Title

Assessing the impact of renewable energy on local development and the Sustainable Development Goals: Insights from a small Philippine island

Author

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1   Introduction

The global community has agreed on 17 Sustainable Development Goals (SDGs) to address various global development challenges and inequalities. The SDGs provide a framework to include social and environmental sustainability in development processes (Stevens & Kanie 2016). Innovative, clean and sustainable technologies are crucial instruments for advancing towards these SDGs (Moyer & Bohl 2019). Supportive technology policy is therefore of paramount importance to stimulate the development and diffusion of those technologies (Liu et al. 2019). An important example is the use of renewable energy (RE) technologies for achieving SDG #7: "Ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations 2015). Thus, many supranational institutions and national governments promote RE for energy transition and rural electrification to provide and improve energy access and to address increasing energy demands in a sustainable manner (Almeshqab & Ustun 2019).

Energy access and electrification can provide opportunities for new businesses, extended study and working hours, better health and education infrastructure and new opportunities for community building activities (Karekezi & McDade 2013). However, context-dependencies prevent generalizable conclusions about these interlinkages that ultimately depend on locally specific factors. Insights from case studies reveal that the capability to benefit from access to electricity strongly depends on the socio-economic and socio-cultural context (Kumar 2018). It is hence necessary to assess the impact of modern and improved energy access at the local level to derive recommendations for policy makers and technology policy interventions (McCollum et al. 2017). The research direction is therefore bottom-up, using case studies to derive local and regional recommendations instead of taking a global approach and breaking it down to the country level.

Such case studies need an interdisciplinary approach combining energy research with social sciences based approaches (Sovacool 2014; Sovacool et al. 2015). This could be

the analysis of an energy supply system by including the consumer perspective via qualitative interviews, quantitative surveys and case studies especially in less studied regions like remote areas of developing countries (Sovacool 2012; Bhattacharyya & Palit 2014). Lessons learnt of such studies can serve as crucial insights for addressing the need for access to energy in a more adequate and sustainable way in the future. In conclusion, supporting technology policy for SDGs needs context and regional specific research to improve evidence-based decision making.

In our paper, we address this need by investigating the impact of providing more affordable, reliable and sustainable access to energy on consumption patterns, appliance uptake and overall socio-economic development. We selected the local community of Cobrador Island in the Philippines as case study. Choosing a typical small island in this region allows to extend recommendations not only in the Philippine context but also for Southeast Asia. Many remote islands in this region suffer from unreliable power supply and in the Philippines, still 2.36 million households (HHs) lack access to sustainable energy supply (IRENA 2017a). The purpose of our study is to highlight the effects of sustainable energy supply on the local community and to address the following research aspects to derive recommendations for policy makers:

(a) How can SDG#7 be achieved on remote islands and what are specific consumption patterns and appliance usages to be considered?

(b) How is the achievement of SDG#7 addressing crosscutting SDG targets such as access to information, access to education, access to health services, income generation and other?

(c) How can the achievement of SDG#7 contribute to poverty alleviation and addressing inequalities?

To find solutions to these questions we have developed and applied a quantitative questionnaire and surveyed a significant share of households on the case study island. We use descriptive statistics to explore the data and analyze relevant aspects in more detail. Findings were compared to historical data of consumption patterns on the island and to results of other case studies. The specific measure that addressed SDG#7 on the case study island was the hybridization of a diesel generator with solar PV and battery storage to provide clean and reliable electricity on a 24/7 base. The geographical, demographic, socio-economic, infrastructural and institutional framework conditions of our case study reflect a situation comparable to a large number of islands in the Philippines and the Southeast Asia. Therefore, this case study analysis can serve for deriving implications for wider RE deployment in the region.

2 Background

The background section introduces the context of this study. First, we examine the interlinkages between energy access, SDGs and RE. Second, we highlight the energy

access situation in the Philippines. Finally, we introduce the background of the selected case study.

2.1 Global context: Energy access and the Sustainable Development Goals

The lack of access to electricity hampers human development in many regards (Bhattacharyya 2013). For example, a lack of modern lighting in households is considered to limit the ability to pursue not only productive activities after nightfall, but also educational and recreational activities. Likewise, business development and the provision of public services like health care and education are difficult (Bonan 2017). Figure 1 provides an overview on possible linkages between SDG#7 and other SDGs.
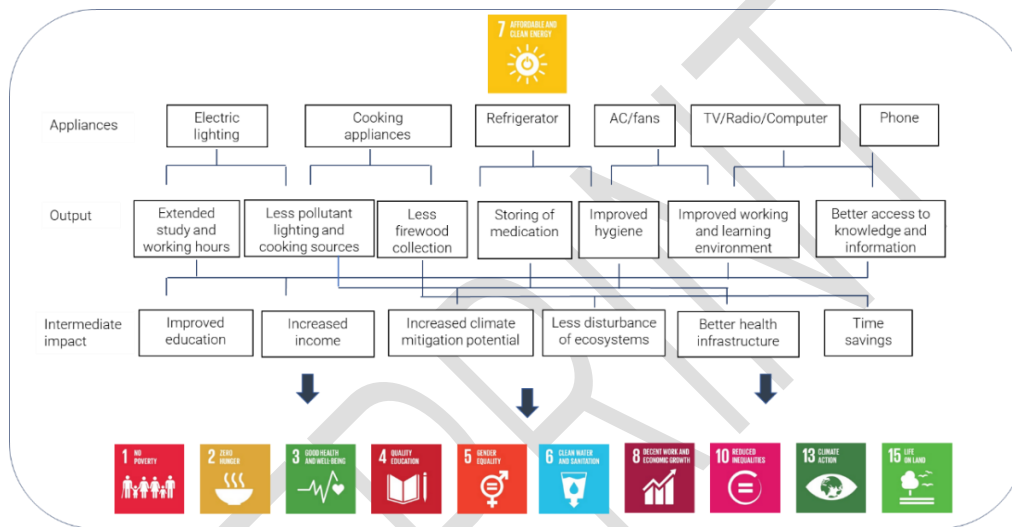

Figure 1: Interlinkage of SDG#7 to other SDG (own illustration).

The possible linkages of SDG #7 to the other SDGs have been studied to a large extend already (Alloisio et al. 2017; McCollum et al. 2017; Le Blanc 2015). A strong interconnection is often found concluding that access to modern energy services enables the implementation of a series of other SDGs, hence significantly contributes to sustainable development in general. Access to modern energy forms is fundamental to human development and to support the alleviation of poverty (SDG #1) according to Akter (2017) as well as Casillas & Kammen (2010). This energy access is also critical to enhance agricultural yields and productivity, which can increase food security (SDG #2) (Acheampong 2017). In terms of increased health and well-being (SDG #3), access to modern energy services can reduce diseases caused by the emissions of traditional biomass for cooking and of kerosene lamps (Amegah 2016). Especially women are highly affected by indoor air pollution (Das et al. 2017). The use of refrigerators facilitates cooling of medicine, especially of vaccines. Moreover, it allows for the cooling of food, which on one hand results in better hygiene and on the other in new economic opportunities by selling preserved food or ice (Palit & Chaurey 2011). Access to modern lighting enables for studying after nightfall, and modern information and communication technologies in schools can raise the quality of education and information access, which contributes to SDG #4 (Collste et al. 2017). A strong impact

of improved electricity access on women's safety and girls' school enrollment is found and it can empower women by improving their income-earning, e.g. through time-saving from household chores (SDG #5) (Akter 2017). Time savings for women can also be used for productive activities and education. SDG #7 can hence have a strong positive impact on the SDGs #5 (Gender equality), #8 (Economic growth) and #10 (Reduced inequalities) (Burney et al. 2017). Moreover, decentralized renewable energy systems such as solar home systems (SHS) or village-scale solar systems can enable more participatory and inclusive processes for managing energy supply on the community-level (Kunze & Becker 2015). Depending on the policies in place it can also help to reduce inequalities between poorer and wealthier households (SDG #10) (Casillas & Kammen 2010). On a local as well as global scale SDG #7 is an enabling factor for the implementation of SDG #13 on climate change mitigation and adaptation (Alloisio et al. 2017; Cherian 2015; Gambhir A et al. 2017; Riahi et al. 2016). Ensuring access to clean and modern cooking and heating energy can also lead to less disturbance of the local biodiversity and the ecosystems through firewood collection and thereby contribute to SDG #15 (Life on Land) (Pagdee 2017).

