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A feasibility study of HiLight as an energy solution for communities in the interior of the State of Amazonas

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Abstract

The project was conducted in the State of Amazonas, Brazil, during a period of eight weeks. The goal was to investigate if the HiLight, a solar powered charger and lantern, could be a feasible energy solution for the isolated communities in the interior of the State of Amazonas.

A pre-study was conducted at the Department of Engineering Sciences, Solid State Electronics, Uppsala University, with supervision of Professor Marika Edoff. The goal of the pre-study was to understand the performance of the HiLight and enabeling calculations of how long time it would take to charge the HiLight in the field.

The field work was conducted in three communities: Caioé, Nova Esperança and Terra Preta, all situated outside of the city of Manaus in the State of Amazonas. The method consisted mainly of interviews with the inhabitants of the communities to investigate their current energy situation. Key people, such as leaders and health agents, were asked to evaluate the HiLight during 12 to 21 days. The results were evaluated from an Environmental Impact Assessment perspective.

The results show that the HiLight can be environmentaly, socially and economically beneficial for the communities. It replaced diesel lanterns, and batteries for flashlights, which results in lower environmental impacts from the nonexisting waste management of batteries, and less indoor pollution from the diesel lanterns.

One of the conclusions is that the HiLight cannot replace diesel generators, gasoline generators, or stationary solar panels. There is a need in the communities for larger electrical appliances such as televisions, refrigirators, and freezers which the energy output of the HiLight is too small for. The HiLight will be beneficial, especially combined with a battery charger, for the communities until they get a continuous energy supply that they are in the plan to recieve before the year of 2023.

Keywords

Solar power, Amazonas, Environmental Impact Assessment, solar charger, solar lantern

Acknowledgements

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This project would not have been possible without the help, time and evaluation made by the inhabitants of Caioé, Nova Esperança and Terra Preta. We will never forget you.

It has been a great learning experience for two future engineers to work with a physical product, for this we would like to thank the company HiNation. We would also like to thank you, Linda and Kristina, for introducing us to CECLIMA and helping out when forming the project.

Deborah and Georgia, our Brazilian mother and sister, thank you for everything.

Last, but not least, we would like to thank our friends and family for their support throughout the project but also for contributing to the fundraiser that enabled us to bring HiLights to leave behind to the people in the communities.

To get a better understanding of the project and the people that contributed to it, please visit our blog http://2amazonsintheamazon.wordpress.com.

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Abbreviations

Amazonas- the State of Amazonas

CECLIMA - State Center of Climate Change

EIA- Environmental Impact Assessment

Eletrobrás- Eletrobrás Amazonas Energia, the electricity utilization company in the state

FAS- Fundação Amazonas Sustentável

PV module- Photovoltaic module

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1 Introduction

The State of Amazonas spans over an area of 1.6 million km^2, 3.5 times the size of Sweden, and is the home to 3.6 million people. The capital of the state is Manaus, and it has 1.9 million inhabitants (Nationalencyklopedin 2013). The state lies within the tropical climate zone and the human settlements in the interior[1] are mostly along the river systems.

The State of Amazonas can easily be confused with the Amazon region. Figure 1 shows the two geographical areas in one map. The light green area represents the Amazon region. It spans over nine countries and has an area of 6 million km^2 (Hubendick, Jakobsson 2013). The Brazilian State of Amazonas is represented in the lime green area. A third geographical area that should be pointed out is the Brazilian Amazon. That is the area of the Amazon region that lies within the Brazilian border. This area should also not be mistaken for the State of Amazonas.

Figure 1. Map of the State of Amazonas, and the Amazon region. Arranged together with Bárbara Nascimento, CECLIMA, 2013-09-17.

[1] Interior is a common used word in the state, defined as the state area outside of Manaus.

This study focuses on the energy system in the State of Amazonas, from now on denoted as “Amazonas”. With a large area, rough topography, and many small communities spread out through the state, the construction of transmission lines is problematic and expensive (Ministry of Mines and Energy 2010, p. 124). Therefore the energy supply in the interior of Amazonas mostly consists of isolated thermoelectric diesel power plants.

Figure 2 below shows a map of Amazonas, whereas Table 1 complements the figure by showing the current installed power in the state. Manaus has until this year been an isolated system, relying mostly on thermoelectric power plants with oil and diesel as energy sources. At the 8th of July 2013, Manaus was connected to the international electricity grid by a transmission line from Tucuruí (Governo do Estado do Amazonas 2013, p.1). In the end of 2009 a gas pipeline was finished from the inland natural gas resource in Urucu to Manaus. With this pipeline, natural gas was introduced to the energy mix of Manaus (Cigás 2013).

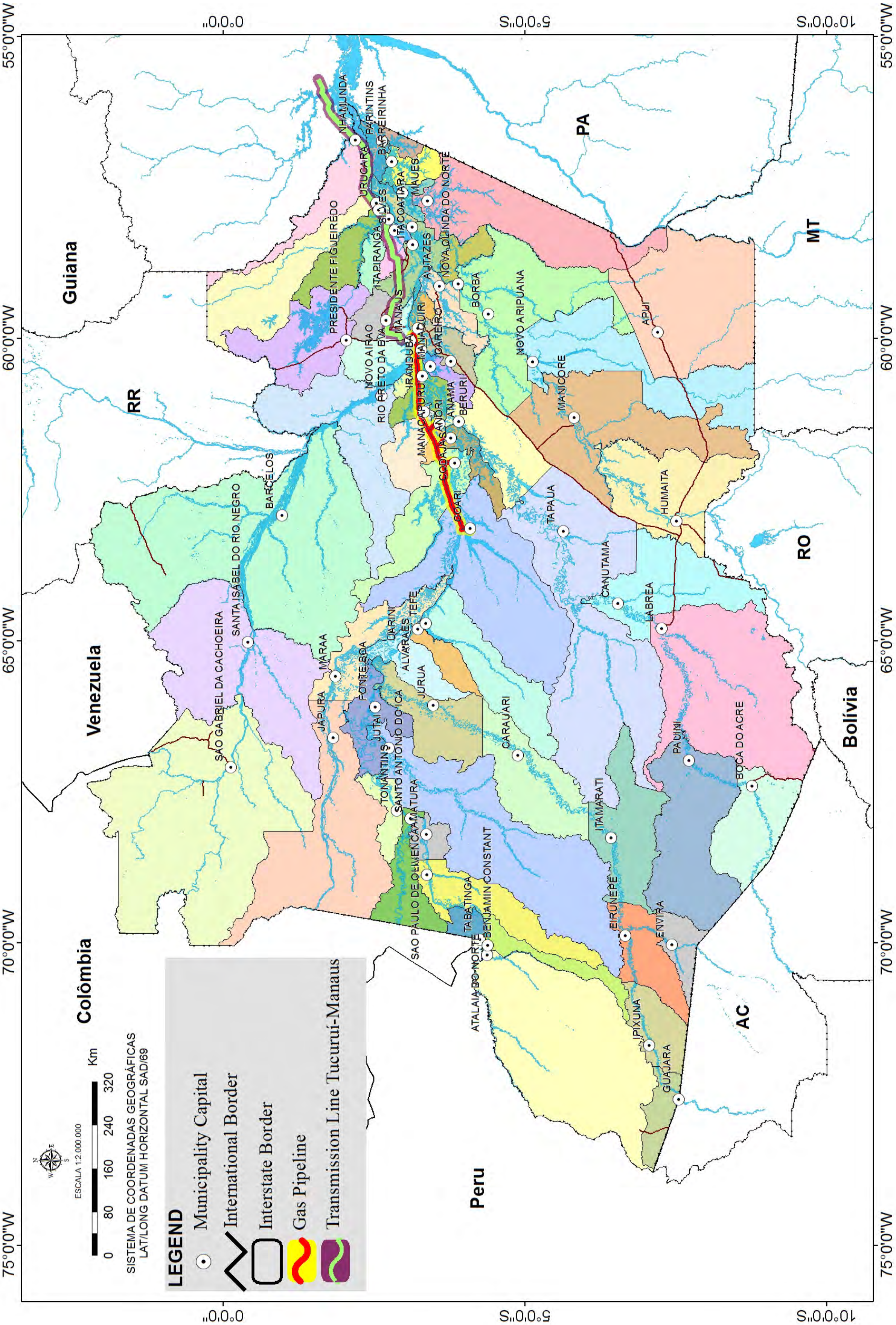

Figure 2. Map of the State of Amazonas, the Capital of each Municipality, the gas pipeline and the transmission line to the international grid. Arranged together with Bárbara Nascimento, CECLIMA, 2013-10-10.

Table 1. Installed power in Amazonas. (ANEEL 2013a; Instituto Brasileiro de Geografia e Estatística 2013). Note: 1. Transmission line from the international electricity grid (Tucuruí-Manaus). 2. Hydropower from Balbina hydropower plant. 3. Guajará is attended by the State of Acre (Eletroacre). 4. Iranduba is attended by a transmission line from Manaus 5. Manacapuru is attended by a transmission line from Manaus. 6. Presidente Figueiredo is attended by a transmission line from Manaus.

Municipality	Population (2010)	Installed power [MW] (2012)	Energy source	Distance from Municipality Capital to Manaus	
				Distance by boat [km]	Distance in straight line [km]
Manaus (Capital of the State of Amazonas)	1 802 014	2500.00	Int. TL Tucuruí[1]	0	0
		571.00	Natural gas		
		503.20	Diesel		
		250.00	Hydropower[2]		
Alvarães	14 088	2.24	Diesel	644	531
Amaturá	9 467	1.24	Diesel	1 251	909
Anamã	10 214	3.3	Natural gas	190	165
Anori	16 317	3.3	Natural gas	234	195
Apuí	18 007	5.1	Diesel	772	453
Atalaia do Norte	15 153	2.535	Diesel	1 623	1 138
Autazes	32 135	7.172	Diesel	324	113
Barcelos	25 718	3.15	Diesel	454	399
Barreirinha	27 355	4.344	Diesel	552	331
Benjamin Constant	33 411	5.67	Diesel	1 575	1 121
Beruri	15 486	3.286	Diesel	231	173
Boa Vista do Ramos	14 979	2.06	Diesel	623	271
Boca do Acre	30 632	11.3	Diesel	2 322	1 028
Borba	34 961	6.85	Diesel	322	151
Caapiranga	10 975	2.2	Natural gas	170	134
Canutama	12 738	2.17	Diesel	1 274	619
Carauari	25 774	5.5	Diesel	1 411	788
Careiro	32 734	6.0	Diesel	168	88
Careiro da Várzea	23 930	2.55	Diesel	32	25
Coari	75 965	22.26	Diesel	421	363
Codajás	23 206	5.46	Natural gas	285	240
Eirunepé	30 665	6.87	Diesel	2 417	1 160
Envira	16 338	3.61	Diesel	2 621	1 208
Fonte Boa	22 817	3.55	Diesel	880	678
Guajará[3]	13 974	-	-	3 171	1 476
Humaitá	44 227	13.03	Diesel	965	590
Ipixuna	22 254	2.67	Diesel	2 936	1 367
Iranduba[4]	40 781	-	-	39	27
Itacoatiara	86 839	31.3	Diesel	211	176
		9.0	Biomass		
Itamarati	8 038	2.58	Diesel	1 930	985
Itapiranga	8 211	3.07	Diesel	284	227
Japurá	7 326	2.55	Diesel	919	744
Juruá	10 802	2.17	Diesel	994	674
Jutaí	17 992	3.28	Diesel	1 001	751
Lábrea	37 701	6.3	Diesel	1 495	702
Manacapuru[5]	85 141	-	-	86	68
Manaquiri	22 801	3.08	Diesel	79	60
Manicoré	47 017	6.45	Diesel	616	332
Maraã	17 528	2.05	Diesel	796	634
Maués	52 236	11.67	Diesel	648	276
Nhamundá	18 278	2.8	Diesel	660	383
Nova Olinda do Norte	30 696	6.16	Diesel	236	135
Novo Airão	14 723	4.08	Diesel	125	115
Novo Aripuanã	21 451	4.67	Diesel	469	227
Parintins	102 033	29.55	Diesel	475	369
Pauini	18 166	3.2	Diesel	2 068	923
Presidente Figueiredo[6]	27 175	-	-	-	117
Rio Preto da Eva	25 719	3.2	Diesel	-	57
Santa Isabel do Rio Negro	18 146	1.87	Diesel	737	630
Santo Antônio do Içá	24 481	3.72	Diesel	1 195	880
São Gabriel da Cachoeira	37 896	7.97	Diesel	1 001	852
São Paulo de Olivença	31 422	3.89	Diesel	1 345	985
São Sebastião do Uatumã	10 705	2.33	Diesel	329	247
Silves	8 444	2.7	Diesel	381	204
Tabatinga	52 272	22.7	Diesel	1 573	1 108
Tapauá	19 077	3.78	Diesel	769	449
Tefé	61 453	18.47	Diesel	631	523
Tonantins	17 079	2.34	Diesel	1 164	865
Uarini	11 891	2.7	Diesel	687	565
Urucará	17 094	4.5	Diesel	344	261
Urucurituba	17 837	3.609	Diesel	248	208

Electric energy in the interior is provided by 106 power plants. The capital of each municipality has one power plant (note that Guajará is attended by the State of Acre), which makes it a total of 60 power plants. There are also 46 extra power plants spread out in the interior, which are included in the numbers in Table 1. In addition to the 106 power plants covered in Table 1, Eletrobrás also runs 12 pilot projects with 100 % solar power with a range of installed power of 8 to 18 kW[2].

The distribution of the power plants covered in Table 1 can be seen in Figure 3. Note the large areas far from power plants. The blue circle in Figure 3 is Manaus and the blue arrow in the picture points at the Capital of Ipixuna. Travelling by boat is the only option to go to Ipixuna due to the rough topography. To transport diesel from Manaus to Ipixuna can take up to 35 days[2].

