75,000**	**3,750,000**
Power depreciation cost 4.6 % p.a.	3,128	156,400
Power cost p. m.	261	13,033
Ice maker depreciation cost10 % p.a.	700	35,000
Ice maker costs per month	58	2,917
Labour costs monthly (4 workers for ice making)	720	36,000
Labour costs p.a. (4 workers for ice making)	8,640	432,000
Costs p.a. total	12,468	623,400
Costs total per month	1,039	51,950
Costs per kg	0.040	2.0
Electricity costs per kWh	0.23	11.3
Ice demand fisher boat total kg	768	
Revenues	**USD**	**PHP**
Price Ice USD per kg	0.1	5
Revenues monthly	2,304	115,200
Revenues p.a.	27,648	1,382,400
Profit p.a.	15,180	759,000
Payback yrs	4.9	
Payback months	59.3	
Return on investment (ROI)	20%	

However, the main bottleneck could be the funding of the investment costs of 75 tsd. USD or 3.75 mln PHP. This amount can be regarded as prohibitive high for existing cooperations of fishermen. To overcome that hurdle, a solution could be to attract micro finance institutions or donor-based initiatives to participate by a loan [see for more Hankel, 2014; Schützeichel, 2018]. That means, the proposed PV off-grid ice-making concept can be extended by adjusting the finance part (Fig. 3). The ice-making facility is founded as a cooperative with the target to fund the required investment amount of 75,000 USD by local shareholders and a loan facility provided by a co-finance credit institution. The fishermen participate as shareholders of 20 % and inject equity as of 15,000 USD. The credit institution contributes 80% or 60,000 USD of the required investment capital. The loan exhibits an amortizing structure at an interest rate of 14% and a lifetime of 15 years. This structure corresponds to an extended pay-as-you-go scheme. As a result the ice-making cooperative has to repay 9,769 USD constantly per year over 15 years.

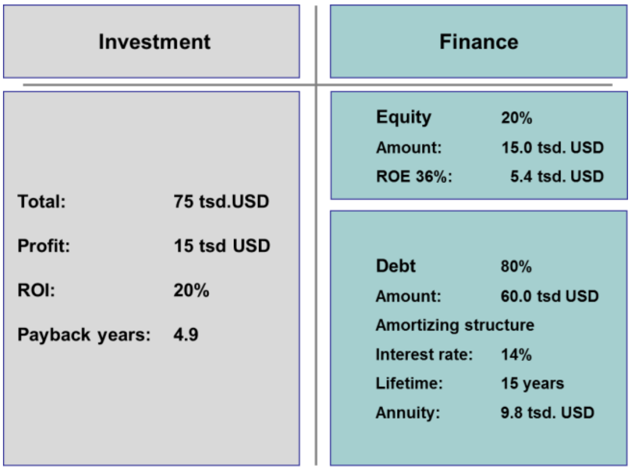

Figure 3 Cooperative finance concept for the PV ice-maker site

Table 5 Profitability PV ice-maker site

Profitability Cooperative	**USD**	**PHP**
Investment size	**75,000**	**3,750,000**
Debt 80%	60,000	3,000,000
Equity 20%	15,000	750,000
Annuity p.a.	9,769	488,427
EBIT p.a.	15,178	758,910
Profit after Debt service	5,410	108,193
Profitability ROE	36.1%	

The annuity of the loan reduces the yearly profit for the shareholders of 15,178 USD to 5,410 USD as given by the profit after debt service (Table 5). The advantage of that structure is, that the return for the shareholders as a return of equity (ROE) is increased considerably: The ROE amounts to 36% of the injected equity and is considerably higher compared to the ROI of 20% due to the proposed leverage structure. Besides the increase in the profitability for the shareholders that funding structure incorporates another important advantage: The implementation of such an ice-making facility seems to be realistic for a typical rural area like the island of Camiguin. Assuming a community of 50 fishermen participating equally in the cooperative the required amount for one person amounts to solely 300 USD or 15,000 PHP. This investment amount was considered as feasible by the fishermen during the interviews taken by the fact finding mission mentioned above. Based in that calculation, one shareholder has the possibility to achieve an additional income of 108 USD or 5,400 PHP p.a. equivalent to 9 USD or 450 PHP monthly representing a significant increase of 14% to the average monthly income of roughly 3,300 PHP. Thus, the concept has the potential to have a long term positive impact to improve the income situation for the local population.

Next steps and conclusion

This paper describes the possible impact to the income situation of a rural village in a small island of the Philippines using a decentralized sustainable energy system to foster productive use of energy. The business case for an off-grid ice making facility shows a sound profitability. Assuming an access to a loan facility provided by a donor organization or a micro finance institution with a share of 80% of the investment sum a sustainable solution could be a cooperative funded by equity of 20%. The equity is provided by the fishermen acting as shareholders of a cooperative with small participation amounts in a denomination of

15,000 PHP shares. This structure allows to transfer the profitability of the ice making facility directly to the fishermen with the consequence that an additional income of 450 PHP monthly or 14% for the fishermen can be attained.

Finally, and most remarkable additional employment by the implementation of the solar off-grid-facility for rural people is created. Accordingly there is a social and economic benefit using this concept for other islands in the Visayas and Mindanao area.

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