Whereas the positive impact of modern energy services on a variety of other fields might be evident, and many governments have acknowledged the importance of action in this field, many still struggle to deploy RE technologies, especially in remote areas. In many developing countries, complex and inadequate regulations, policies, and legal frameworks hamper the development of new RE or electrification projects and technologies (Blechinger 2013; Brahim 2014). Lack of financing for off-grid entrepreneurs and affordability of clean energy for poorer households is found to be a major challenge for the implementation of modern energy services (UNDP & ETH Zurich 2018). Furthermore, the positive relations are highly dependent on the policy instruments in place. For example, if distributional costs of new energy policies (e.g. supporting renewables and energy efficiency) fall disproportionately on the poor, then this could even work against the promotion of social, economic and political equality for all (McCollum et al. 2017).

In conclusion, the positive effects of SDG#7 on other SDGs have been widely studied and acknowledged on a global scale. Nevertheless, country specific contexts need to be considered when designing supporting policies. Thus, findings from interventions targeting SDG #7 in remote areas of the Philippines are of importance for more accurately and sustainably designing an appropriate technology policy in the future.

2.2 Country context: Energy access in the Philippines

As an archipelago comprised of more than 7,000 islands the Philippines are a considerably fragmented country (Boquet 2017). Continuous power supply is provided to the most populous and economic relevant "on-grid" islands through two main electric grids (IRENA 2017b). Isolated grids supply the "off-grid" areas, which defined as islands or remote areas not connected to one of the two main grids. Frequent power rationalization in off-grid areas is a consequence of high costs due to the use of diesel generators (Roxas & Santiago 2016) and 24 hours supply is mostly not available (DoE

2016). The remaining non electrified areas ("missionary areas") are a large number of small islands with no power supply or informal power supply only. The objective of the government of the Philippines is to provide access to clean and continuous energy supply to all parts of the country for improving the living conditions. Therefore, 100% electrification of all households by 2022 was set as target within the Philippine Energy Plan (PEP) (DOE 2015). Nevertheless, the share of electrified households was only at 89.6% in 2016, reflecting 2.36 million households without electricity supply and many other with only basic and limited energy supply (IRENA 2017a). The Philippine Renewable Energy Act (RE Act), inaugurated in 2008 (RA9513 2008), serves as technology policy instrument for stimulating the deployment of RE technologies in the country (Roxas & Santiago 2016). High expectation arose as a large number of fiscal and non-fiscal incentives was implemented under it (Rosellon 2017), with specific schemes envisioned to facilitate rural electrification through private sector participation. However, a study on the risks and uncertainties of RE implementation on the Philippines, (Bertheau et al. 2019) indicates that the lack of clear implementation for these policies hinder them from successfully supporting the energy transition in remote islands. Numerous attempts for RE based electrification in the framework of international development cooperation were undertaken in the Philippines. Early initiatives focused on deploying SHS (Heruela 1992), followed by hybrid energy systems comprised of solar PV, batteries and diesel generators for back-up power supply (Hong & Abe 2012). Although many donor based RE projects have been conducted by USAID, GIZ, UNDP and others (Marquardt 2015), little information on their evaluation can be found. Several studies (Hong & Abe 2012; Marquardt 2015; Yaqoot et al. 2016) indicate that most of the donor-based projects proved unsustainable due to weak local capacities for proper operation and maintenance of the systems which then led to low acceptance towards new technologies among the population. In summary, the Philippines are a renewable resource rich country which currently fails in exploiting its full potential to achieve SDG#7. More locally adapted interventions are necessary to facilitated the implementation of RE technologies on remote islands and provide access to energy.

2.3 Case study context: Cobrador Island Solar – Diesel Project

Cobrador Island forms a single barangay[1] as part of the province of Romblon, located centrally in the Philippines. The island is small with an area of 2.6 km² comprised by a small beach stripe and mainly hilly terrains. It is home to approximately 1,000 people living in about 250 households scattered over seven sitios[2]. The island has a barangay hall (town hall), health station, a primary school and kindergarten and the main source of income is fishing. With these typical characteristics, Cobrador island is representative for a large number of small islands in the Philippines and the region (Meschede 2018). Some households of the island were initially electrified in 1997 by means of solar-home-systems within a governmental electrification program. In 2010, the local electric cooperative (EC), installed a diesel generator of 15 kW capacity to address an increasing

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[1] Smallest administrative unit in the Philippines
[2] Part of a barangay

demand. However, due to high fuel costs electricity was provided for eight hours per day and due to difficult terrain to 138 HHs only. This situation changed with the inauguration of the Cobrador Island Solar – Diesel Project in August 2016, which facilitated 24 hour electricity supply. The new hybrid system consists of a solar capacity of 30 kW, battery (lithium-ion) capacity of 180 kWh and a diesel back-up generator of 15 kW. As a result it improved the reliability of supply (24 h), affordability (50% electricity price reduction) and environmental soundness (renewable energy share of up to 92% per day). In the first year of operation the bulk of required electricity was supplied by the solar plant with 32.7 MWh and 10.6 MWh were supplemented by the diesel generator. This reflects an average RE share of 75%. Solar PV and battery storage was selected as appropriate RE technology given its matureness and ease of installation. Other RE technology options were not considered given the unfeasibility of installation (wind power) or uncertain fuel supply (biomass). The intervention was realized through international collaboration in the framework of the Asian Development Bank's Energy for all (E4ALL) initiative which aims at contributing to SDG#7 through various activities. The project included technical and financial cooperation for the Romblon Electric Cooperative (ROMELCO) from the Asian Development Bank (ADB), Korea Energy Agency (KEA) and the National Electrification Administration (NEA) of the Philippines. The overall costs summed up to approx. 500 thousand USD split between KEA (300,000 USD grant fund), ADB (100,000 USD grant fund) and NEA (100,000 USD loan fund). ROMELCO contributed with workforce, constructed the powerhouse and purchased the necessary land. The outlined case study presents an example for the deployment of an innovative and sustainable energy solution through technology policy. The specific conditions of the island are comparable to a large number of islands in the Philippines and in the region. Given the remoteness of the island, external influences are low and clear system boundaries are defined. This makes the island a suitable research subject to understand the socio-economic implications of an intervention targeting SDG #7 with a focus on electrification through RE.

3 Material and methods

Our study mainly relies on primary data from Cobrador Island. The primary data collection builds upon a household survey since this allows for assessing the impact of an improved and RE-based energy supply on the household level. By covering other characteristics of the studied HHs such as socio-economic data it is possible to study coherences and derive key findings. Surveys are a cornerstone of empirical research in the field of social science based energy research (Sovacool et al. 2018) and are combined with literature analysis and data on historical energy consumption for this study. The material and methods section describes the development of the applied household questionnaire, the preparation of the field survey, the implementation of the field survey and the limitations faced during the data collection.

3.1 Questionnaire design

We developed the applied questionnaire in an iterative approach to assure its appropriateness and applicability (Preston 2009). Specific challenges can occur when conducting questionnaire surveys in remote and marginalized communities of developing countries, such as low educational level of respondents, cultural traditions, gender roles, local languages (UN-DESA 2005). To address these challenges, Philippine experts (scholars from University of the Philippines-Diliman), familiar with the case study region, were involved in the questionnaire design from an early stage on. Additionally, we analyzed relevant literature and questionnaires applied for addressing similar research questions, e.g. (Hong & Abe 2012; Sullivan & Barnes 2006; Sovacool et al. 2018).

The iterative development and design process included the following steps: (1) Design of first questionnaire draft based on literature analysis. (2) Feedback round with Philippine and international experts. (3) Design of second questionnaire draft based on feedback. (4) Double blind translation of questionnaire from English to Tagalog and Tagalog to English. (5) Design of third questionnaire draft based on issues revealed during translation. (6) Pretesting of questionnaire, workshop and training with group of enumerators. (7) Creation of fourth questionnaire draft based on feedback from pretesting and workshop. During the field survey, the team conducted daily meetings for feedback and necessary adaption of the research design. Figure 2 illustrates the approach applied for developing and designing the questionnaire.

Figure 2: Approach for questionnaire design (own illustration).

The finally applied questionnaire is comprised of four sections with 58 main questions, and additional follow-up and sub-questions. Most questions are closed-ended but few are open-ended questions to account for not anticipated responses (Sullivan & Barnes 2006). Answering the questionnaire took approximately one hour during pretesting and during the field survey. Table 1 presents and describes the four main sections of the questionnaire.

Table 1: Questionnaire structure.