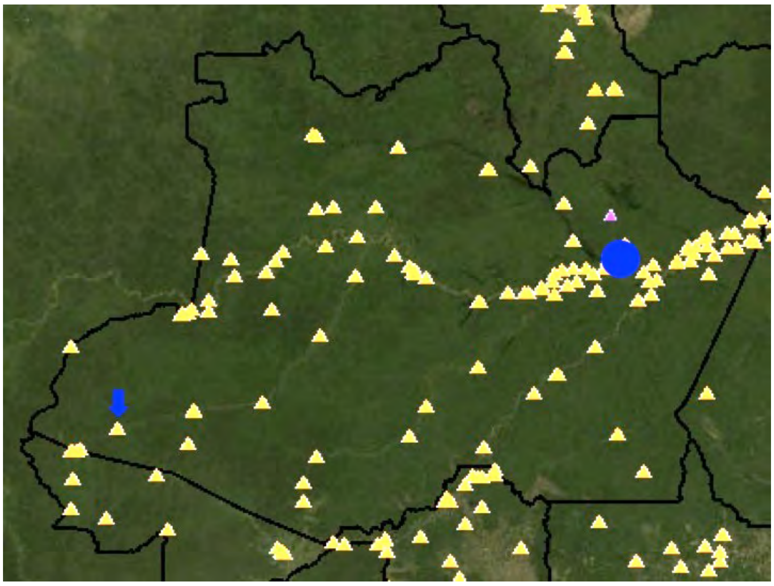

Figure 3. Power plants in Amazonas (ANEEL 2013b). Yellow triangles- thermoelectric power plants, purple triangle- biomass power plant. Manaus is represented by the blue circle and Ipixuna by the blue arrow. The black lines represent the state borders. Prepared by the authors.

It is common that communities in the interior install their own diesel generators. There are no numbers of the total installed power of small-scale diesel generators, but it is by far the most commonly used energy supply[2].

[2] Bittencourt, Anderson; Coordinator of the State center of Climate Change, Secretary of Environment and Sustainable Development, Manaus, Brazil. Meeting at CECLIMA, 29 of August 2013.

1.1 Light for all program – Programa Luz para todos

"The Program "Light for All" is much more than the possibility to turn the light on, it is one of the greatest programs on social inclusion existing in the world, which brings to families the rescue of dignity and the accomplishment of citizenship."
- (Ministry of Mines and Energy 2010, p. 5)

In November 2003 the Brazilian Federal Government launched the program Luz Para Todos, Light for All, to reach out to 10 million people without continuous electricity. The Light for All program has made a revolution in the rural areas of Brazil since it includes its citizens in social development. It gives people opportunities in forms of generating jobs and income, while also improving their living standards (Ministry of Mines and Energy 2010, pp. 4-5). The goal is to give all Brazilian households access to two lamps and three electrical sockets, with a maximum consumption of 30 kWh per month and household[2].

Eletrobrás is the company responsible for the financial and technical analysis of the program Light for All (Ministry of Mines and Energy 2010, pp.35-36). During the years 2004 to 2013, Eletrobrás managed to attend 83,172 new households in Amazonas. The new goal for the period 2013 to 2023 is to attend 90,643 additional households in Amazonas (Eletrobrás 2013). This is the same number that Eletrobrás use to state the number of households, still lacking electricity in Amazonas. With an average number of 4.4 members per household (IBGE 2010), this means that around 400,000 people in Amazonas still lack electricity. It also means that some inhabitants will not have electricity access in another ten years, without own initiatives.

1.2 Scope of the study

The purpose of this study is to evaluate if the HiLight, a solar powered lantern and charging equipment, could be a feasible energy solution for communities in the state of Amazonas. The evaluation is inspired by the methods and structures used in Environmental Impact Assessments (EIA). The authors would like to stress that this study should not be seen as a complete EIA.

The evaluation includes the study of HiLight as an energy source; it considers alternative options fulfilling the same purpose, while also discussing the "no action" option. The feasibility will be evaluated from the EIA, and from an economical perspective.

The main method for data collection was through qualitative interviews with strategic members of three communities: Caioé, Terra Preta, and Nova Esperança. The position of the communities can be seen in Figure 4. The communities can be accessed within three hours with a fast motorboat from Manaus. For a community member it can take up to 12 hours to reach Manaus with their current method of travel, which is smaller private boats or larger boats for public transportation. Terra Preta and Nova Esperança are indigenous communities.

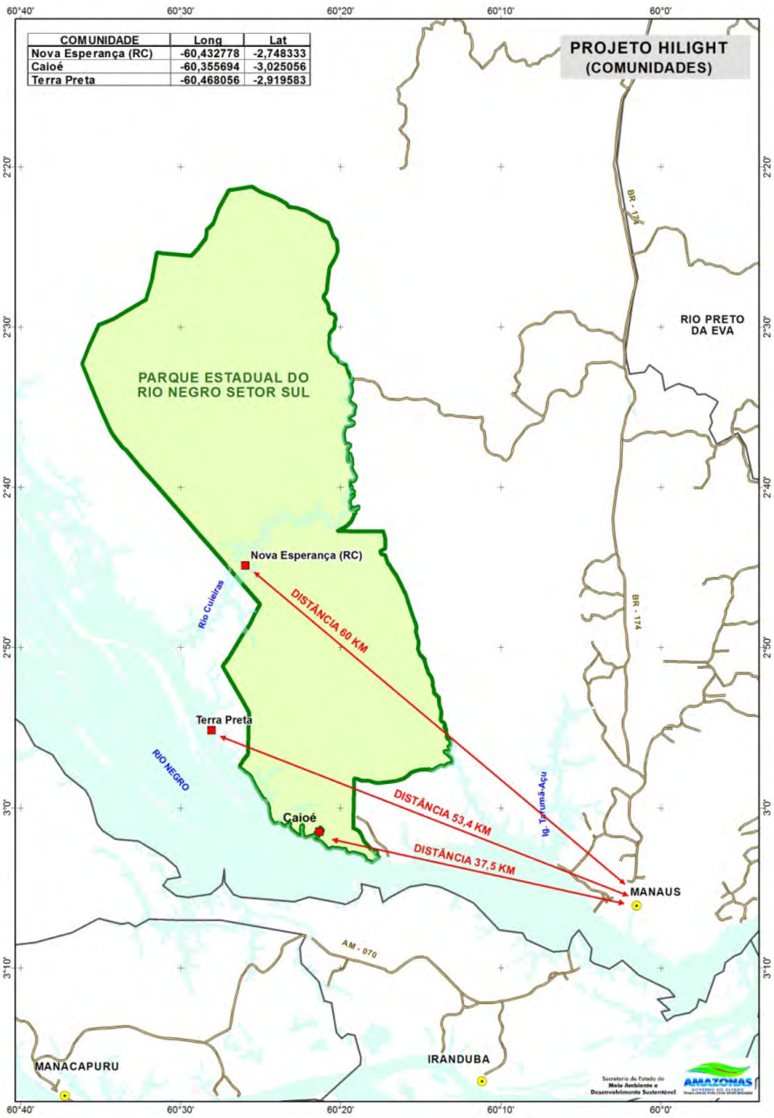

Figure 4. The position of the participating communities in this study (Caíoe, Terra Preta, and Nova Esperança) and their distance from Manaus.

This study has been carried out together with CECLIMA, the State Center of Climate Change. CECLIMA is a state government institution with the purpose to formulate public policies on climate change (CECLIMA 2010). The coordinator of CECLIMA, Mr. Anderson Bittencourt, was the supervisor of this project at site. Bittencourt also assisted with logistics, permits, and to find suitable communities to participate in this study.

CECLIMA is located in Manaus, which was the point of departure for trips to the three communities in the interior of Amazonas.

1.3 Limitations

The study should be seen as a case study for three specific communities in Amazonas. Therefore this study is not representative for all communities. Its purpose is to give rise to an increased knowledge on the current energy situation in the region, and using this information for a better understanding of the feasibility of introducing HiLights to Amazonas.

This study mainly focuses on the usage step of the life cycle of different energy solutions. Other steps of the life cycle such as production and waste management of HiLights, and other energy sources mentioned in this study, has not been investigated. A complete life cycle assessment of the HiLight, and other possible solutions, is suggested to be conducted in future studies.

2 Background

2.1 The HiLight

The HiLight, seen in Figure 5 below, is a product made by the Swedish company HiNation. It is a rugged solar powered charger and lantern with the following features:

- PV module consisting of six silicon solar cells
- Lithium ion battery
- LED lamp
- USB output
- Micro USB input
- On/Off button
- Four green lights that indicate the battery level
- A red light that indicates problems

Figure 5. The HiLight.

The battery can power a built-in LED lamp, seen in Figure 6 below, which has two settings. By pushing the On/Off button once, the light will come on and will, when the battery is fully charged, last for up to 20 hours. By pushing it twice the light will become stronger and last for up to 10 hours if fully charged. The HiLight also have four green diodes indicating the battery level and a red diode that will, if turned on, indicate that the module has been over heated or that the device that is being charged takes too much power from the battery.

Figure 6. LED lamp of the HiLight

The HiLight can charge devices via a USB port seen in Figure 7 below. When the battery is fully charged it can charge up to ten cellphones, depending on the battery size of the phone.

Figure 7. The On/Off button and USB port

To charge a device you can use a USB cable. Since it was not known what devices that needed to be charged in the communities, an “octopus cable” with several outputs was brought, seen in Figure 8 below.

Figure 8. USB cable for charging different devices, called an octopus cable.

To charge a device you simply connect it to the USB port and press the On/Off button for one second as seen in Figure 9 below.

Figure 9. Charging a cellphone with the HiLight.

For further technical specifications, see Appendix A.

2.2 Limiting factors

There are some limiting factors when using the HiLight. One is the temperature range that the battery operates in. This is to protect the battery. The HiLight functions between -5 °C and 60 °C (HiNation 2012).

The technical lifetime for the battery and LED lamp is shown in Table 2 below.

Table 2. Technical lifetime of the HiLight[3].

Battery	500-1000 cycles from empty to fully charged
LED lamp	100 000 hours of light

If using the lamp for 20 hours, the maximum hours of a full cycle, the LED lamp still has technical lifetime left when the battery has reached the end of its lifetime. This shows that the battery is the limiting component of the product.

[3] Krondahl, Linda; CEO of HiNation. Meeting at the HiNation office, Stockholm, 3rd of April 2013.

2.3 The HiLight in the field

When visiting the communities the first time an introduction meeting was held to inform the community members about the product and how to use it. The meeting also included information such as problem solving where the most common problems, such as the ones below, were discussed.

Some external devices that can be connected to the HiLight via USB were brought. The participants evaluated a radio, battery charger, fan, and an external LED lamp to see if, and how these devices could be beneficial. More information about the external devices can be found in Appendix B.

2.3.1 Kick starting the HiLight

If the battery of the HiLight runs too low it will not charge from the sun. It then needs a "kick start", transmitting some power from a stable power source before it is able to charge from the sun again. This can be done in various ways. One is to charge it via the micro USB from the electricity grid or a computer. A second option is to use another, charged, HiLight and connect them together as shown in Figure 10 below. The USB port is connected to the charged HiLight and the micro USB to the HiLight with no battery. When connected on has to press and hold the On/Off button for one second for it to start charging.

Figure 10. How to kick start a HiLight with another HiLight.

2.3.2 Overheating

If the temperature of the product exceeds the temperature interval a red light will come on. The product then needs to be put in the shadow to cool off before functioning again.

2.3.3 If the product gets wet

If the product gets wet, all charging devices should be disconnected, the lamp should be turned off, the cover removed and the module should not be placed in the sun for charging. The HiLight needs to be put in a dry place.

2.3.4 Further information

In 2012, HiNation got a diploma from WWF (World Wide Fund for Nature) for the HiLight and its potential of being a Climate Solver (WWF 2012) The HiLight is also RoHS compliant which limits the usage of heavy metals and flame retardants (Kemikalieinspektionen 2012).

2.4 The potential users

When investigating the HiLight's role in the energy system of Amazonas, the first step is to classify the different user groups. The users in the interior could be classified into four different groups, depending on their current electricity situation. Below these groups are explained further, ranked after the need of electricity. Group 1 should be considered to be the group with the highest priority of receiving electricity, while Group 4 has the lowest priority.

2.4.1 Group 1- People lacking electricity

People in this category have no access to electricity. The amount of people within this group is hard to estimate, since many communities and households install their own diesel generators and the number of these is unknown.

2.4.2 Group 2- People with a few hours of electricity per day

The energy supply for the communities in this group consists of diesel or gasoline generators. This is the most common situation regarding electricity for communities in the interior of Amazonas. Group 2 includes a larger amount of people than Group 1; together these groups are estimated to constitute 400,000 people in total (Eletrobrás 2013; IBGE 2010).

The most common situation is that the generators run from 6 pm to 10 pm; when it gets dark until the community members go to sleep. The main reason why the generators do not run for more than four hours is because the fuel expenses are not affordable for the community members. The average energy consumption for a household in Group 2 is 23 kWh per month[4].

Note that Group 2 will emerge with Group 1 during the 20 hours of the day when the generators are not running, or during the times when they lack fuel.

2.4.3 Group 3- People with 24 hours of electricity but with limited access

An example of people in this group, are the communities that have been attended by the Light for All program. The average consumption is 30 kWh per month and household, a standard set by Light for All. The standard also includes two lamps and three electricity sockets, which means that they normally use two lamps, a TV, a radio, and a small refrigerator.

2.4.4 Group 4- People with access to 24 hours of electricity but in need of portable energy

This is the most common situation for people living in the capitals of the 61 municipalities in the interior of Amazonas. These people receive the electricity mainly from diesel power plants. The average electricity consumption for this group

[4] Bittencourt, Anderson; Coordinator of the State center of Climate Change, Secretary of Environment and Sustainable Development, Manaus, Brazil. Meeting at CECLIMA, 8 of October 2013. Calculation based on an average installation of 380 W per household in the interior, used 4 hours per day during 15 days of the month. Anderson means that the normal case is that community members only can afford diesel for 15 days of the month. Numbers based on a study CECLIMA that did with 135 communities in 7 municipalities.

is 75 kWh per month and household, which can be compared with 150 kWh per month for a household living in Manaus. Many people that live in the capital of the municipalities go to the forest to fish and hunt. For this reason they could be in need of portable energy for light and cellphone charging.