Section	I	II	III	IV
Topic area	General socio-economic information of the households	Electricity demand and usage	Subjective perceptions of changes	Challenges
Questions	Household size, adults/children, age, education status, main income sources and expenditures	Electricity bill, willingness to pay, appliances (what, how many, since when, how often used), activities with electricity	Impact of electricity access on health, security, education, safety and income	State major challenges for the household and the island within the next two years

Rationale	Setting basic socio-demographic context and providing key information for interpreting the survey results	Enables a detailed understanding of the usage of electricity	This data allows for an understanding whether residents perceive an impact of electricity on their daily life	Enables an understanding of the major concerns of the residents and if they are related to electricity access.

3.2 Survey design

We applied a stratified random sampling technique for the selection of respondents to make sure that all households, within the predefined household classes, have the same probability of consideration. Data on monthly electricity consumption, of all households of the case study island, served as stratification variable. Data was classified by means of the Jenks optimization method for minimizing the deviation from the average within a class and for maximizing the deviation to the average of other classes (Jenks 1967). We applied four classes since it provides an acceptable goodness of variance fit (GVF) value with 0.92. Table 2 presents the derived classes based on the electricity consumption of households.

Table 2: Questionnaire structure.

Class	Lower boundary (kWh/month)	Upper boundary (kWh/month)	Count	Considered in sample
1	5	195	164	108
2	210	607.5	55	36
3	742.5	1,567.5	14	9
4	1,942.5	3,217.5	6	4
GVF			0.92	

We determined a statistically representative sample of at least 158 HHs questionnaires based on a population of 239 households, a 95% confidence interval, and 5% margin of error and non-response factor (Barlett et al. 2001). According to the share of the total population of each class, it was then determined how many households of each class had to be interviewed (Table 2). For each class the proportionate amount of respondents was randomly selected for the final sample. On site, the enumerators approached only the randomly derived households through asking the villagers for directions. For anonymization reasons, a code was assigned to each household in the questionnaire. In case that the assigned household was not available for an interview for any reason (e.g. declined to respond, absence, only underage household members available), the enumerator selected the next household of the same class from a randomly comprised list. Finally, it was possible to interview 170 HHs, considered as sufficient to expect a sampling error close +/- 5% at a 95% confidence interval for the given population (Sovacool et al. 2018).

3.3 Household questionnaire survey

The author and a team of five enumerators, all volunteers and students from the University of the Philippines – Diliman, conducted the field survey. The team of enumerators took most of the questionnaires due to their proficiency in Tagalog and the local dialect (mix of Tagalog and Cebuano). Prior to the survey the local government

unit, electric cooperative, barangay captain (community unit) and local leaders, as well as interested inhabitants were invited to a stakeholder meeting informing about content and purpose of the study, and assuring confidentiality of responses in order to meet the ethical standards of cross-cultural studies. The questionnaire were digitized and each enumerator was provided with a tablet applying KoBoToolbox© which is a free open source tool for mobile data collection. The tablet approach was selected to minimize survey costs and material use (Leisher 2014). Before starting with the questionnaire, each enumerator explained about purpose, content and length of the questionnaire explicitly highlighting that the respondent can decline to respond to the questionnaire. The household head was addressed for the interview; in case of absence another full-aged household member was asked to respond to the questionnaire. Finally, 170 questionnaires were conducted (Figure 3).
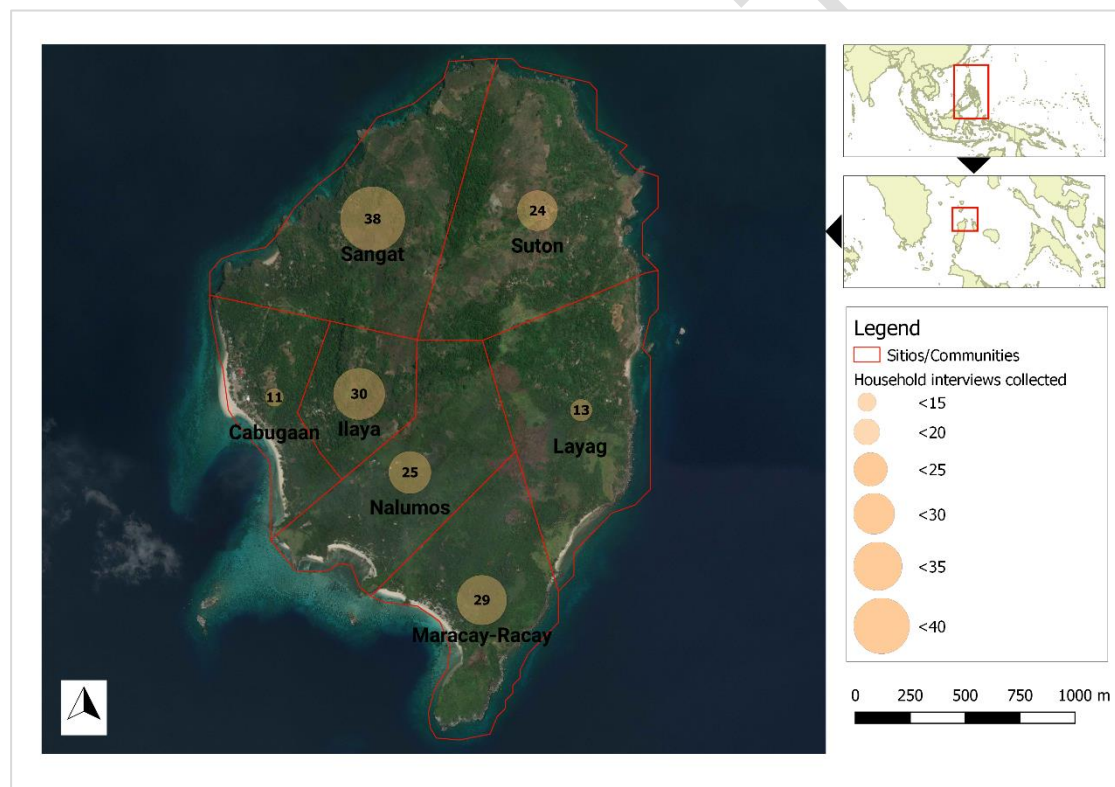

Figure 3: Overview map for case study area and questionnaires conducted per sitio/community (own illustration).

3.4 Statistical data analysis

In order to derive statistically valid conclusions based on the collected primary data, a range of tools and methods can be applied. Here, collected data was compiled into a single dataset and prepared for further processing. The statistical data analysis was carried out with the software SPSS©[3]. Minor data cleaning and the definition of variable types was necessary before statistical analysis were applied. Descriptive statistics served to gain a comprehensive overview of the current socio-economic situation as

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[3] IBM SPSS Statistics 25

well as the general usage of electricity on the case study island. Frequency distributions, cross tables, and mean/median values were used to describe the collected data. In order to analyze the data with regard to differences between poor and wealthy households, income groups were separated by the mean income per month. Households whose income was above the mean were classified as "above-average income households", households with an average monthly income below the mean were grouped as "below-average income households". On the basis of this classification, several hypotheses were tested by means of chi-square test, t-test and Mann-Whitney-U test based on the variable type and data characteristics focused on.

3.5 Limitations

Only a few households declined to respond to the questionnaire. In contrast to that, the arrival of the enumerator team were attracting a significant share of people of the visited communities. Thus, it was sometimes challenging to keep the privacy of interviews and it was necessary to request neighbors and passers-by to not disturb the interview. Additionally, neighbors of interviewed households offered or requested to hold an interview with them and it was necessary to explain that respondents are selected randomly. Another limitation from the approach is a bias in responses for several reasons: Although the enumerators were comprehensively trained in conducting the interviews, a bias based on the enumerator cannot be entirely ruled out. Another limitation could be the bias in responses of the interviews. Although enumerators made clear that, they are not representing a governmental unit or the electric cooperative respondents may have responded according to what they perceived as the favored answer. No disaggregated baseline data on the aspects analyzed are available for the case study. The impacts assessed here might thus not represent long lasting developments. An attempt was made to reconstruct the pre-electrification state and examine the changes by including respective questions in the household survey. For all quantitative data gathered in the household survey, e.g. monetary data about incomes and expenses, uncertainty regarding the reliability and accuracy must be taken into consideration. For most of the information no exact accounts are held by the households and statements are mostly based on respondent's estimates.

4   Results

In the results section we present the main findings from the household survey. We highlight socio-economic characteristics, electricity consumption patterns, electric appliances inventories and perceived changes of the hybrid system implementation for the surveyed households. We put a specific emphasize on differences between below and above-average income households to study the effect of sustainable energy supply on inequality and poverty alleviation.

4.1 Socio-economic characteristics of households

We interviewed 170 out of approximately 250 households for the survey.