2.4.5 The user group focus in this study

The initial view of the HiLight's role in the energy system of Amazonas is that the HiLight can neither replace diesel or gasoline generators, nor stationary solar panels. This conclusion is based on interviews with community members in the interior (Appendix D), and discussions with Anderson Bittencourt at CECLIMA[4]. One of the main reasons for this is the need of refrigerators and freezers to preserve food. These are equipment that the HiLight is not capable of powering. The installation of cooling equipment in a community has shown on many economical and health benefits[5]. Therefore no comparisons of when the HiLight would completely replace the stationary diesel/gasoline generators or solar panel systems have been made. Though, the usage of HiLight could mean that some of the usage time of the stationary systems could be shortened. For instance when the generator is only operating for illumination, the HiLight could be a substitute.

This study focuses on three specific communities in Group 2. For Group 1, 3 and 4 the HiLight could be useful but this lies outside of the scope for this study, and has therefore not been evaluated in the Environmental Impact Assessment.

The communities of Caioé, Terra Preta, and Nova Esperança were chosen for three main reasons:

1. *Representative energy usage*- Their energy usage is representative for the average community in the interior of Amazonas.
2. *Structure*- These communities are structured and interested in participating in projects. They are reliable and provide constructive and accurate feedback. These communities are therefore preferable when conducting a short pilot project such as this study.
3. *Distance to Manaus*- The communities are located in isolated areas, and are not in the plan to be connected to an electricity grid in the near future. They are in the Light for All program for 2013 to 2023 but no plans have been made for the area yet[6]. At the same time they are located close enough for CECLIMA to be able to monitor the project for a longer period of time.

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[5] Ibid.

[6] Ibid. Date: 12 of September 2013.

All three communities are located at the riverfront. Two of them, Terra Preta and Nova Esperança, are indigenous communities composed of several tribes. The inhabitants of Caioé are ribeirinhos, an expression for people riving by and off the river. The communities consist of 17 to 36 households, with one or more families living in each house. The normal constituents of a community are mentioned below.

- *Community center*- Where everyone in the community gathers to share meals, have meetings etc.
- *Medical center*- The place where people go to get medications, tests for malaria, or help with other medical issues.
- *School*- All three communities have a school. The schools also receive students from other communities, and often offer education to the adults.
- *Farinha house*- A common structure for each community. Farinha is flour made out of cassava, served as a side dish to most meals.
- *Church*- Many of the communities, even the indigenous, have a Christian church.

Every community has a leader, called kasike in the indigenous communities. Other common positions in the community are teachers, health agents, and people responsible for the water and diesel generator.

All three communities visited had a similar appearance, a typical example shown in Figure 11 below.

Figure 11. Picture of Caioé.

3 Material and methods

Throughout the study different materials and methods were used. To prepare for the fieldwork and to understand the HiLight a pre-study (Appendix C) was conducted at the Department of Engineering Sciences, Solid State Electronics, Uppsala University, with supervision of Professor Marika Edoff. During the pre-study measurements of the HiLight were done, and diagrams of the results were created. The diagrams were done so that the short-circuit current from the HiLight could be measured in the field, and the solar irradiation and the amount of hours to fully charge the battery could be found in the diagrams. Once reaching the communities during this period, measurements in the field were excessive due to the clear weather with continuous high solar irradiation and the fact that shadowing did not constitute a problem.

During the fieldwork interviews were conducted mainly to get a picture of the communities current energy situation, and how they used the HiLight during the evaluation period. The results from the interviews were then evaluated through a feasibility study inspired by the method of an EIA. This includes the description of the current energy situation, the energy situation when the HiLight is introduced, the no-action option, evaluating reasonable alternative options to the HiLight, and circumstances that are specific for this site. The feasiblitiy of HiLight was also evaluated from an economical aspect.

3.1 Interviews

Most of the data was collected through interviews. Using interviews enabled flexibility for the project that was necessary for a proper evaluation of the HiLight. It also gave a deeper understanding on the situation in the communities and their needs. The interviews were conducted at two separate occasions with 12 to 21 days in between. Three people, one asking the questions and leading the interview, one secretary, and one interpreter conducted the interviews.

3.1.1 Selection

The selection process for the participating communities and community members were made in two steps. First the villages were selected, for the three reasons mentioned in “Background”. This was made together with Anderson Bittencourt and Alcilene de Araújo Paula, Chief of State Park of Rio Negro, South Sector. After selecting the villages, key people who would receive a HiLight were selected.

Examples of key people are:

- Leaders of the communities
- Health agents
- Midwifes
- Hunters

The method of selection was chosen for the product to be as beneficial as possible to the communities. By prioritizing key people it was hoped to avoid jealousy between people and also that the HiLight would come to greater use to the whole community. Another way of avoiding jealousy was to make the participants contribute to the research by filling out a table and spend their time on the interviews; a mutual relationship instead of just giving away the product for free.

3.1.2 Interview work

Since the work took place in three different communities, four HiLights were distributed in each community; one to each key person. Interviews were conducted with each person before receiving the HiLight, and after 12 to 21 days of usage.

The method of qualitative interviews was chosen for many reasons. One was that there was too little knowledge about the community members' energy use to be able to ask specific questions. Another reason was that the group of interviewed people was too small to be of statistical relevance for a quantitative research.

The interviews were conducted in as much privacy as possible. This was so that the answers would be personal and not influenced by the other people in the group. Some of the interviews had to be done in a group because of time constraints.

3.1.3 Interview guide

To maintain a structure to the interviews, two interview guides were made (Appendix E and F). They were constructed as a list of topics of interest so that all questions were open without directing the interviewee towards a specific answer. This was to enable the interviewee to direct the interview as much as possible, a method suggested by Trost (2010).

Some of the topics asked about were:

- What a normal day looks like
- Energy use
- Waste disposal
- Economy
- Usage of the HiLight

By using unspecific questions, supplementary questions were easy to ask. This resulted in that areas that were not thought of in advanced were detected and could be investigated further.

3.1.4 First interview opportunity

The first interview opportunity gave a possibility to understand the community members' current living situation. The interview guide was brought, and used as a tool through the interviews. One of the most beneficial questions for the research was the question of what a normal day looks like for the interviewee. The answer to this question gave a broad understanding of energy usage and limitations in the community members’ daily lives due to lacking electricity.

During the first interview a manual containing information about the HiLight was handed out. The back of the manual had a table that the HiLight users should fill out at the end of each day. The information asked for was hours charged from the sun, hours of used light, and number of cellphones charged (Appendix H). A questionnaire was also handed out to all the participants. The questionnaire (Appendix G) had questions such as name, occupation, specific energy use etc. It was used both as a complement, and to verify the information retrieved during the interviews.

3.1.5 Second interview opportunity

When returning to the communities the tables with data that the interviewee had filled out was collected (Appendix D). A second interview was conducted with each person who received a HiLight, to evaluate the usage.

3.1.6 Difficulties

The language barrier resulted in that some of the interesting facts were left out. Also the interpreters did not fully understand the thought of keeping the questions very open and sometimes gave examples that would lead the interviewee towards an answer.

Other difficulties were that many disturbances took place. For instance there would be people who would interrupt the interview out of curiosity, dogs barking, children playing etc.

3.2 The HiLight as an energy solution evaluated from an EIA perspective

3.2.1 Specific for this site

3.2.1.1 Sun, shadow and heat

The microclimate of the communities along the river is composed of open areas with a few trees. Shadowing does not constitute a problem; therefore the sites are suitable for solar power.

Figure 12. Picture of Caioé.

Figure 13. Picture of Terra Preta.

The average solar irradiation in Manaus is 5.16 kWh per m^2 and day. The values for average solar irradiation does not differ much per month over the year; the lowest value is 4.49 kWh per m^2 and day in June, and the highest value is 5.77 kWh per m^2 and day in September (Grupo de Pesquisa Estratégica em Energia Solar da Universidade Federal de Santa Catarina 2011). Assuming an efficiency of the PV module of 16 % and using its area of 142.5 cm^2 (Appendix C), one can calculate how much the battery can be charged during a full day of sun. The size of the battery of the HiLight is 14.4 Wh (HiNation 2012). When calculating the maximum charging the battery of a HiLight can get from solar irradiation during an average day in Manaus, one can see that it can maximally be charged up to 11.76 Wh if assumed placed perpendicular to the sun. This means that it cannot be assumed that there is enough sun to be able to fully charge the battery every day of the year. To be able to charge the battery fully, the solar irradiation needs to be at least 6.3 kWh per m^2 and day. In all calculations above, the transmission efficiency from the PV module to the battery is assumed to be 100 %.

The heat can decrease the battery time of the HiLight. The temperature in the region can be up to 40 °C, and most of the participants experienced sometime that the red light went on due to overheating (Appendix D). The leader of Terra Preta, Rafael, was the only one who timed the usage of the HiLight. He said that he once charged the HiLight from 06.00 to 16.00, until it was fully charged. Then he used the light on the strongest mode from 22.00 to 04.00, when it turned off. Rafael was therefore disappointed that the lamp would only light for 6 hours, which he meant is far from “up to 10” which is stated in the user guide. The authors did the same test with two HiLights; by first charging it fully from the grid, and later leave it at the stronger setting to see how long it would last. The batteries lasted for 8 and 8.5 hours, respectively.

All the other participants were pleased with the size of the battery and the time they could use the LED lamp from each cycle.

3.2.1.2 Rain and humidity

Amazonas has two seasons: the dry and the wet season. This study was conducted during the dry season. Rain occurred and the humidity was up to 95 % at times, though no rain or humidity issues arose during the evaluation period. When asking the participants if they thought the usage would be different during the rain season, the answers were various. Some participants thought they could use the hours of sun during the rain season for charging, and that it would not be a problem to keep the HiLight out of the rain. Other participants thought the rain could constitute a problem.

Since the humidity level in the region is high, some participants described problems with other electronics breaking due to this. Since the HiLight have one USB and one micro USB port, humidity could enter the product.

The overall impression is that rain and humidity could constitute a problem. To receive more knowledge about this, the project needs to be monitored over a longer period of time. The authors would therefore like to stress the importance of evaluating these parameters, when CECLIMA follows up the project after one year.

3.2.2 Current energy situation

The information concerning the current situation is a summary based on the interviews conducted in the communities during the fieldwork (Appendix D).

The current energy situation in the communities visited is defined under “Background” as “Group 2 - People with a few hours of electricity per day”. These communities lack continuous energy supply and have only a few hours of electricity per day. Two of the communities, Terra Preta and Nova Esperança, are dependent on donated diesel from the municipality of Manaus, and on that community members contribute with monthly payments. In Caioé they have a community diesel generator but some households also have their own diesel or gasoline generators. The communities often lack fuel when they lack money. This means that it is not certain that the community has electricity during all days of a month.

The diesel generators, often situated inside the community near to the houses, create noise pollution. The sound they emit makes it hard to talk, watch television and listen to the radio (Appendix D.1.2).

As a light source inside the houses it is most common to have a diesel lantern. The diesel lantern gives a weak and diffuse light and creates indoor pollution consisting of smoke from the combustion. Some of the interviewees complained about the soot that would create black stains on walls and bed linen. They also said that the smoke made it hard to breathe. The health agent and leader of Terra Preta, Rafael, said that his patients would come to him when they were sick and that the smoke would make them feel even worse (Appendix D.3.3). Since the houses in the communities mainly consist of wood, using a burning diesel lantern inside for illumination creates an increased fire hazard.

The situation regarding the usage of diesel lanterns in Nova Esperança and Terra Preta are similar. The households participating in the study used between one to two liters of diesel per month for their diesel lanterns. The use of diesel in lanterns creates emissions of carbon dioxide shown in Table 3 below. Note that other pollutants such as soot also create indoor pollution.

Table 3. Emissions per month and household from diesel lanterns used in Terra Preta and Nova Esperança (Energihandbok 2006)

Amount of diesel (liter)	**Emission (kg CO_2)**
1	2.62
2	5.24

A flashlight powered by batteries is the most common light source outside of the house. It is used in various activities such as hunting and fishing. The communities use a variation of alkaline AAA, AA and D batteries for the different equipment. In Nova Esperança and Terra Preta approximately 12 batteries are used per household and month. In Caioé there is a monthly consumption of up to 36 batteries per household.

Since 2001 there are regulations of limitations of hazardous substances used in batteries. All alkaline batteries imported or produced in Brazil can have a maximum weight percent of 0.010 % mercury, 0.015 % cadmium, and 0.200% lead (Ministry of Mines and Energy 2001).

Mercury, cadmium and lead are heavy metals that all have environmental impacts. They are toxic and affect both the environment, and the health of animals and people. They all have in common that they accumulate in the bodies of people and animals instead of being execreted through urine, sweat or feces. Batteries that are left in the nature can start to leak which means that the heavy metals will spread. The accumulations of these heavy metals can lead to damage on the central nervous system, skeleton, kidneys, liver and spleen (Batteriinsamlingen).

The usage of batteries for the flashlights results in one of the major problems in the communities' waste management. Normal household waste in the communities of Amazonas is usually buried in the ground, burnt or thrown in the river. Both Terra Preta and Nova Esperança have a system for waste management of batteries. The batteries are handed in to organizations that work with sustainability in the region. In Caioé the families buried the batteries in plastic bags in the ground or burned them with the household waste.

In Terra Preta, there has been a study on the soil quality and the conductors of the study urged the community to start collecting batteries and not to bury them since the quality of the soil was starting to become very poor.