Table 3 summarizes key characteristics of the households. The average age of respondents is 46.7 years and most are married (57%). On average, 3.6 persons live in one household which is below the national average of 4.4 persons (PSA 2017). With the 170 households a population of more than 602 individuals (39% younger than 18) is represented.

Table 3: Respondent and household characteristics

|		M or %	SD	Min	Max	N
HH head	Yes	59.4				101
	No	38.8				66
	N/A	1.8				3
Gender	Male	34.1				58
	Female	64.7				110
	N/A	1.2				2
Age		46.7	15.76	18	84	170
HH size		3.6	1.73	1	10	170
Male		1.9	1.11	0	5	170
Female		1.7	1.17	0	7	170
Children (<6)		0.4	0.63	0	3	170
Children (6-18)		1.0	1.27	0	9	170

Education

The highest educational degree per household is predominantly primary school (until grade six) followed by secondary school (until grade ten). Figure 4 provides an overview about the obtained educational degrees per household. The share of women with no degree and only attending primary school is higher compared to the highest degree of the household (compare Figure 5), which is predominantly the degree of the male HH head. HH income correlates with years of education for the highest degree in the household, with ($r = .382, p = .000, N = 162$) and medium effect size.

Figure 4: Highest education degree for the surveyed households in % (n=170).
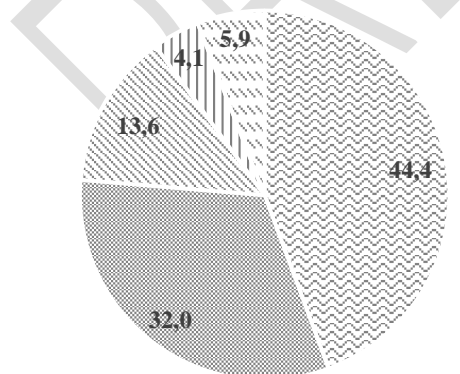
Primary school   Secondary school

College/University   No degree

Other

Figure 5: Highest education degree for female respondents in % (n=110).
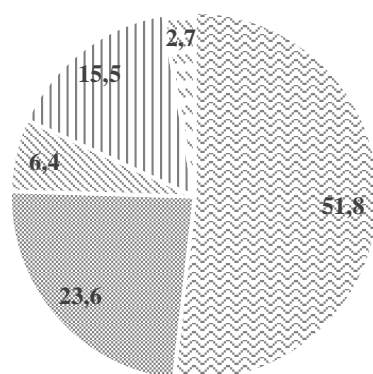
Primary school   Secondary school

College/University   No degree

Other

Income

The survey responses reveal that a large share of 33.5% of households is poor (monetary wise) with a weekly income lower than 500 PHP (9.6 USD)[4] compared to the World Bank's extreme poverty line of 1.9 USD/day (Warwick et al. 2018) (see Table 4). Most HHs have intermittent incomes and a weekly analysis reveals a strong impact: A week with a lower than average income increases the share of HHs with a very small income by + 30.5% to 64%. In contrast, a week with a higher than average income reduces the share of HHs with a very small income only by 10.8%. The observed intermittency is due to the dependency on fish catches and selling as main income source of most HHs.

Table 4: Income classes of surveyed households.

	Average weekly income		High income week		Low income week	
	Percent	Frequency	Percent	Frequency	Percent	Frequency
<500	33.5	54	22.7	37	64.0	105
<1,500	38.5	62	30.7	50	20.1	33
<3,000	16.1	26	27.6	45	6.7	11
>3,000	11.8	19	19.0	31	9.1	15
N/A		9		7		6

Analysis reveal that the mean income is 10,485 PHP (~200 USD) per household and month (Median = 4,850 PHP) with a standard deviation of 18,592 PHP. For further analysis we classify HHs with monthly income larger than 10,485 PHP as above-average

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[4] For PHP – USD conversion we apply a currency exchange rate as of 1st March 2018: With 1 USD = 52 PHP.

income HHs (N = 43) and HHs with monthly income lower than 10,485 PHP as below-average income HHs (N = 121). Mean HHs expenditures per month are 6,045 PHP (~116 USD) (median of 4,531 PHP) per month with a standard deviation of 5,748 PHP. The high standard deviation for both income and expenditures reflects the large heterogeneity among the households.

Figure 6 shows main sources of income and Figure 7 shows main purposes for expenditures for the surveyed HH. Many households have diversified their income sources and it is common that both, men and women participate in income generating activities with women often additionally taking care of the household chores. The main income source is fishing (47.7%). Followed by home business activities (17.6%), for which 21% of the households use electricity. The most common home business type is a small shop (sari-sari store), where foods, drinks and miscellaneous things are sold. Other home business types are boat manufacturing and boat renting, mat weaving, copra drying and occasional street food selling. Government employment (11.5%) is a secure income source with a fixed monthly salary. Other income sources (10.1%) include non-home businesses such as charcoal production and selling, carpentry, construction and some support from government programs. More than 43% of the HH receive remittances from relatives that live either abroad or in Manila which contribute to overall income by 5.8%. Even though marble processing is one of the main income sources in Romblon province, on Cobrador island only 3% of the income is generated by it. Farming mostly serves as means for self-subsistence rather than as a monetary income source. Services make up a minor share of income. There are no significant differences in income sources between income classes.
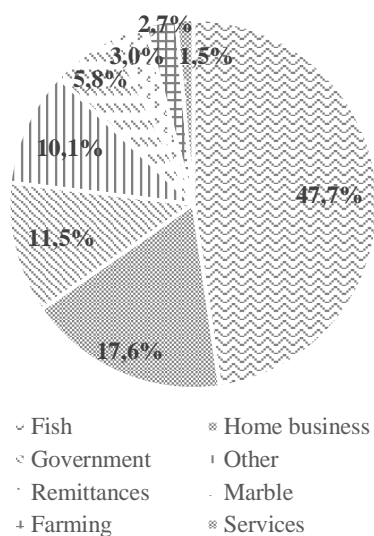

Fish	Home business
Government	Other
Remittances	Marble
Farming	Services

Food	Education
Domestic needs	Transport
Electricity	Other

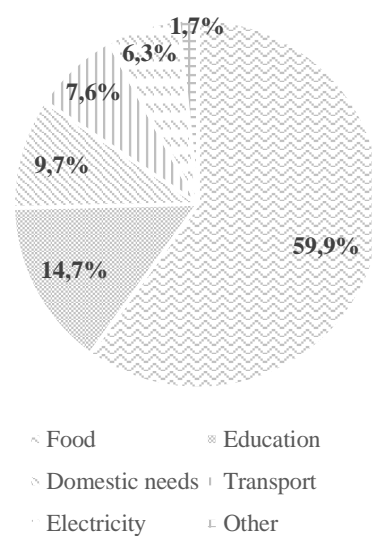*Figure 6: Monthly income sources of surveyed households (n=170).*

Figure 7: Monthly expenditure purposes of surveyed households (n=170).

The major share of the HH income is spent for food (59.9%). Households with schoolchildren spend a significant share of their income on education, with an overall

expenditure of 14.7%. This high expenditure is due to the absence of a secondary school on the island. Older children have to visit secondary school on Romblon Island, where they stay during the week in paid accommodation. Domestic needs comprise drinkable water, medicines, toiletries and baby foods (9.7%). Transportation expenditures are relatively high due to the remoteness of the island (7.6%). Electricity is a minor share of expenditures (6.3%) and other expenditures are spend for leisure activities such as liquor, cigarettes and gambling. Similar expenditure patterns have been reported for other regions of the Philippines (Agbola et al. 2017). A higher share of below-average income HH (44.3%) spend more than 75% of their total expenditures for food compared to above-average income HH (21.4%), a significant difference was identified through means of chi-square test ($\chi^2(3) = 14.49, p = .002, \varphi = .304, N = 157$). Besides that no other significant differences in expenditure patterns between income groups were identified. However, chi-square test revealed that a significant higher share of above-average income households (72.1%) can tap savings for daily expenditures or investments than below-average income HHs (48.8%), by applying chi-square test ($\chi^2(1) = 6.97, p = .008, \varphi = .206, N = 164$).

4.2 Electricity consumption patterns

Almost all HHs use electricity from the hybrid energy system as primary source of electricity as 97.7% of respondents stated to have access to electricity via the distribution grid. Other devices such as automotive batteries (7% of HHs), SHS (12% of HHs) and small diesel gensets (2% of HHs) are applied by few HHs and rather occasionally as a back-up source.

Electricity consumption

Prior to the implementation, a steep growth in electricity demand was expected once the electric service was made available 24 hours per day. Electricity for refrigeration and ice-making were among the identified uses e.g. in support of the island's fishing sector. Figure 8 shows the annual energy sales development. Energy sales increased from 2015 to 2016 through the implementation of the hybrid energy system which included the connection of additional HHs and the provision of 24 hours supply. Energy sales further increased through appliance uptake from 2016 to 2017 and averaged at a daily demand of 142 kWh/d. Figure 9 highlights the growth of the maximal peak demand on a daily basis. Compared to 2016 the maximal peak demand for 2017 and 2018 increased significantly during early afternoon and in the evening hours. The maximal daily energy demand observed for 2017 and 2018 exceed the average demand by far with 270 kWh (2017) and 279 kWh (2018). Such extreme demands exceed the capacity limits of the implemented system. We can conclude that the provision of 24 supply increased electricity consumption and that large differences in mean and maximal daily demands occur.
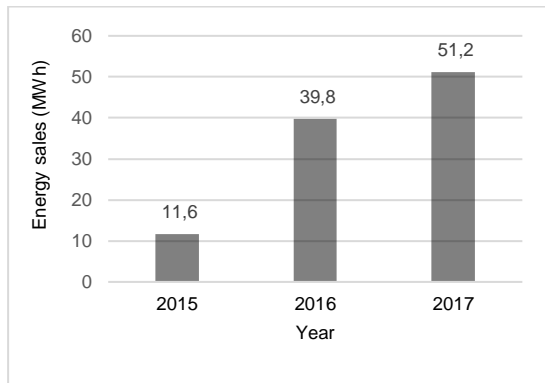
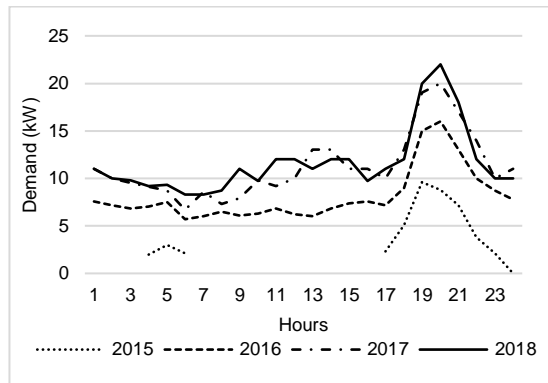Figure 8: Annual energy sales growth from 2015 - 2017 (MWh).

Figure 9: Annual maximal peak demand growth from 2015 - 2018 (kW).

HHs were asked for their monthly electricity expenditures, responses were converted into monthly electricity consumption based on the uniform tariff of 15 PHP/kWh. Table 5 gives the monthly electricity consumption for the two income groups.

Table 5. Distribution electricity consumption within below-average, above-average income groups, and total

| Income group | Electricity consumption | | | | |
	< 6 kWh	< 30 kWh	< 60 kWh	>60 kWh	N
Below-average	33.6%	60.2%	4.4%	1.8%	113
Above-average	4.8%	61.9%	19.0%	14.3%	42
Total	25.8%	60.6%	8.4%	5.2%	155

The majority of HHs have a relatively small monthly consumption of up to 33.3 kWh. According to the Multi-Tier Framework (MTF) for Measuring Energy Access (MTF) most of the HH can be classified into Tier 2 and Tier 3 (Bhatia & Angelou 2015). The cross table indicates a clear difference between income groups since a high share of below-average HHs (33.6%) uses only very little electricity per month. Chi-square test reveals a significance with medium effect size, $(\chi^2(3) = 27.0, p = .000, \varphi = .417, N = 155)$.

Electricity usage

Electricity is not intensively used for income related work and household chores as shown in Table 6. The prevailing income related activities are conducted mainly during daytime and do often not require electricity. However, a high share of children (51.4%) study after sunset and require electricity (98.6%) to do so. HHs of different income classes significantly differ in their statement towards household chores after sunsets, by means chi-square test $(\chi^2(1) = 5.59, p = .018, \varphi = .185, N = 164)$. Above-average income HH commonly employ domestic helpers (e.g. maids), which can explain the difference.

Table 6: Electricity usage after sunset.

	No	Yes	If yes, is electricity required?	N
Do household members do income-related work after sunset?	69.5%	30.5%	76.0%	164
Do household members do household chores after sunset?	65.9%	34.1%	94.6%	164
Do children of the household study after sunset?	48.6%	51.4%	98.6%	144

For a further understanding of the income's group capabilities to use electricity for income generation we explore for coherences between income groups, income generation through an own business (taking place at the HH – e.g. shop, handicraft, e.g.), and if electricity is required for such activity. Table 7 provides an overview on observed cell frequencies and expected cell frequencies.

Table 7: Cross table highlighting the income group's home business activities.

		I: Do you generate income through an own business in your household?		II: Do you use electricity in your household for income generation purposes?		III: Since when do you run the own business?		
		No	Yes	No	Yes	After 24 supply	Bef. 24 h supply	No answer
Below-average	Count	92	29	98	20	6	12	2
	Expected	86.1	34.9	91.6	26.4	8.9	16.2	1.5
Above-average	Count	24	18	27	16	6	10	0
	Expected	29.9	12.1	33.4	9.6	3.1	5.8	0.5
	Total	116	47	125	36	12	22	2

The differences between observed cell frequencies and expected cell frequencies indicate a possible coherence between income group and the three presented items. To prove the significance of the coherence we apply chi-square test for the item I and II (presented in Table 7) since the expected cell frequencies are met (0.0% < 5). The results show that income group significantly affects the likelihood of income-generation through an own (home) business, with $\chi^2(1) = 5.42, p = .02, \varphi = .0182$ (medium effect size). Above-average income groups are more likely using electricity for income generation in their HH, with $\chi^2(1) = 7.45, p = .006, \varphi = .215$ (medium effect size). Additionally, the results show for item III that HHs with above average income already operated more businesses before 24 hours supply and were able to set up more businesses, although no chi-square test was possible due to insufficient cell values.

Tariff and willingness to pay

Most HHs approve (59.4%) the current electricity price (15 PHP/kWh). A certain dissatisfaction originates from many villager's knowledge that the electricity price of the neighboring larger island is half the price of their electricity costs. Wealthier HH are less satisfied with the electricity price and occasionally demanded for an adjustment of the price to neighboring islands during the interviews (Figure 10), we reveal a significant difference between income groups by applying Fisher's exact test (=11.1, $p = .017, \varphi = .280, N = 157$). Respondents stated that they spent more (20%) and even a lot more (15.3%) money for electricity before the hybrid system intervention. Contrasted by 24.1% stating that they spent approximately the same amount for electricity or even less. Figure 11 shows differences between below- and above-average income groups: A higher share of wealthier HHs states to spend less money since the hybrid system intervention. Nevertheless, by applying chi-square test no significant difference was detected, although the p-value is close to the significance threshold value, $(\chi^2(4) = 9.19, p = .056, \varphi = .255, N = 141)$.
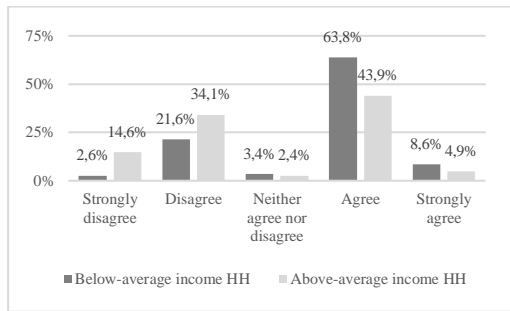
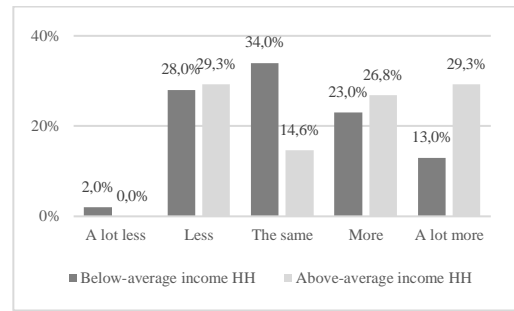Figure 10: HH responses for: "The price for electricity that we are currently paying is just fine".

Figure 11: HH responses for: "Did the HH pay more or less for electricity before the installation of the solar plant?