Using diesel generators and lanterns creates further problems if the diesel is spilt when handled inside of the community. In Terra Preta there has recently been a large spilling of diesel that resulted in health problems among the community members. The diesel polluted the soil used for agriculture and the river water; the same water that the community members drink and bathe in.

Other health aspects occur when handling the diesel lanterns. The midwife, Ugulina, in Nova Esperança uses diesel lanterns as a light source when she is helping to deliver babies. She exemplifies with one time that she had to re-fill her diesel lantern during the childbirth. The timing was unfortunate and she had to receive the baby with diesel on her hands.

3.2.3 The situation with the HiLight

When returning to the communities it was possible to distinguish the different areas of usage for the HiLight. It was mainly used as a light source and to charge cellphones. Overall the community members decreased, or even stopped, using their diesel lanterns and batteries for their flashlights. Some of the interviewees even decreased their usage of diesel or gasoline for the generators.

An outcome of this reduction of fuel and batteries is that the emissions from the diesel lanterns mentioned under "Current Situation" are reduced or no longer existing. Also the waste created by the 12 to 36 batteries used per household and month will no longer occur. Seen in Table 4 below is the total amount of batteries that the families can save during the lifetime of the HiLight. The technical lifetime is between three and 10 years, and the usage of a HiLight would replace between 432 and 4320 batteries in total during this period.

Table 4. Batteries avoided depending on the technical lifetime and usage of batteries.

Avoided batteries per month	Avoided batteries if the HiLight is used for 3 years	Avoided batteries if the HiLight is used for 10 years
12	432	1440
36	1296	4320

One limiting factor that needs to be considered is how many AA and D batteries the HiLight can charge on one cycle. The capacity of AA and D batteries are 4.5 Wh and 13.5 Wh, respectively. When comparing this to the capacity of the battery in the HiLight of 14.4 Wh, one cycle could charge one D battery or three AA batteries.

A benefit of having a HiLight is that it will work outside of the generators operating hours, and is a complementary electricity source. This creates redundancy and increases the energy security in the communities. If the generator is non-functioning, the community members can still use the lamp, and charge their cellphones and other appliances.

The majority of the interviewees stated that the light from the HiLight was enough to illuminate a room. The leader of Terra Preta, Rafael, stated that he would like a less diffuse light when working as a health agent. He wishes for a brighter and more focused light for his work (Appendix D.3.3), while e.g. the midwife of Nova Esperança was satisfied with the light for her work. The people that practice hunting or fishing also wished for a more focused light. One suggestion was a headlamp with a USB cable that could be attached to the HiLight.

The light of the HiLight enabled some of the interviewees to work after their generator was turned off. Rosimeire, the leader in Nova Esperança, was able to stay up during the night to sign documents for the community members that she, before receiving the HiLight, had difficulties to find time for (Appendix D.2.3).

3.2.3.1 Negative consequences of the HiLight

Even though the HiLight does not release any greenhouse gases during usage, one must consider the emissions from other parts of its lifecycle such as production and waste management.

The environmental impacts of a silicon solar panel occur mainly during the production process. How large the impacts are depends on the materials and energy mix used. The life length of the solar cell also matters when considering emissions since they often are calculated as emissions per kWh. There are also environmental impacts concerning the metals used in the solar cells (Naturskyddsföreningen 2011).

Other environmental impacts occur during the waste management of the solar cells. Solar cells can be partly re-cycled but there is no known company operating in this field in the State of Amazonas[7]. This creates a problem if the HiLight would break or when the technical lifetime is ended. An idea is that the responsible distributor or reseller in the area could replace some broken parts or the battery. The electronic components and the lithium battery will have environmental impacts if buried in the ground, burned or thrown in the river. Though these impacts could be seen as small compared to the batteries replaced, seen in Table 4.

An alternative to the communities waste management would be to establish a refund system, where the community members would get a smaller amount of money for returning the HiLight after it has been used.

To further investigate the HiLights' environmental impacts a Life Cycle Assessment should be conducted on the product used in this specific area.

3.2.4 No-action option

All three communities are in the Light for all plan of receiving continuous electricity before year 2023[8]. If no-action is taken before, the energy situation in the near future will look much alike the "Current situation". One should assume more expensive diesel prices (IEA 2012) that could result in even longer times of electricity shortage in the communities.

The no-action option is considered over the lifetime of the HiLight. It is assumed that the communities will continue to use their diesel lanterns and battery-driven devices as they do today. The emissions from the diesel lantern usage are shown in Table 5 below. Note that the HiLight would also decrease the usage of the diesel generators,

[7] Bittencourt, Anderson; Coordinator of the State center of Climate Change, Secretary of Environment and Sustainable Development, Manaus, Brazil. Meeting at CECLIMA, 2nd of September 2013.
[8] Bittencourt, Anderson; Coordinator of the State center of Climate Change, Secretary of Environment and Sustainable Development, Manaus, Brazil. Meeting at CECLIMA, 12 of September 2013.

but these numbers are hard to predict and are therefore not included. The soot created by the lamps, the risk of spilling diesel and the risk of a larger diesel leakage will continue to affect the health of the people in the communities.

Table 5. Carbon dioxide emissions from diesel lanterns if no action is taken during three to 10 years. Calculations are based on the emissions of 2.62 kg of CO_2 per liter of diesel (Energihandboken 2006).

Amount of diesel used per month (l)	**1**	**2**
Emissions during 3 years (kg CO_2)	94	189
Emissions during 10 years (kg CO_2)	314	629

The problem concerning waste management of the batteries will still exist and depend on organizations such as the ones collecting the batteries in Nova Esperança and Terra Preta. In Caioé 432 to 4320 batteries will be used, the same amount that will be saved if using the HiLight, see Table 4 under ”The situation with the HiLight”. They will still be buried or burned unless organizations will help with the collection. The no-action alternative might increase the accumulation of heavy metals in the soil by leakage of batteries.

3.2.5 Alternative solutions

Since the HiLight has a limited energy output and can only power devices via USB, it is not reasonable to compare it with diesel generators or other larger energy systems. When visiting the communities two main alternative solutions were thought of.

The first is a battery charger to charge rechargeable batteries. There is a device like this with a USB input, suitable for the HiLight, which was evaluated in the study. A photo of the battery charger can be seen in Figure 14 below.

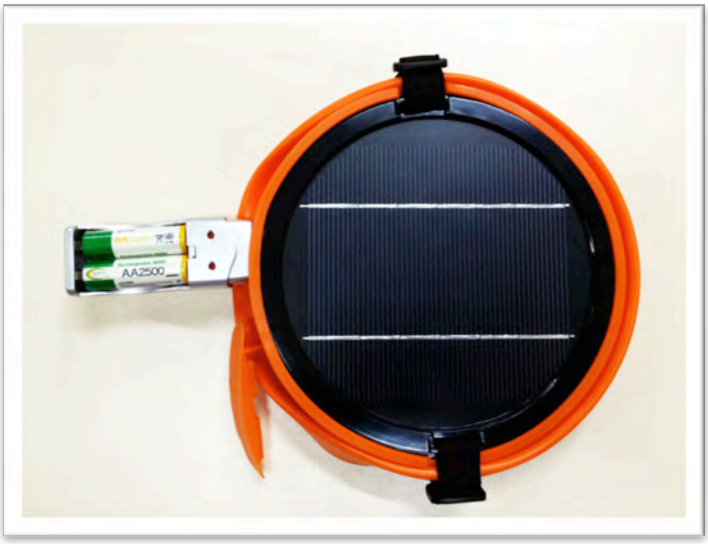

Figure 14. The battery charger with a USB input

A battery charger like this could substitute the single-use battery usage and the light, when the batteries are used in existing flashlights. Though, it could not substitute the cellphone charging possibilities.

A battery charger that is connected to a diesel generator via an electrical socket as seen in Figure 15, could fulfill the same purpose as the battery charger for the HiLight, and is therefore considered to be an alternative solution. It would be a cheaper alternative than the HiLight, but could only be used while the generator is running. It could not substitute cellphone charging and would, compared to the HiLight, increase the usage of fossil fuels and is therefore not preferable from an environmental perspective. Though, when this solution is compared to the no-action option, the battery charger would be economically and environmentally beneficial since it would decrease the usage of other single-use batteries and diesel lanterns.

Figure 15. Picture over a battery charger powered from the grid (Gullbergs 2013).

Another alternative solution is to use solar powered flashlights. This product could neither substitute single-use batteries for other purposes than light, nor provide cellphone charging. Since the production of solar cells is energy demanding, a solar powered device might as well provide cellphone charging. When compared to the no-action option it would decrease the usage of single-use batteries and diesel lanterns, which is beneficial from health and economical perspectives.

3.3 Economical aspects

3.3.1 The price of a HiLight

The price of a HiLight for a private person in Sweden is 1,200 Swedish Krona (SEK). During the summer and fall of 2013, 1 Brazilian Real (R$) is equal to approximately 3 SEK. This gives a price of R$ 400 per HiLight.

For companies, governmental institutions etc. in Brazil, the price per HiLight could be different than R$ 400 due to Brazilian taxes and the quantity of HiLights that is being bought. How the price is influenced by taxes is up to the Brazilian government to decide, while it is known that the price per HiLight set by HiNation decreases with the increasing quantity of HiLights.

3.3.2 Savings due to HiLights

When conducting the interviews in the communities two general situations were found. The interviewees in the two indigenous communities of Nova Esperança and Terra Preta did only use the diesel generator that was common for the communities, while the interviewees in Caioé had their own diesel or gasoline generator. This resulted in two different economical cases presented below.

3.3.2.1 The general family in Nova Esperança and Terra Preta

The leader of Nova Esperança, Rosimeire, says in the interview after trying the HiLight that it replaced her diesel lantern and the batteries she usually used. She would therefore estimate the saving for her household to be R$20.50 per month. This includes 1 liter of diesel for R$ 2.50 and 12 batteries at a cost of R$ 1.50 each (Appendix D.2.3).

The leader of Terra Preta, Rafael, says that the families in Terra Preta usually buy three batteries per family per week for a price of R$1.50 each. All families also have their diesel lanterns and the interviews shows that they spend R$ 5 to 6 on diesel for these lamps per month. Rafael means that each family would save R$ 18 per month on not having to buy batteries. He also says that the HiLight completely substitutes the diesel lanterns (Appendix D.3.3). Therefore it could be estimated that a general family in Terra Preta saves R$ 23 to 24.

In Figure 16 below one can find the payback time of a HiLight for a general family in these communities. It could be estimated that the HiLight could result in an avoided cost of R$ 20 to 25 per month, which gives a payback time for a HiLight of 16 to 20 months.

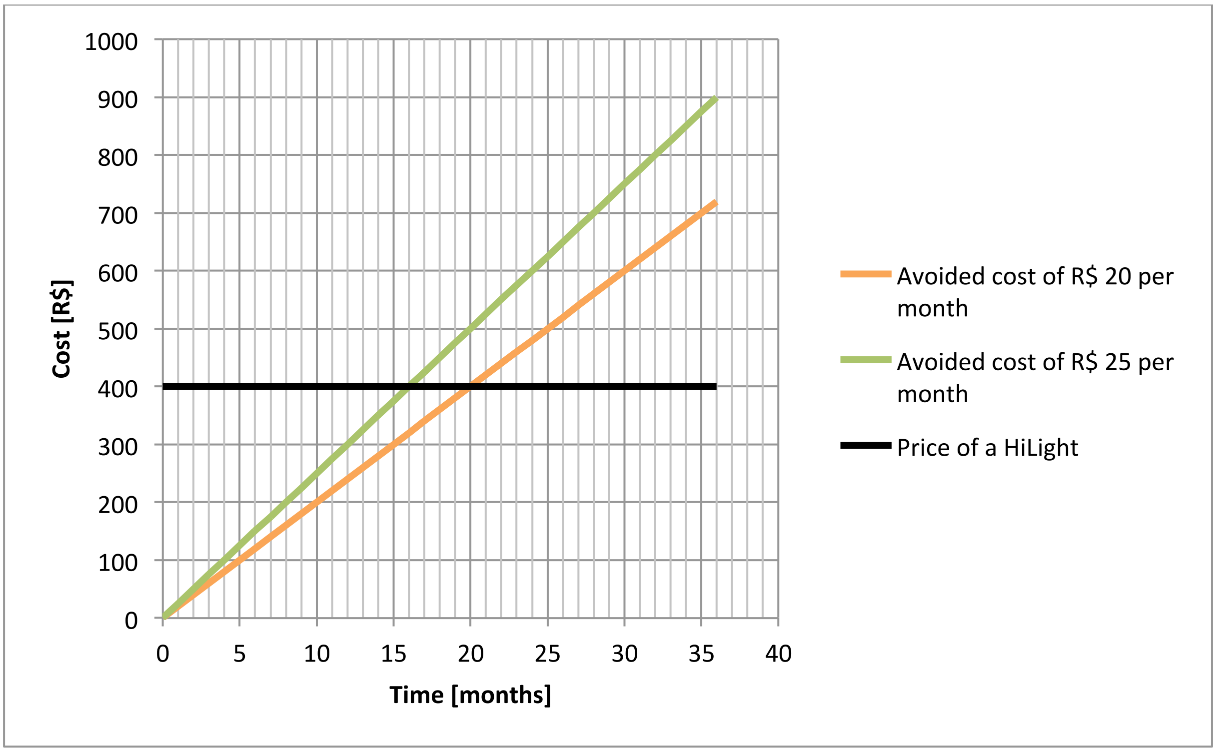

Figure 16. The payback time for a HiLight in a household in Nova Esperança or Terra Preta. The time could be compared to the limiting factor of a HiLight of 500 to 1000 battery cycles.

3.3.2.2 The interviewees in Caioé

Two of the interviewees in Caioé have their own diesel generator while a third has his own gasoline generator. The interviews show that the interviewees stopped using their generators for some of the evaluation period, for the purpose of saving money. At the same time they stress that the HiLight cannot replace the generators. The HiLight cannot power refrigerators, freezers, television etc. Therefore, the avoided costs that the interviewees presented might not be representable in the long-term.