When asked if respondents would pay a higher price for electricity the slight majority agreed to be willing to pay double the price (54.4%), which quickly decreases to overwhelming disagreement when asked for triple or quadruple the price (Figure 12). Whereas respondents state that they can simply not afford 3 times or 4 times the electricity price, they would rather spend their income on other things when refusing to pay double the price. No correlation between income and willingness to pay for electricity supply was identified. The main problems with the electricity supply stated are power outages, damaged appliances through outages and high costs. Most of the HH need electricity during evening hours when light is required or for gathering at home for jointly watching TV (Figure 13). Both income groups show similar patterns when asked to for the most important period of the day where they need electricity.
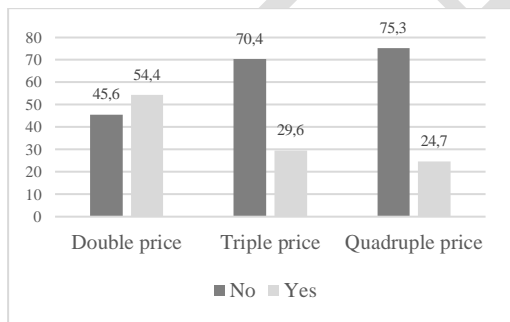

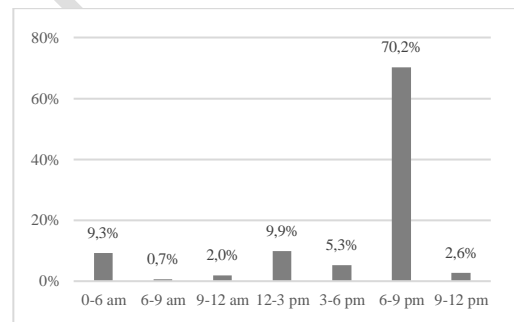Figure 12: Willingness to pay higher electricity costs.

Figure 13: Need for electricity during the day.

Overall, our results indicate that electricity is primarily used for entertainment and information gathering compared to income generation, whereas the availability of constant lighting allows for increased study hours for children. Nevertheless, the direct impact on the HHs depends on consumption of electricity and electric appliance inventory. Here we find that wealthier HHs consume considerably more electricity and at the same time profit more from the reduced electricity prices. Paradoxically, wealthier HH are less content with the applied electricity charge and both groups do not differ in their willingness to pay more for electricity. Besides the household level the hybrid renewable energy system improved access to health and education since the elementary school now provides computer classes (mandatory for the students of

grades four to six) and the services of the health center have improved through continuous access to electricity and new devices, which leads to more security and possibilities for curing and treating diseases. Since both school and health center are community entities these outcomes are accessible to all households. Additionally, the higher reliability of electricity supply allows replacing some rather health-affecting appliances such as kerosene lamps, and more sensitive electric appliances, e.g. for entertainment, such as sound systems or multimedia devices, can be powered with a reduced risk of damage through power outages. For lighting purposes, a larger variety of sources besides electricity is used, e.g. candles (17% of HH), kerosene lamps (18% of HH) and rechargeable flashlights (70% of HH), which are important appliances for night fishing activities. The findings indicate that the households favor the electricity from the mini-grid over other and formerly used solutions.

4.3 Electric appliances

We asked the HHs for their electric appliance inventory to study the use of certain devices. Electric lighting is the main electricity appliance used in almost all surveyed households. 92% of the HHs use electricity for lighting, on average a typical HH possess 2.5 light bulbs. A typical appliance inventory consists additionally of cell & smart phones (88%), television (73%) and fan (70%). Followed by other entertainment appliances such as DVD players, sound systems and radios. Household appliances and IT appliances are less frequent. Wealthier households own generally more (Fisher's exact test: $p = .000, \varphi = .333, N = 164$) and more energy intensive appliances. Results show a significance between income class and ownership of fridges by applying chi-square test ($\chi^2(1) = 13.43, p = .000, \varphi = .286, N = 164$), ownership of washing machines by applying Fisher's exact test ($p = .001, \varphi = .282, N = 164$) and ownership of water heaters by applying Fisher's exact test ($p = .001, \varphi = .282, N = 164$). Mostly firewood, charcoal and in some instances LPG stoves are used for cooking, but no electrical ovens are owned or used. Only one household owns an AC. Figure 14 shows the quantity of HHs with certain appliances and the quantity of appliances purchased after the increase of electric service hours. The data indicates that HHs purchased some appliance types more often since the provision of 24 hours power supply. This is especially true for appliances outside the light, TV, fan, cell phone standard set. Appliances with highest growth rates are water heaters (86%), refrigerators (76%) and sound systems (73%), which are appliances with high or constant power demand or vulnerable to power outages. Increased appliance purchases and more frequent appliance usage contributed to the rapid demand growth in addition to new connections.
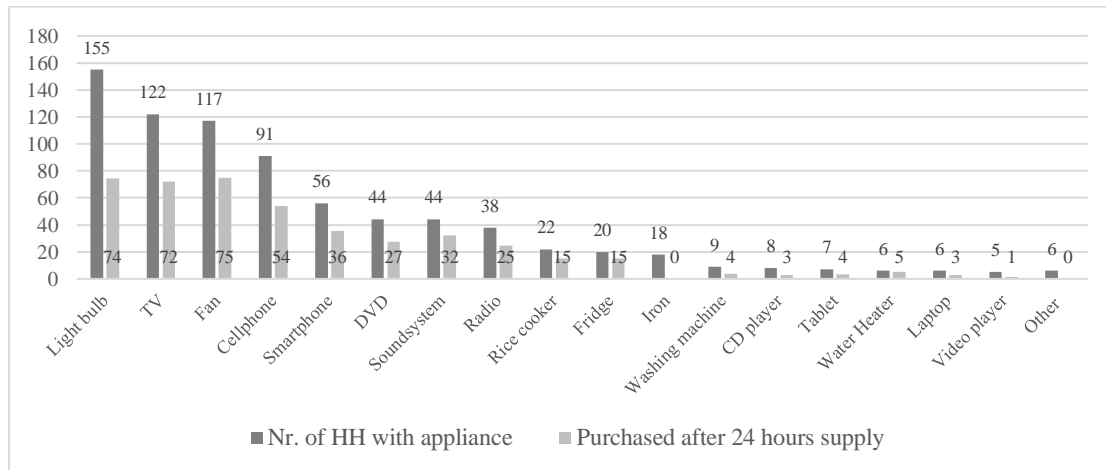
Figure 14: Electric appliance inventory and purchases.

We asked for planned appliance purchases to investigate if the power demand is likely to further increase. However, the larger share of HHs (57%) stated not to plan to purchase any appliances in the next two years. This indicates that first demand for essential electric appliances is saturated. Nevertheless, a number of HHs still plans to purchase energy-intensive appliances like fridges (13%) and washing machines (4%) which can significantly add to the baseload and peak load in the hybrid energy system. Figure 15 provides an overview on planned electric appliance purchases.
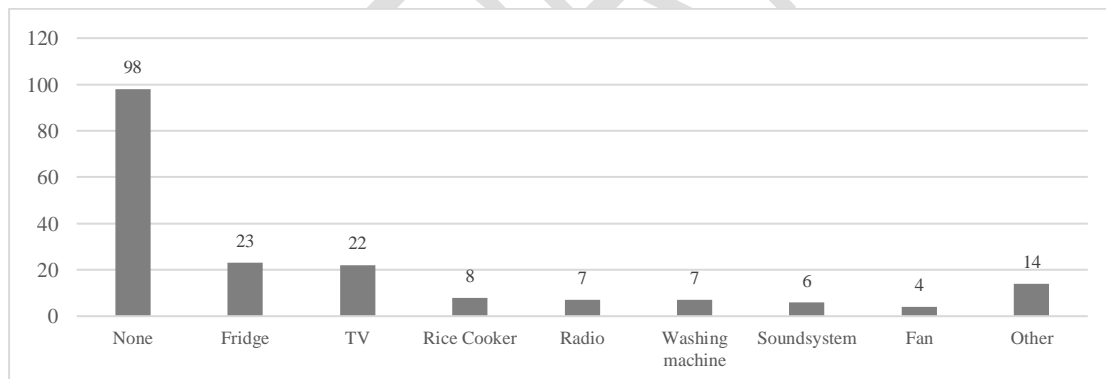

Figure 15: Planned purchases in the next two years.

4.4 Perceived impact of SDG#7 intervention

The implementation of the Cobrador Island Solar – Diesel project clearly complies with the SDG #7 to provide reliable, affordable and sustainable energy access. This was achieved through the implementation of solar power combined with battery storage leading to lower electricity charges, 24 hour supply and a high renewable energy share. However, with regard to energy access it needs to be underlined that the improvements address electricity access and no other forms of necessary energy access (e.g. energy for cooking).