The interviewees showed avoided costs in the interval of about R$ 120 to 375. The lower saving is represented by 20 liters of diesel on the evaluation period of 13 days (Appendix D.1.1). The higher saving is represented by R$ 80 of diesel savings per week, and 9 batteries at a cost of R$ 1.5 each saved per week (Appendix D.1.4). This gives a total of R$ 374. The payback time for a household in Caioé can be seen in Figure 17.

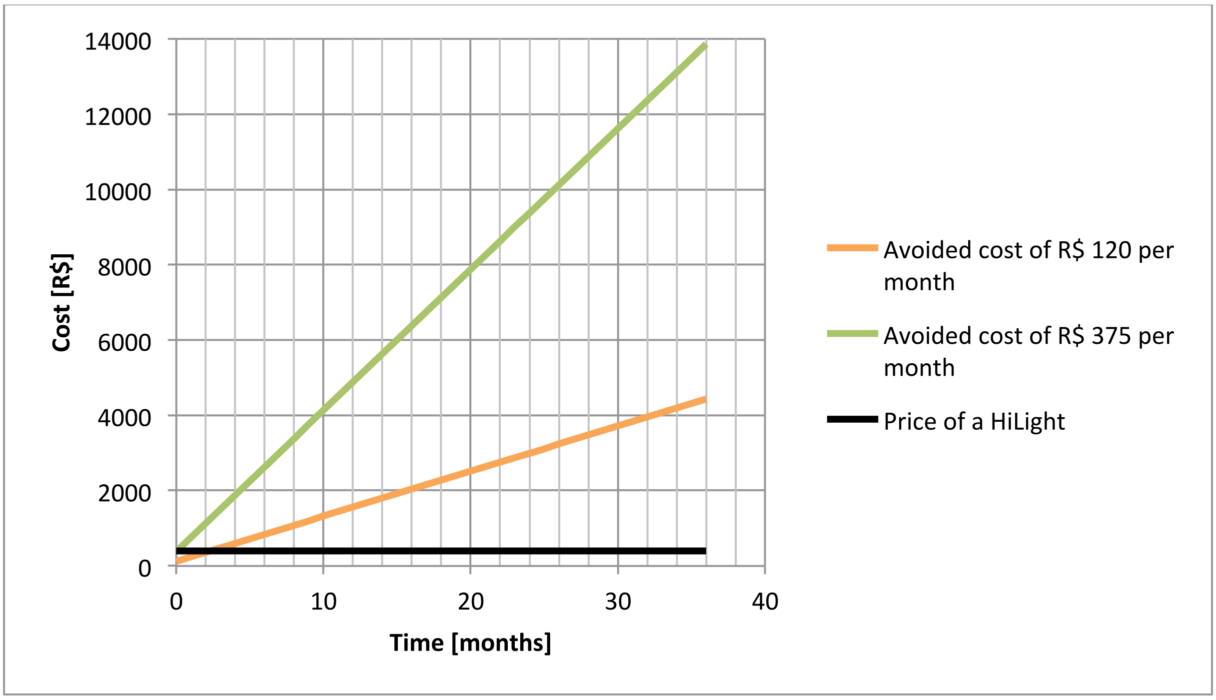

Figure 17. The payback time for a HiLight in a household in Caioé. The time could be compared to the limiting factor of a HiLight of 500 to 1000 battery cycles.

Further economical benefits that the households could experience are lower travel costs; the community members do not have to travel to buy single-use batteries. The communities could be self-sufficient on energy for light and charging and are therefore not sensitive to price changes on diesel, gasoline or batteries.

3.3.3 Environmental-economical aspects

If the HiLight is introduced in a larger scale in this area, also indirect long-term environmental-economical aspects should been considered. When emissions of pollutants from diesel lanterns can be avoided, this could result in increasing health.

This would lead to decreasing costs of hospitals in the municipalities but also to less health investments from the state Government in Public Health.

By decreasing the usage of single-use batteries, fewer batteries that will go to waste will be produced. When batteries do not have to be buried or thrown in the river, this could result in better water and soil quality. This could lead to better health and lower health costs, but also in better crops and fishery. In long-term this would be an environmental-economical investment for the communities and the state.

4 Results

The result of the study is that the HiLight cannot replace diesel generators, gasoline generators, or stationary solar panels. The reason for this is the need of larger electrical appliances such as television, refrigerators, and freezers. Though, the usage of HiLight could shorten some of the usage time of the stationary diesel/gasoline generators. For instance when the generator was only operating for illumination, the HiLight could be a substitute.

The microclimate in the communities is suitable for solar power. Shadowing does not constitute a problem. The study was conducted during the dry season. How humidity and rain affects the feasibility of the HiLight needs to be evaluated further.

The average solar irradiation in Manaus is 5.16 kWh per m^2 and day, the battery of the HiLight could therefore maximally be charged up to 11.76 Wh per day, which should be compared to the battery size of 14.4 Wh.

The EIA inspired feasibility study made together with three communities in user group 2, shows that introduction of HiLight will mainly replace diesel lanterns and single-use batteries. The HiLight was mainly used as a light source and to charge cellphones. The households participating in the study used between one to two liters of diesel per month for their diesel lanterns, responding to 2.62 to 5.24 kg CO_2 emissions. All participants replaced the diesel lantern with the HiLight. The HiLight could also decrease some use of diesel generators.

A mixture of AA, AAA and D batteries for different electronic devices was avoided in two ways. Firstly by replacing the flashlight usage with the light from the HiLight. Secondly when recharging batteries in the USB battery charger instead of using the single-use batteries they used before. Between 12 and 36 batteries per month and household was avoided when using the HiLight. During the technical lifetime of the HiLight, it would replace between 432 and 4320 batteries.

The HiLight resulted in avoided costs from both the diesel lanterns and the single-use batteries. In Terra Preta and Nova Esperança the use of the HiLight resulted in an avoided cost between R$ 20 to 25 per month and household, which gives a payback time for a HiLight of 16 to 20 months. In Caioé, the avoided cost for a household was R$ 120 to 375, which gives a payback time of 1 to 3.5 months. The HiLight could also lead to increasing health of the community members, which could from an environmental-economical perspective lead to lower hospital costs.

A benefit for the communities is that the HiLight works outside of the generators operating hours. It is therefore a complementary electricity source, which increases the redundancy. The HiLight also reduces noise pollution from diesel generators, decreases indoor pollution from the diesel lanterns, and decreases fire hazard that the diesel lanterns usually constitute.

The HiLights were distributed to key people in the community. The participants in the study were frightened that the product would break and therefore they only used it themselves. Tendencies of selfishness were also shown. One exception was Rafael, the leader of Terra Preta, who educated other adults and children in the community about the product directly after the first meeting (Appendix D.3.3). Though, Rafael suggested one HiLight per household if the introduction of HiLights should to be beneficial to all the community members.

5 Discussion

CECLIMA is suggested to evaluate how the HiLight works during one year, including the rain season. Humidity has been a problem for other electronic equipment in the region, the same might occur with the HiLight. Humidity is therefore a parameter that needs to be investigated further for a complete evaluation.

The result that show that the battery of the HiLight can maximally be charged with 11.76 Wh should be kept in mind, but was not a problem for the majority of the participants.

The participants of the study mainly suggested one improvement of the product, more focused light for fishing and hunting. A headlamp with a USB cable that could be attached to the HiLight, could be a solution to this.

Even though the HiLights were distributed to key people in the community, the results show that the HiLights was not beneficial for all community members. The tendencies of selfishness shown during the test period might be a result of the energy output of the product being so small. If the communities would have bigger solar panels, the members might cooperate and share in the same way they do with the common diesel generators. The authors suggest one HiLight per household if the purpose is to help all the members of a community.

6 Conclusions

The opinion of the athours is that the HiLights will be beneficial for communities until they get a continuous electricity supply from a stationary energy system, a solar panel system preferred over diesel generators. For some communities this might not happen until year 2023, and until then HiLight is a feasible solution. Compared to the alternative solutions, battery charger and solar powered flashlight, the HiLight is considered a better option due to the fact that it replaced both diesel lamps and battery usage for flashlights and other electronic equipment. Combined with a battery charger to charge batteries for equipment that cannot be charged via USB, the environmental, social and health benefits will be many. For this use the HiLight is considered a feasible solution.

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Appendix A: Technical specifications of the HiLight

Table 1. Technical specifications for the HiLight (HiNation 2012).

PV module	2.4 W Mono-crystalline silicone cells
Outlet	USB port (1A, 5V)
Input	Micro USB or Solar irradiation (1 A, 5 V)
Battery	14 Wh Li-Po (3.7 V, 3900 mAh)
LED lamp	1 W
Temperature interval of operation	-5 °C to 60 °C

Appendix B: External devices to the HiLight

The following external devices powered by the HiLight were evaluated in the field: octopus cable, radio, battery charger, fan and a LED lamp.

External Device 1. An octopus cable with possibilities to charge different devices such as cell phones, cameras etc.

External Device 2. An AM/FM radio with possibilities to play mp3 files via USB or SD card

External Device 3. A battery charger with possibilities to charge AA and AAA batteries

External Device 4. A fan

External Device 5. An external LED lamp

Appendix C: Pre-study

Aim

The purpose of the pre-study is to get a better understanding of the PV charged HiLight lamp and charger and how it works under different conditions. The results from the pre-study have been used to facilitate the measurements in the field; to investigate the photovoltaic module (PV module) performance in the different communities depending on the solar irradiation.

One goal has been to be able to estimate the solar irradiation, by only measuring the short-circuit current through a PV module with a multimeter. When information about the solar irradiation is obtained, the measured parameters from the pre-study can be used to calculate the time it will take to fully charge the battery of the HiLight.

The pre-study was conducted at the Department of Engineering Sciences, Solid State Electronics, Uppsala University, with supervision of Professor Marika Edoff.

Theory

The PV module performance was tested under standard test conditions (STC) with a lamp calibrated to correspond to the solar spectrum of AM 1.5 and the module was kept at a temperature of 25 °C. The desired parameters to measure were short-circuit current (I_{SC}), open-circuit voltage (V_{OC}), output power (P_{max}), fill factor (FF), and efficiency (η). The definitions are shown in Table 1 below.

Table 1. Definitions of the measured parameters of the PV module (Photovoltaic Education Network 2013).

Parameter	Definition
I_{SC}	The current through a solar cell when the voltage is equal to zero (i.e. the maximum current generated by a solar cell).
V_{OC}	The voltage that occurs in a solar cell when the current is equal to zero (i.e. the maximum voltage of a solar cell).
P_{max}	The maximum power output of a solar cell. $P_{max} = V_{mp} * I_{mp}$ P_{max} corresponds to the biggest area within the I-V curve for a solar cell (i.e. when the product I*V is at its maximum). In Figure 1 below, P_{max} is illustrated with the grey area.
FF	The ratio of the maximum power point of a solar cell to the product of V_{oc} and I_{sc}. The FF is the ratio of the grey area to the dashed area, illustrated in Figure 1 below. $FF = \frac{V_{mp} * I_{mp}}{V_{oc} * I_{sc}}$
η	The ratio of output power from the solar cell to the incoming power from the sun (i.e. the fraction of incoming solar power which is converted to electricity). $\eta = \frac{V_{oc} * I_{sc} * FF}{P_{in}}$

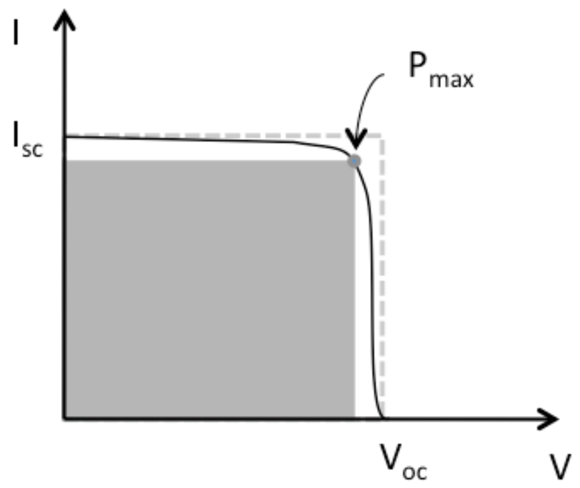

Figure 1. The I-V characteristic of a solar cell, illustrating V_{oc}, I_{sc} and the maximum power point denoted P_{max}. The fill factor is the ratio of the maximum area within the I-V curve (the grey area) to the product of V_{oc} and I_{sc} (the dashed area).

Method

To simulate solar irradiation a QuickSun 120CA, Cell Solar Simulator system was used. The PV module was connected to the system as shown in Figure 2 below. The system sent a flash of a specific, desired radiance to measure the parameters; I_{SC}, V_{OC}, P_{max}, FF, and η. A computer program then saved the results in a text-file, and plotted the results in graphs to facilitate the analyzing.

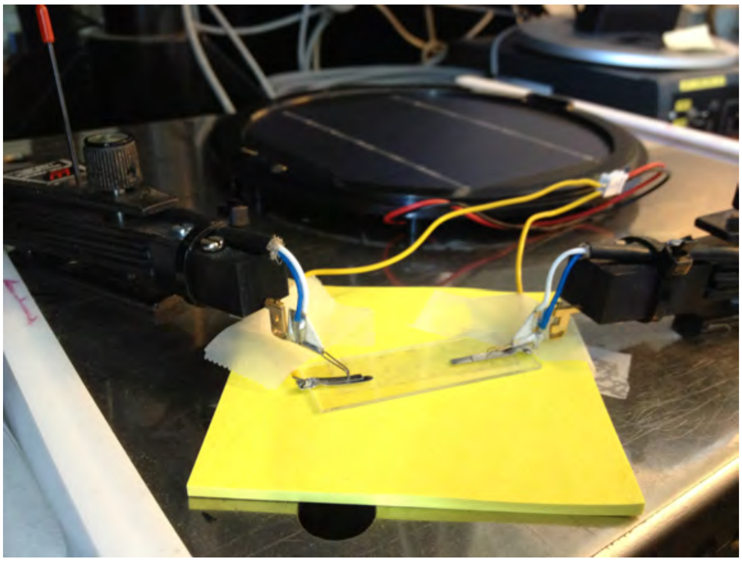

Figure 2. Set-up of the test of a HiLight.

This method was used to evaluate two HiLights with the same properties, to examine if the results would differ. The names used in this report to separate the two HiLights are HL100 and HL107, according to HiNation's own naming system.

The cell area was calculated and used as an input parameter in the computer program. The HiLight consist of six cells with an area of 23.75 cm^2 per cell. Before conducting the tests on the PV module the system was calibrated with a solar cell that had a known short circuit current at a given radiance.

Measurements for solar irradiation between 200 W/m^2 and 1000 W/m^2

The Quicksun 120CA can operate within the interval of 200 W/m^2 to 1000 W/m^2. Maximum solar irradiation is defined as 1000 W/m^2 whereas 200 W/m^2 is the incoming solar irradiation on a cloudy day[9]. The measurements were performed in this interval, with steps of 50 W/m^2. The measured values got unstable at lower radiances; therefore an average was used for more accurate results.

Measurements with solar irradiation below 200 W/m^2

To perform measurements with solar irradiance below 200 W/m^2 the sunlight outside of the Ångström Laboratory was used. As a reference one could know that a solar irradiation of 50 W/m^2 is defined as shadow[9]. Clouds were simulated with white, thin cloths that were put on top of the PV modules. This decreased the incoming photons that hit the PV surface.

[9] Edoff, Marika; Professor at the Department of Engineering Sciences, Solid State Electronics, Uppsala University. 2013. Introduction to solar cell measurements at Ångström Laboratory, 17 of June.

Two HiLights were used in this test as shown in Figure 3 below. From the top PV module, the I_{SC} was measured. Since I_{SC} is proportional to the solar irradiation, this current could be used to estimate the solar irradiation when adding different layers of cloth. The PV module at the bottom in Figure 3 was fully assembled with the battery and circuit board into a HiLight. The HiLight has an indicator that flashes when the battery is being charged. Both PV modules were covered with cloths until the charging indicator was turned off. These measurements were made with the purpose to see at which solar irradiation the HiLight would stop to charge.

Figure 3. Measurements below 200 W/m^2. Note that only one of the multimeters in the picture was used. This was attached to the top PV module to measure the I_{SC}.

Calculating the number of hours required to fill up the battery, with respect to solar irradiation

In the field, a multimeter can be used to measure the I_{SC}. When the value of I_{SC} is known, it can be used to approximate the solar irradiation. Measurements and diagrams for I_{SC} will be used, since this parameter does not change as much with temperature as V_{OC}[9].

To calculate the number of hours of charging required to charge the battery from empty to full, the following calculations were made:

The battery capacity is 3.9 Ah and 3.7 V (HiNation 2013). This is equal to 14.43 Wh.

The output power for each solar irradiation can be calculated from Equation 1.

$$P_{max} = V_{mp} * I_{mp} = V_{OC} * I_{SC} * FF \quad \text{(Eq. 1)}$$

When knowing the values for V_{OC}, I_{SC}, and FF for each value of solar irradiation, Equation 2 can be used to calculate the number of charging hours required.

$$Number\ of\ charging\ hours\ [h] = \frac{14.43\ [Wh]}{V_{OC} * I_{SC} * FF\ [W]} \qquad \text{(Eq. 2)}$$

Results

The results can be seen in Figure 4 to Figure 11.

The I_{SC}, V_{OC}, and FF are measured values. The number of hours required to fully charge the battery was calculated from these measured values, together with the capacity of the battery. The efficiency of the modules can be approximated to 16 %.

The measurements for solar irradiation below 200 W/m^2 showed that the HiLight was able to charge its batteries down to a radiance of 20 W/m^2. This is a result to be aware of but in Figure 10 and Figure 11 irradiations below 200 W/ m^2 was not plotted. The reason for this is that the values below 200 W/m^2 gave uncertain results due to large fluctuations of the values for each measured parameter.

From the measured values of the short-circuit current a linear approximation for values down to 0 W/m^2 was made. This can be seen in Figure 4 to Figure 5.

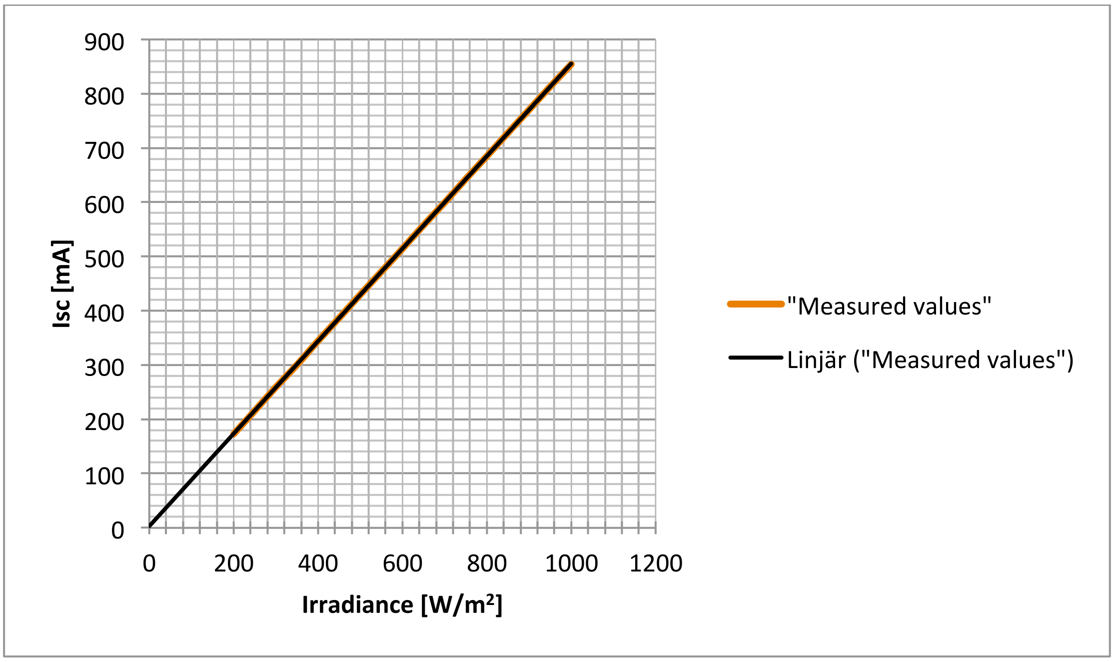

Figure 4. Short-circuit current for HL100. The black line is a linear approximation of the measured values.

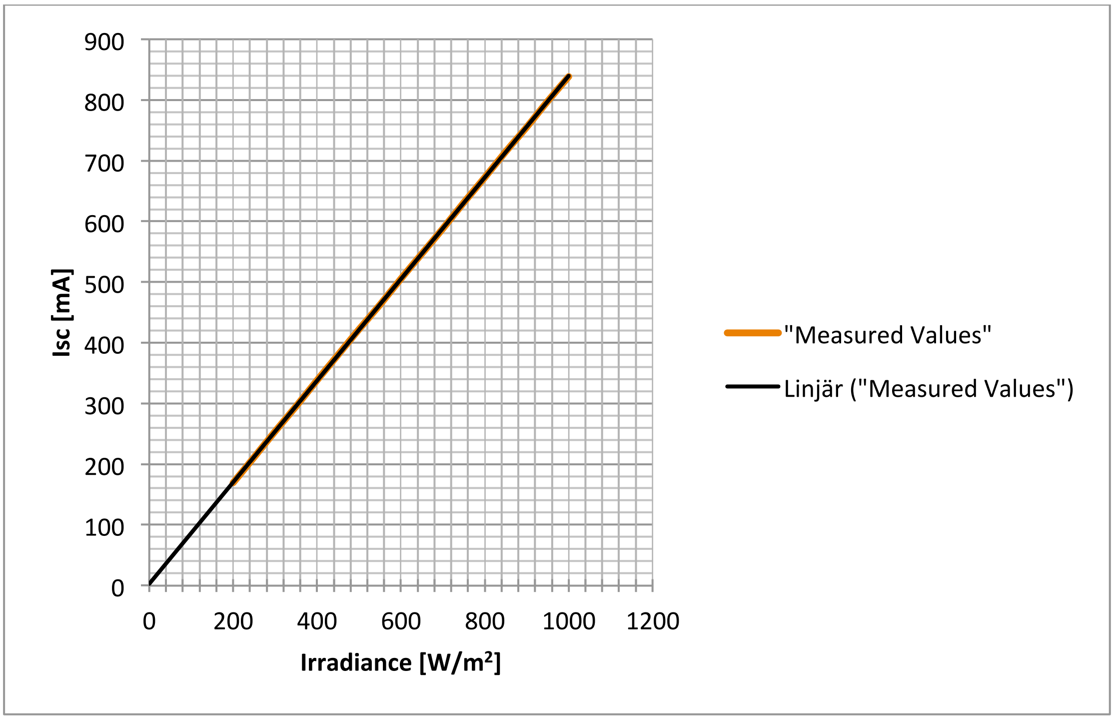

Figure 5. Short-circuit current for HL107. The black line is a linear approximation of the measured value

The open-circuit voltage can be seen in Figure 6 to Figure 7. The values that were measured when clouds were simulated (for irradiations below 200 W/m^2) were added.

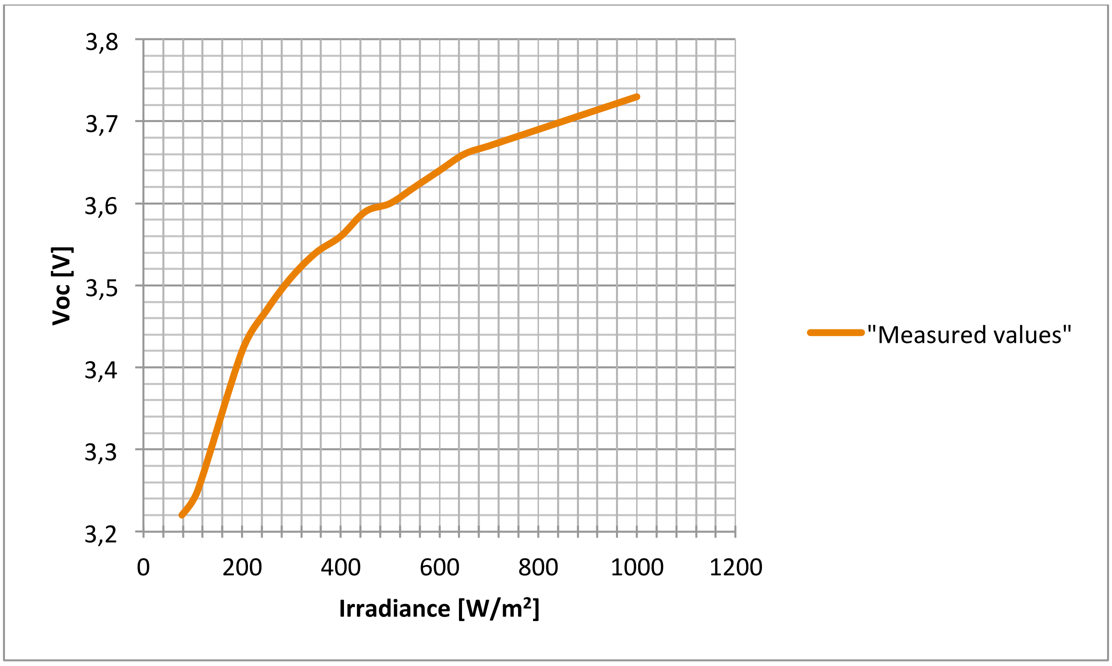

Figure 6. Open-circuit voltage for HL100

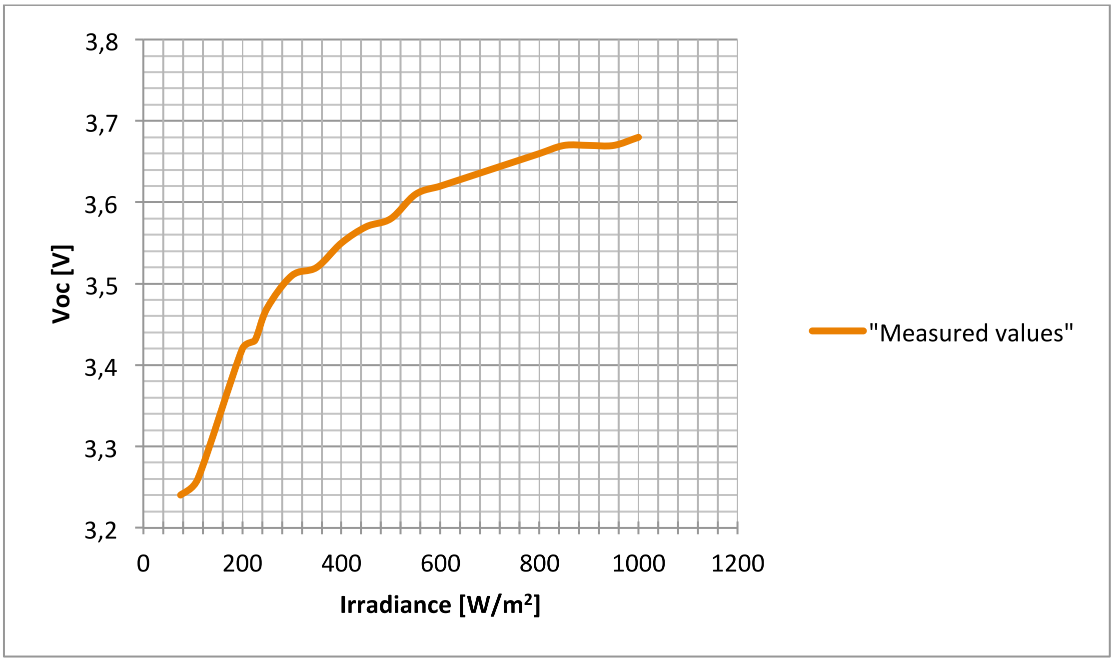

Figure 7. Open-circuit voltage for HL107

The fill factor for the two PV modules can be seen in Figure 8 to Figure 9. For solar irradiance below 200 W/m^2 a fill factor of 78 % was assumed for the HL100. This assumption was based on measurements when adding simulated clouds while doing measurements with the Quicksun 120CA. When less and less solar irradiance reached the PV module, the fill factor was approximately 78 %. No similar tests were made for the HL107, therefore data on solar irradiances lower than 200 W/m^2 this is left out.