Other SDGs have been addressed through the intervention by realizing reliable electricity supply in the health station, school and power devices for sterilizing water: This includes

SDG#3 "Good health and well-being", SDG#4 "Quality education" and SDG#6 "Clean water and sanitation". Due to absence of socio-economic data characterizing the situation prior to the installation of the hybrid power plant and availability of 24 hours power supply, we asked for the respondents perceived changes after the hybrid energy system intervention for the six key target fields of safety situation, education, information, communication, income and health services. Respondents were asked to state to agree or disagree to the statements, using a 5-point likert scale (strongly disagree (1), disagree (2), neither disagree nor agree (3), agree (4), strongly agree (5)). Table 8 provides an overview about the perceived changes. The objective is to identify whether any significant differences in below-average and above-average income classes in the perception of the aforementioned topic areas exist.

Table 8. Subjective perception of changes after 24 hours electricity supply.

Statement	Income group	Strongly disagree (%)	Disagree (%)	Neither/ Nor (%)	Agree (%)	Strongly agree (%)	N
The safety situation has improved.	Below-average	1.7%	12.1%	7.8%	60.3%	18.1%	116
	Above-average	2.3%	18.6%	16.3%	46.5%	16.3%	43
	Total	1,9%	13,8%	10,1%	56,6%	17,6%	159
Access to education and quality of education has improved.	Below-average	0%	4.4%	17.6%	58.2%	19.8%	91
	Above-average	0%	13.5%	24.3%	35.1%	27.0%	37
	Total	0%	7.0%	19.5%	51.6%	21.9%	128
Access to critical information has improved.	Below-average	1.7%	9.4%	6.0%	54.7%	28.2%	117
	Above-average	0.0%	14.0%	4.7%	46.5%	34.9%	43
	Total	1.3%	10.6%	5.6%	52.5%	30.0%	160
Access to communication means has improved.	Below-average	1.7%	6.0%	2.6%	57.3%	32.5%	117
	Above-average	0.0%	7.0%	7.0%	51.2%	34.9%	43
	Total	1.3%	6.3%	3.8%	55.6%	33.1%	160
The income situation has improved and/or increased.	Below-average	10.3%	35.0%	20.5%	26.5%	7.7%	117
	Above-average	4.7%	25.6%	16.3%	41.9%	11.6%	43
	Total	8.8%	32.5%	19.4%	30.6%	8.8%	160
Access to health services and quality of health service has improved.	Below-average	0.9%	19.0%	11.2%	54.3%	14.7%	116
	Above-average	2.3%	23.3%	9.3%	53.5%	11.6%	43
	Total	1.3%	20.1%	10.7%	54.1%	13.8%	159

The majority of HH respondents agrees or strongly agrees that the safety situation (>74%), access to education (>73%), information (>82%), communication (>89%) and health services (68%) has improved or increased. For the income situation, we find a less clear picture with 41% disagreement and 39% agreement. When taking into account the income groups we find only few noteworthy differences: A higher share of below-average income HHs (+16%) perceives the safety situation as improved and an additional 16% of below-average HHs perceived the education situation as improved compared to above-average income HH. However, the perception of income groups towards the perception of the income situation differs distinctively: More below-average income households (+15%) overall disagree that the HHs income increased after the intervention whereas more above-average income HH (+19%) overall agree that the HHs income has increased. We applied further tests to explore if the differences between income groups are statistically significant. Since the considered six dependent variables are ordinal scaled and not normally distributed, the Mann-Whitney U test is applied. Table 9 provides the results and reveals that below-average households (m = 3) perceive

significant less improved or increased income opportunities compared to above-average income groups (m = 4), with z=2.143, p=0.032, and medium effect size r = 0.169.

Table 9. Mann-Whitney U test results for below average and above average income households.

	The safety situation has improved.	Access to education and quality of education has improved.	Access to critical information has improved.	Access to communication means has improved.	The income situation has improved and/or increased.	Access to health services and quality of health service has improved.
Mann-Whitney U	2155.000	1542.500	2405.500	2512.000	1979.000	2328.500
Wilcoxon W	3101.000	2245.500	9308.500	9415.000	8882.000	3274.500
Z	-1.461	-0.806	-0.466	-0.015	**-2.143**	-0.705
Asymp. Sig. (2-tailed)	0.144	0.420	0.642	0.988	**0.032**	0.481

Our findings highlight that the implemented technology enables the realization of SDG#7 in the given framework conditions. Further SDGs are positively addressed through, in particular SDG#3, SDG#4 and SDG#6. However, wealthier HHs profit more from achieving SDG#7 than less wealthier ones as no impact on SDG#1 and SDG#10 is achieved. This discrepancy of being able to profit from more reliable, affordable and sustainable energy supply even bears the threat to further increase inequalities.

5 Discussion

Our findings indicate that upgrading the former diesel-based energy system to a hybrid energy system using solar power and battery storage clearly improved the livelihood and wellbeing of the local community. This was achieved by improving sustainability (increased RE share), reliability (establishing 24 hours supply) and affordability (tariff reduction). However, our findings reveal that HHs do not equally profit from the intervention. In the following we are highlighting the implications for energy access planning, implications for addressing other SDGs, implications for addressing poverty and inequalities and contextualize the findings of our case study.

5.1 Implications for energy access planning and SDG#7

The new hybrid system is able to fully supply the loads on Cobrador Island. Universal access to electricity has now been achieved on the island. Anyhow, we find that a large number of HHs use small amounts of electricity compared to few HHs with a larger consumption. This becomes obvious when comparing the identified consumption levels with the Multi-Tier Framework (MTF) for Measuring Energy Access (Bhatia & Angelou 2015). The majority of HHs do not exceed tier 2 or 3 of the MTF characterized by a monthly consumption of <6 kWh and <30 kWh respectively (compare section 4.2). The most common appliances (light bulb, fan, television, phone) owned by HHs of this case study reflect the typical appliance inventory for tier 2 HHs (compare section 0). This is an important finding for planning energy access projects. Tier 2 and 3 can most often be supplied through SHS in the economically most effective way. It also shows

that an oversizing of supply systems would take place when assuming a Tier 5 level for all HHs. SHS are an appropriate technology to deliver electricity access at least for tier 1 and 2 (Narayan et al. 2019). Whereas tier 3 can be addressed with SHS as well, tier 4 and 5 are currently out of reach of SHS products. Thus, depending on the local situation, it might make sense to not connect all HHs to the island's grid, but supply some of them with SHS. This would reduce the costs of supply per customer and ultimately increase the affordability of electricity.

One could criticize the MTF for its inability to accurately access the demand for vital services required for HHs' wellbeing (Groh et al. 2016) and given its global scope it is inaccurate to national conditions (Pelz et al. 2018), but due to our locally collected data it can be a good guidance for energy access planning in the Philippines. However, addressing the electricity demand of the low income HHs with SHS would decrease the customer base for the hybrid system and might reduce its future economic attractiveness. Additionally, electrification with SHS is less capable of powering productive loads (Bhattacharyya & Palit 2014). A more accurate assessment of electricity demands and planning of the energy system can avoid oversizing and suitable approaches have been presented in the scientific literature (Riva et al. 2019). Two main implications can be derived for future energy access planning for similar islands: First, it is necessary to decide if all HHs shall be connected to the hybrid system based on detailed electricity demand assessment. Deploying SHS to far away and scattered HHs with low present and low projected electricity demands can lower the overall costs while addressing the surveyed electricity demands. HHs could be connected to the hybrid energy system in a later step when an increased demand economically justifies a connection. Above all, it is important to consider whether two different electrification schemes would lead to increased energy injustice as demonstrated for other case studies (Monyei et al. 2018). Second, a large share of the investment was spent for the battery storage system. This seems appropriate given the remoteness of the case study island and the objectives of a high RE share allowing for sustainable energy supply. However, a smaller sized battery storage system in combination with deploying SHS to the most remote HH could increase the replicability of the implemented technology solution through decreasing necessary investments. Battery storage costs are projected to decrease significantly which could enhance the replicability of the implemented energy system (Kittner et al. 2017).

5.2 Implications for addressing other Sustainable Development Goals

HHs use electricity mainly for leisure and entertainment (TV, DVD, cell phone, sound system) and well-being (light bulb, fan) as indicated through the analysis of the HHs' appliance inventory (see Figure 14) which is in accordance with other findings for the Philippines (Hong & Abe 2012). The majority of HHs is satisfied with the electricity service/costs (compare Figure 10) and consider supply safety and reliability as most important, similar findings have been found for case studies in South Asia (Sharma & Chan 2016). Further SDGs have been addressed through implementing SDG#7: As an example SDG#3 "Good health and well-being" by realizing more reliable electricity supply

in the health station, SDG#4 "Quality education" by using appliances such as computers and fans in the school and by using electric lighting for studying at home, and SDG#6 "Clean water and sanitation" by powering devices for sterilizing water. We focus with this case study on electricity supply but recommend that future studies and interventions targeting SDG#7 have to address the energy demand for cooking. For the case study, observations reveal that cooking is largely based on fuelwood and in few cases HHs use LPG stoves. Thereby the potential of clean energy supply for addressing SDG#3 "Good health and wellbeing", SDG#5 "Gender equality" and SDG#15 "Life on land" is not fully exploited as cooking based on fuelwood negatively affect these three SDGs (Das et al. 2017). Recent studies have revealed that innovative electric cooking technologies can be beneficially incorporated in hybrid energy systems (Lombardi et al. 2019).