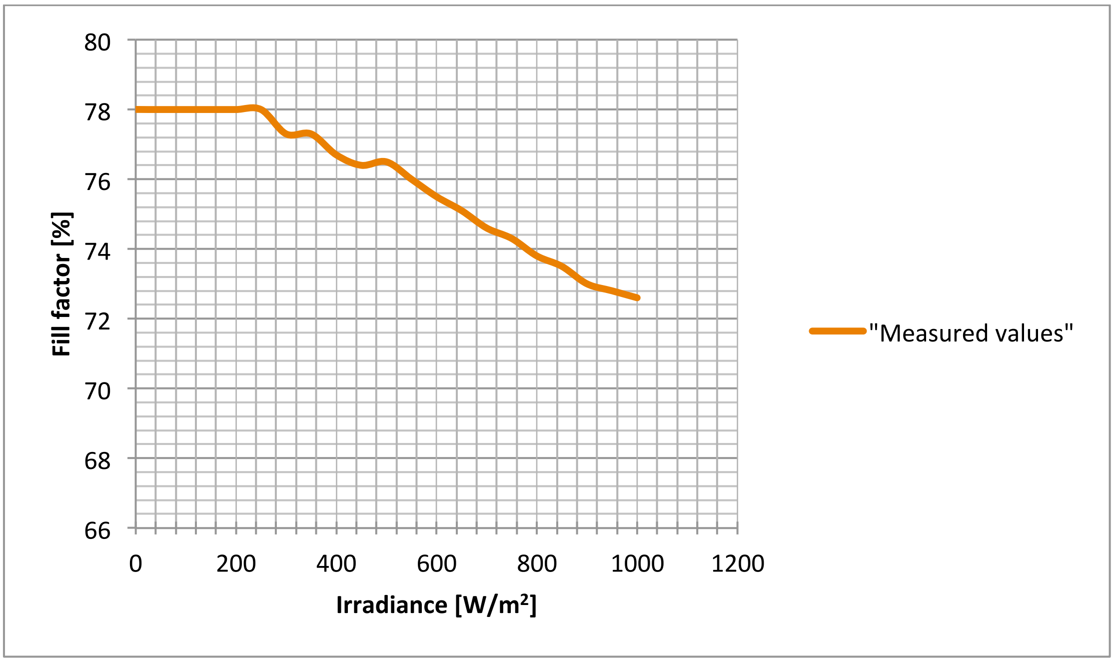

Figure 8. Fill factor for HL100

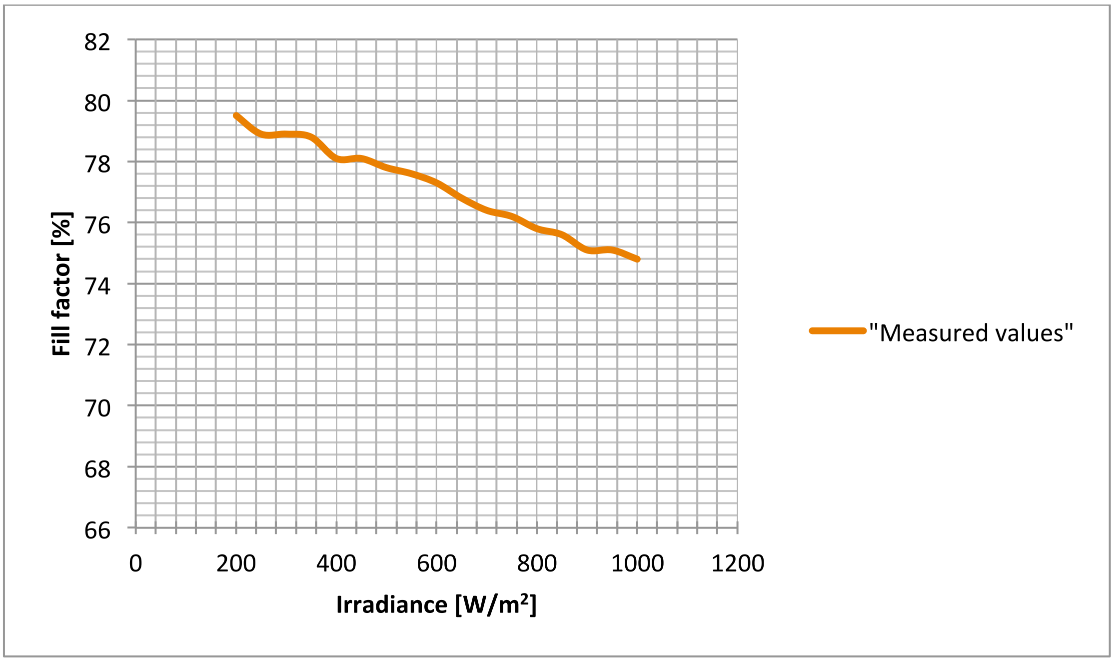

Figure 9. Fill factor for HL107

The results from the calculations of required charging hours can be seen in Figure 10 and Figure 11 below.

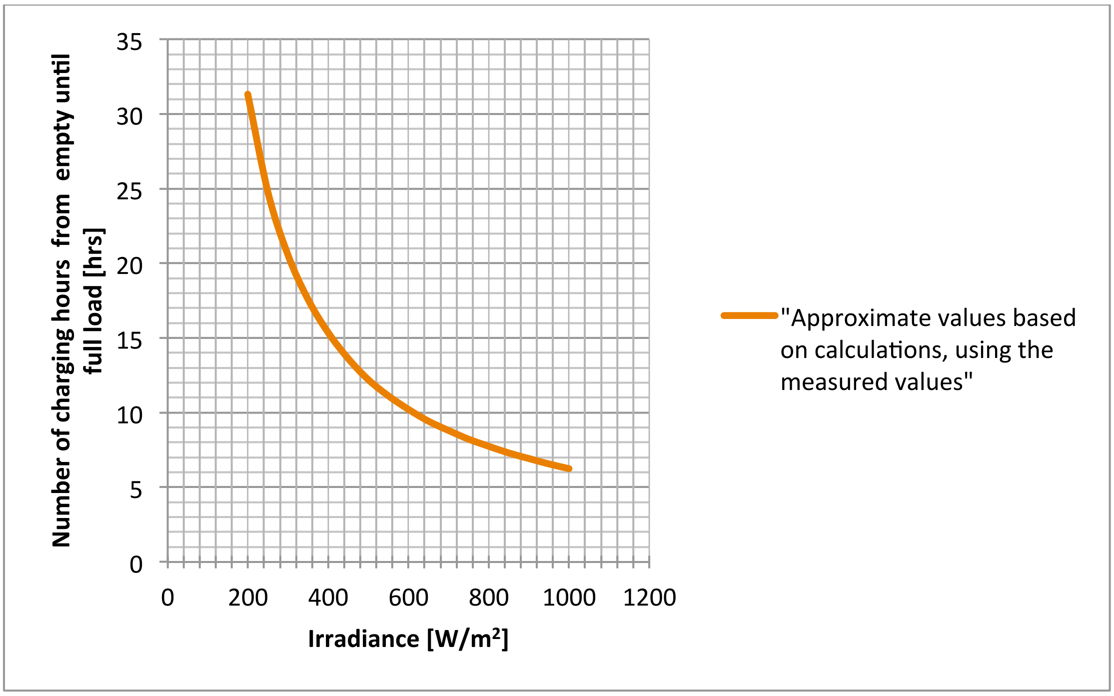

Figure 10. Number of charging hours required to fill up the battery for HL100

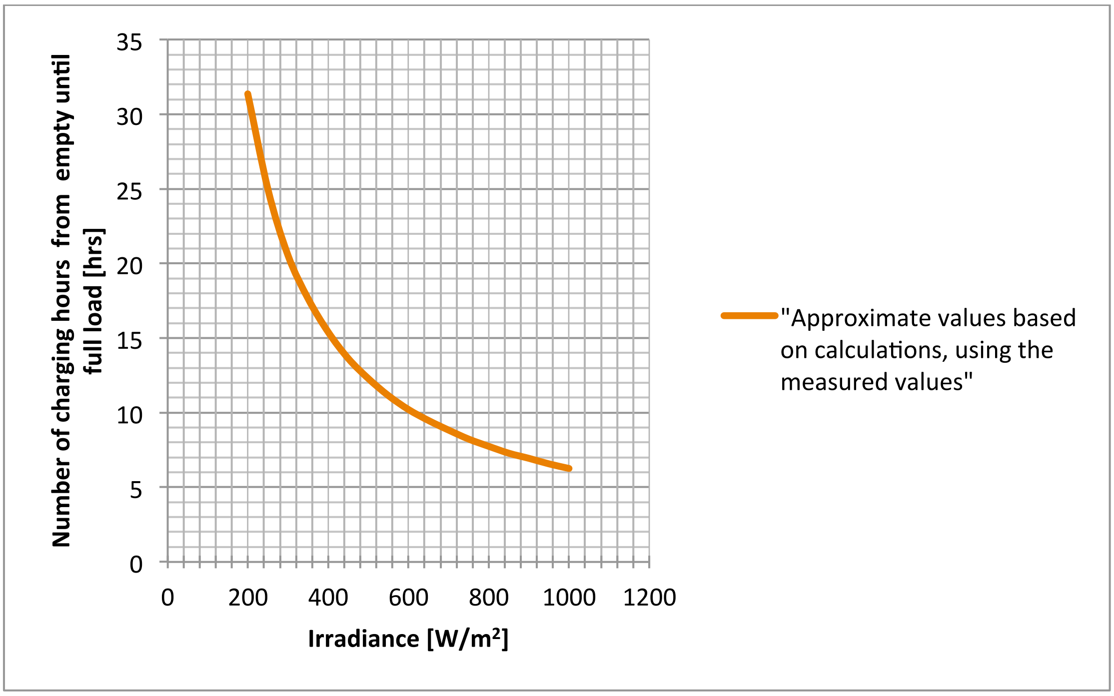

Figure 11. Number of charging hours required to fill up the battery for HL107

Discussion and conclusions

Firstly, it should be stressed that only values for the PV modules were measured. The performances of the battery, LED lamp etc. have not been evaluated in this pre-study. How the assembled HiLight works in the field is in the plan for the fieldwork and will be evaluated together with the community members in the State of Amazonas.

As seen in Figure 8 and Figure 9 the fill factor increases with lower solar irradiation. This is most likely a result of a high series resistance. The series resistance is a collective name for three different resistances that can occur between the cells in a PV module. The values for the series resistances were measured to 73 mΩ per cell for HL100 and 110 m Ω per cell for HL107.

The series resistance affects the PV module performance more at higher short-circuit currents, which occurs at higher solar irradiation. This means that the PV modules are optimized for low solar irradiation. The fill factor should be constant for all values of incoming solar irradiation. If HiNation doesn't have a purpose with the fact that the PV module is optimized for low solar irradiation; this is something that HiNation is recommended to further investigate.

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Appendix D: Interview results

D.1 Caioé

Figure 1. Microclimate of Caioé

Name of community	*Caioé*
Location	*Caioé is part of the State Park of Rio Negro. 38 km from Manaus, 1 hour by motorboat.*
Number of households	*22 families in 13 households*
Important structures of the community	*Community center, church, farinha house and a school*
Energy supply	*Caioé has a diesel generator that belongs to the school. Six of the households have their own diesel generators with specifications shown below.*
Energy consumption	*The diesel generator of the school consumes 520 liters of diesel per month.*
Energy availability	*Some of the families have their own diesel generator, which data is shown below. The school generator that some of the families use runs for 12 hours per day.*
Electricity usage	*The electricity is mainly used in the school, church and for running home appliances such as television, refrigerator and washing machines.*
Water supply	*The community use the river water for drinking water which they clean with chloride tablets*
Future energy plan	*The community is in the plan for isolated systems until 2023. The plan means that the upgrade of the system will be paid by Eletrobrás.*

1.1.1. Generator - Mr. Adonias Fernandes dos Santos

- Type of generator: diesel generator 6kVA - 10HP;
- Fuel consumption: 300 liters/month;
- Fuel cost: R$2.60/liter of diesel;
- Operating time generator: 5 hours per day (18:00 to 23:00).

1.1.2. Generator - Mr. José Ribamar

- Type of generator: gasoline generator 5kVA;
- Fuel consumption: 150 liters/month;
- Fuel cost: R$4.00/liter of gasoline;
- Operating time generator: 4 hours per day (18:00 to 22:00).

1.1.3. Generator - Mr. Luiz Bernardo

- Type of generator: diesel generator 3kVA – 5,5HP;
- Fuel consumption: 150 liters/month;
- Fuel cost: R$2.60/liter of diesel;
- Operating time generator: 4 hours per day (18:00 to 22:00).

1.1.4. Generator - Mr. Elias dos Santos da Silva

- Type of generator: diesel generator 15kVA – 22HP;
- Fuel consumption: 120 liters/month;
- Fuel cost: R$2.60/liter of diesel;
- Operating time generator: 4 hours per day (18:00 to 22:00).