5.3 Implications for addressing poverty and inequality

Our results show that the HHs perceive an overall positive impact on their livelihoods. However, the perceived impact on income generation is divided among the HH wealth groups. Here, we identify that the majority of above-average income HHs perceive a positive impact on income generation whereas a high share of below-average HHs perceives no impact on income generation (compare section 4.4). It can be concluded that there is so far no significant increase in income generating activities through electricity on Cobrador Island and that few households have opened up new businesses. Other case studies have found similar results for India (Khandker et al. 2012), Brazil (Obermaier et al. 2012) and Rwanda (Lenz et al. 2017). There are however significant differences between wealthy and poor households in terms of electricity usage. Wealthier households have a higher ability to save money for major investments and do not necessarily have to take up a loan. As a consequence they own a higher number of electronic appliances. The results show that wealthier households use electricity more frequently for income generating activities and have opened more businesses than poorer households.

We propose that projects addressing SDG#7 must incorporate specific poverty reducing measures coupled with the implementation of more reliable, affordable and sustainable electricity. Such measures could include to offer micro-finance products (MFP) for appliance purchases, to implement a cross-subsidy scheme within the community or initiating cooperative-based companies. MFP could enable below-average income households to profit from the improved electricity supply through small credits for important appliances, such as refrigerators or appliances allowing for productive use (Gutiérrez-Nieto & Serrano-Cinca 2019). However, an analysis of potential markets and demands for the producible products needs to be conducted first. It has been shown that a slow effect on income generation can be based on the lack of demand and markets (Lenz et al. 2017). A cross-subsidy scheme within the community could enable a higher usage of electricity for below-average HHs subsidized by above-average income HHs. Most probably the social acceptability of such an approach would be a challenge. Nevertheless, for hybridization projects on other islands the communities

could be consulted if they would agree to a cross-subsidy scheme if this would increase the likelihood of project realization. Finally, strengthening cooperative based business models could contribute to poverty alleviation and could even contribute to balance power demands in the system. As an example, a cooperative small ice factory or cold storage could be implemented through selling out cooperative shares. Ice for cooling catches and food is an important product. If that could be offered in an affordable manner to cooperative shareholders it would reduce expenditures, reduce the demand for individual refrigerators in the HHs and could even serve for balancing the power grid. Future research should focus on incorporating one of the aforementioned measure into the planning of rural electrification and SDG#7 measures.

5.4 Contextualization of findings

Case study research as applied here allows for an in-depth examination of a particular subject (e.g. the impact of renewable energy and addressing the SDGs on local communities) but lacks breadth and external validity (Sovacool et al. 2018). Nevertheless, contextualization provides some crucial findings for further energy access planning in insular framework conditions. With a population of approx. 1,000, fishing as main source of income, an accessibility of 45 -60 minutes by boat and a formerly unreliable power supply our case study is representative for a large number of similar islands in the Philippines (Bertheau & Blechinger 2018). The specific number is difficult to access, however a recent geospatial analysis estimated a number of 2,200 islands with a population of 1.49 million without any known electricity supply (Bokharee et al. 2018). Fishing as main source of income was identified for other cases studies in the Philippines (Hong & Abe 2013; Hong & Abe 2012) and islands with a population of up to 1,000 have been found as the largest group among surveyed not electrified Philippine islands (Meschede 2018). The mean income (10 thousand PHP) and mean expenditure (6 thousand PHP) are lower than the national monthly mean HH income of 22 thousand PHP and mean expenditure of 18 thousand PHP (PSA 2017). Reflecting that the case study island represents typical islands deprived of development and growth. With 33.5% the share of HHs living below the poverty line is higher than the national average of 21.6% (PSA 2017). Hence our findings can be extrapolated for other similar islands and serve for deriving policy recommendations. Furthermore, a large number of small islands with characteristics similar to our case study can be found outside the Philippines, in particular in Indonesia, Malaysia and Pacific small island states (Blechinger et al. 2016).

6   Conclusion and recommendations

Achieving the Sustainable Development Goals by 2030 implies to provide reliable, affordable and sustainable access to energy to far flung places like small islands of the Philippines. Policies need to stimulate the deployment of those technologies capable to address the SDGs. With this study we are focusing on hybrid renewable energy systems as technology for delivering the SDG#7 and inform policy-makers about its prospects

for contributing to further SDGs. We applied a quantitative survey to assess the impact of the provision of sustainable, reliable and affordable renewable based energy access on local development and on the SDGs for the case study island of Cobrador. Our findings underline that hybrid renewable energy systems are an appropriate solution to address SDG#7 in archipelagos and clearly improves the livelihoods of HHs. However the HH's capability to take advantage of the improved energy access largely depends on their level of income and wealth.

Finally, we can address the research questions as outlined in the introduction section. Electricity consumption patterns increase with the provision of continuous electricity supply. Daily consumption and peak demands increased most rapidly in the first year after the implementation of the hybrid renewable energy system. Electricity is mostly used for entertaining purposes as television and sound systems belong to the most frequently owned electronic appliances on the island besides light bulbs, fans and cell phones. However, most HHs consume only small amounts of electricity and would be described by tier 2 or tier 3 of the MTF. We find a positive impact on SDG#3, SDG#4 and SDG#6, as all households, regardless of their income profit from improved access to education and health services. However, we find mainly the wealthier households' using electricity for income generation purposes. We conclude that SDG#1 and SDG#10 are currently insufficiently addressed and recognize a threat of further increasing inequalities in the local communities through providing access to electricity. Future projects implementing SDG#7 in the Philippines and similar regions need to take this challenge into account.

In conclusion, future technology policies need to address the following issues: Effective incentives for renewable energy deployment, appropriate energy access planning and supporting measures for addressing poverty and inequality.

This study finds the applied renewable energy technology as appropriate for achieving SDG#7. Nevertheless, the project was only realizable through grant funding which questions the replicability of the project. Still the project showcased that RE are more cost-effective compared to the common application of diesel generators as the reduction of electricity charges was possible. High investment for RE remains a main challenge for wider deployment in the Philippines. Affordable loans and grants are necessary to overcome this challenge. Product innovation especially in the field of battery storage should be carefully observed by policy makers since battery storage cost reduction holds a huge potential for decreasing investment costs for hybrid energy systems. Finally, fiscal and non-fiscal incentives need to be tailored and made accessible to the beneficiaries making the most use of it. In the case study the local electric cooperative proofed to be capable and eager to improve the energy access situation for their customers. Given the disappointment about private sector involvement in delivering access to energy in the Philippines, electric cooperatives could evolve as more effective recipients of incentives for RE deployment. More appropriate and evidence based energy access planning has to be enhanced for all involved stakeholders. For the case study it was found that most HHs need electricity for basic

appliances. Future planning should discuss if such HHs should be provided with access to energy through SHS and if stepwise connection of HH based on the projected electricity demand could increase the feasibility and replicability of hybrid renewable energy systems. Finally, supplementary measures are necessary to prevent that proving access to energy leads to increased inequalities in terms of income and opportunities in small island communities. As an example the promotion of electricity use in schools, health stations and barangay halls increases the impacts on SDG#3 and SDG#4. Incentivizing the purchase of clean cooking, water sanitation and food preservation products can address further SDGs. Stimulating productive use can mitigate the increase of inequalities but has to be carefully designed according to local conditions and accessible markets.

Furthermore, this case study finds important aspects for future interdisciplinary research focusing both on technical, operational and socio-economic aspects. Energy and economic related research should focus on tools for cost-effective designing of hybrid energy systems incorporating the socio-economic framework conditions. Product innovation like containerized energy storage solution bear the potential of significantly decreasing cost in remote areas as the studied one. Focusing on cooperative anchor clients and productive use such as cold storage application holds the potential for decreasing costs while delivering added value to beneficiaries. Finally, community cross subsidy schemes should be studied by means of social sciences methods, interesting aspects would be if such schemes could be acceptable in small communities.

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7 References

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