Microclimate

The community of Caioé lies by the river and has many open areas. Some trees still stand within the community but they are not considered a problem for shadowing the panels since the sun stands almost in zenith during the day. The microclimate in Caioé is in this way suitable for solar panels.

Date of interviews
First interview opportunity: 13th of September 2013
Second interview opportunity: 26th of September 2013

D.1.1 Caioé – Adonias Fernandes dos Santos

Name	*Adonias Fernandes dos Santos*
Occupation	*Leader of Caioé*
Energy supplier	*His own diesel generator*
Number of hours with electricity	*4 hours per day*
Cost of energy per month	*R$ 520 per month for diesel and an extra of R$ 25 per month for oil that he has to mix with the diesel.* *He also uses 12 batteries per month, R$ 2 per battery.*
Current electricity usage	*He uses the electricity for a refrigerator, television, to charge cell phones, running a light and a fan.*
Possible usage areas with extra electricity	*He would use it for cooling more products that he could sell but also for extended use of the already existing usage areas.*
What do you think you will use the HiLight for?	*For light and charging his cell phone*
Water supply	*From the river, cleaned by chloride tablets*
Received equipment	*A HiLight and an octopus*
Considered reasonable price for a HiLight	*R$500*

Figure 2. Adonias Fernandes dos Santos

First interview opportunity

Adonias wakes up really early to go out to fish. To do this he uses a flashlight with re-chargeable batteries. He thinks he is going to use the HiLight for light and to charge his cell phone.

Second interview opportunity

Adonias thought the HiLight was very useful; he used it mainly as a light source and to charge his families' cellphones. With the HiLight he didn´t have to turn on the diesel generator for these purposes.

The HiLight's battery had been fully discharged during this period and it took him a few days to figure out how he could shock the battery.

He didn´t use the HiLight when fishing since the light from the HiLight is to scattered. He would like it to be more focused if used for fishing. He thinks the best solution is to have a headlamp that would make him able to use both his hands while working.

They used the HiLight when receiving guests by the river and to show them the way up to the house.

Sometimes the generator of the family breaks. It can then take a few days or a week to get it fixed. Adonias thinks the HiLight will be really good to use during these circumstances.

He saved 20 liters of diesel during the 13 days with the HiLight.

The lower lamp setting was enough for lightning a room up.

Adonias thinks that the HiLight could bring many benefits to the State of Amazonas. Especially to health clinics that needs light to receive patients and handing out medicines.

"Thank you for bringing light into our lives."

He would consider paying R$500 for a HiLight.

Table 1. Adonias Fernandes dos Santos

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	4	2	1
2	4	2	3
3	3	2	2
4	4		3
5	4		1
6	4		4
7	4		2
8	4		1
9	4		
10	4		
11	4		
12	4		
13	4		
14	4		
15	4		
16	4		

D.1.2 Caioé – José Ribama Ferreira dos Santos

Name	*José Ribama Ferreira dos Santos*
Occupation	*Retired technician that now works with poultry*
Energy supplier	*José has an own gasoline generator*
Number of hours with electricity	*4 hours per day, everyday of the month*
Cost of energy per month	*R$ 7.50 per day which is an average of R$ 225 per month. He also pays R$22.50 per month for batteries for a lamp.*
Current electricity usage	*José uses the electricity mainly for television, radio, charging his cellphones and light*
Possible usage areas with extra electricity	*He would use it for cooling more products that he could sell but also for extended use of the already existing usage areas.*
What do you think you will use the HiLight for?	*For light, listening to radio and charging cellphones*
Water supply	*From the river or rain water*
Received equipment	*One HiLight, battery charger and batteries, and a fan.*
Considered reasonable price for a HiLight	*R$300*

Figure 3. José Ribama Ferreira dos Santos

First interview opportunity

José thinks he will use the HiLight for light, to charge batteries for his cellphone and lantern, and to listen to the radio.

He uses batteries for a flashlight during the night.

Second interview opportunity

José found that the HiLight was very useful. He used it to charge batteries for his radio and his cellphone. He pointed out that it was not useful for bigger appliances such as the fridge or television. The light from the HiLight was very useful since it would illuminate the whole room.

José complained about the noise pollution from his generator, it was so loud he couldn´t hear the radio during the night. With the HiLight he didn´t have to turn on the generator and could listen to the radio. This was beneficial both in avoiding the noise pollution and avoiding the costs of gasoline.

José also tried an USB-driven fan that he could connect to the HiLight. During the day it was to hot and the fan to small to make it cooler but he said it worked better during the night.

José had to kick start the HiLight during this period.

He saved 5 liters of gasoline per 2 days, three 3V batteries on four days (1 battery has the cost of R$2.0).

He had no problems with the HiLight but he is a little bit skeptical on how it is going to work during the rain season. But he thinks he will be able to load it during the some hours when the sun comes out during the rain season.

He also would like a bigger solar system that could support bigger appliances such as a refrigerator and television.

He said that the reputation about the product would spread. He also commented that people who are retired or in governmental projects needs to go to municipality sedge, the capital of the municipality, to collect their monthly payments and there they could also buy a HiLight if available.

Waste disposal

Until a year ago there was a boat collecting the trash in the area. Now there are plans discussing to get this service started again.

José uses a lot of batteries. Since the municipality doesn´t has any good waste management he throws the trash into holes big enough to last for a month. He then burns the trash and makes a new hole. He also uses this hole to throw away the used batteries.

He would still consider to pay R$300 for a HiLight.

Table 2. Jose Ribama Ferreira dos Santos

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	2	5	
2	6	8	1
3	10	5	
4		9	
5	9	8	1
6			
7			
8	9	4	1
9	4	4	
10	10	6	
11		5	1
12	4	4	
13	8	6	1
14			
15			
16			

D.1.3 Caioé – Teachers

Names	*Marina Nascimento Queiroz* *Denisson Souza da Silva* *Josenilda Palma Panteja*
Occupation	*Teachers in the school of Caioé*
Energy supplier	*The school has its own diesel generator*
Number of hours with electricity	*12 hours per day*
Cost of energy per month	**-**
Current electricity usage	*Computers and light*
Possible usage areas with extra electricity	**-**
What do you think you will use the HiLight for?	**-**
Water supply	**-**
Received equipment	*One HiLight*
Considered reasonable price for a HiLight	**-**

Since the teachers of Caioé didn´t attend the first meeting, data was collected from interviews at the second interview opportunity with the community therefore some data is missing.

Josenilda was very pleased with the HiLight. She said that there are a lot of animals such as poisonous snakes and that it´s necessary to have light to see them during the night. She thinks that it wont be possible to use the HiLight during the rain season.

Denisson pointed out that people in isolated communities have a cellphone even though they lack service. The people in these communities often bring their phone to other communities that have service to make calls. He thinks the HiLight would be of great use to these people.

Marina says that she didn´t use any batteries during the period with the HiLight.

As suggestions to make the product better they think it would be very useful with two USB-ports.

Figure 4. Josenilda Palma Panteja and Danisson Souza da Silva. Photo by Georgia Sinimbu Silva.

Table 3. Teachers in Caioé

Day	Number of hours charged from the sun	Number of hours of using the light	Number of hours of charging cellphones and other appliances.
1		3	
2		12	
3	2		

D.1.4 Caioé – Elias dos Santos da Silva

Name	*Elias dos Santos da Silva*
Occupation	*Gardener and housekeeper*
Energy supplier	*Has his own diesel generator*
Number of hours with electricity	*4 hours per day*
Cost of energy per month	*R$160 per month for diesel plus an extra R$5.20 per month for a diesel lamp.*
Current electricity usage	*Light, charging cellphones and using a freezer*
Possible usage areas with extra electricity	*He would use it to start a trade with frozen products such as chicken, and to be able to sell cold beverages.*
Thinks he will use the HiLight for…	*For light and charging his cellphone.*
Water supply	*From the river, cleaned by chloride tablets*
Received equipment	*One HiLight*
Considered reasonable price for a HiLight	*R$ 300, but he emphasized that the value of the product is greater.*

Figure 5. Elias dos Santos da Silva and his family

First interview opportunity

Elias has for the last seven years worked to maintain the facilities and yard of a congressman’s house. He said that the time when he has energy is the time when he has money. He hopes that the HiLight will be of help during the month when he can´t afford diesel to the generator, mostly for light and charging cellphones.

Second interview opportunity

In the interview, Elias wife also made some comments.

The family really liked the HiLight. Since they can´t always afford diesel they have to go to another community to charge their phones. With the HiLight they didn´t have to do this trip.

They mainly used the HiLight for light and to charge their three cellphones. The wife bought an octopus cable from a relative for R$10.

Evaluating the light they thought that the HiLight’s light was strong enough to light up the whole house.

They think that they can use the HiLight during the rain season when the sun comes out.

They saved R$80 on not having to buy diesel during one week with the HiLight.

During the period when trying the HiLight they saved money on not having to buy batteries. Before receiving the HiLight they bought three batteries for R$1.50 five times a week, a total of 15 batteries per week for R$22.5.

When using the HiLight they only bought six batteries per week which is a cost of R$9 per week.

The HiLight also enabled the family on not having to use their diesel lamp that generated a lot of black smoke that resulted in black walls and made it hard to breathe.

Elias thinks that some environmental benefits of using the HiLight is that you could avoid spilling diesel, and to bury and burn batteries.

Elias thinks the HiLight is worth R$400 but can only afford to buy one for R$300.

Waste disposal

The family digs a hole every week that they fill with trash that they burn. They have been taught not to burn batteries so they separate the batteries from the trash and put them in a plastic bag that they bury separated from the rest of the trash in the ground.

Table 4. Elias dos Santos da Silva

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	10	2	
2		2	
3		2	3
4	5	2	
5		2	
6		1	
7		1	3
8	10	2	
9		2	
10		2	3
11		2	
12		2	
13			
14			
15			
16			

D.2 Nova Esperança

Name of community	*Nova Esperança*
Location	*The community is located on the left bank by Cuieiras river in Parque Estadual do Rio Negro. 5-6 hours by motorboat from Manaus.*
Number of households	*17*
Important structures of the community	*Community Center, medical center, church and a school*
Energy supply	*The community has a diesel generator that runs when the school has classes. The community gets 700 liters of diesel from the Secretary of Education of Manaus.*
Energy consumption	*850 liters of diesel per month. The community pays R$ 2.50 per liter diesel. Every household pays R$ 25 for the extra diesel each month.*
Energy availability	*The diesel generator runs for 4 hours per day during weekdays and 3 hours per day during weekends. When the school receives food for the school children from Manaus, the generator operates 8 hours per day to preserve the food. Manaus delivers food every 15 days, but it is not always carried through.*
Main energy use areas	*Community center, church, medical center and school. Other usage areas are the pump for the well and tools for handcraft production.*
Water supply	*A well that is not used at the moment because it needs cleaning. Instead river water is being used and cleaned with chloride tablets.*
Future energy plan	*The community is in the plan for isolated systems until 2023. The plan means that the upgrade of the system will be paid by Eletrobrás.*

Figure 6. The microclimate of Nova Esperança, showing the Community Center and Medical Center

Twice per day, the diesel generator is started so the pump for the well can be used. When the community does not have access to diesel and therefore no electricity, they cannot use the well at all. This results in that the people of Nova Esperança are forced to drink the river water instead. Drinking the river water results in health problems such as diarrhea among the community members.

Lacking electricity also results in lack of income. When the diesel generator is not running, the tools for handcraft productions cannot be used and therefore fewer handcrafts are produced.

Microclimate

The community of Nova Esperança is located by the riverbank of Cuieiras. The community has an open microclimate with few trees around the houses and many open areas. The microclimate makes it suitable for solar power.

Date of interviews

First interview opportunity: 12th of September 2013
Second interview opportunity: 27th of September 2013

D.2.1 Nova Esperanca – Geandro Reis da Costa

Name	*Geandro Reis da Costa*
Occupation	*Teacher of information and physical education*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*4 hours per day*
Cost of energy per month	*R$25 for the community diesel generator.*
Current electricity usage	*Charge cellphones, his notebook and battery for a flashlight*
Possible usage areas with extra electricity	*He would use it for extra home appliances like a TV, notebook etc.*
Thinks he will use the HiLight for…	*To charge his cellphone, use it as a flashlight and to charge his notebook*
Water supply	*From the river, cleaned by chloride tablets*
Received equipment	*A HiLight*

Figure 7. Geandro Reis da Costa

First interview opportunity

The community receives 700 liters of diesel per month donated by the Secretary of Education in Manaus. This donation is made so that the diesel generator can run when the school has classes. Geandro thinks the need for energy is much greater. They can use a maximum of four hours per day in the community and the school classes uses most of these hours which means that many nights the community doesn´t have electricity. The electricity in school is used for showing power points, running the computers and for the IT-classes they have during the night.

Geandro claims that if the community could get more access to electricity they could increase the souvenir production that is the biggest income for the community.

Second interview opportunity

Didn´t participate.

Table 5. Geandro Reis da Costa

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1		8.5	
2		8.5	
3		8	
4		5.5	1 speaker
5		3	
6		5	
7		2	
8			
9			
10			
11			
12			
13			
14			
15			
16			

D.2.2 Nova Esperanca – Jonas Garrido Melo

Name	*Jonas Garrido Melo*
Occupation	*Hunter, health agent and student*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*4 hours per day*
Cost of energy per month	*R$25 per month for the community diesel generator and an extra R$2.50 per month for one liter of diesel for a lamp*
Current electricity usage	*Television, cellphone charging and light*
Possible usage areas with extra electricity	*He would like to have other home appliances such as a fan and a refrigerator*
Thinks he will use the HiLight for…	*To replace his flashlight and cellphone charging.*
Water supply	*From the river, cleaned by chloride tablets*
Received equipment	*A HiLight and an external LED lamp connected to the HiLight with a USB cable*

Figure 8. Jonas Garrido Melo

First interview opportunity

Jonas wakes up early between 4 and 5 am to hunt animals for the community. He also hunts during the night after the diesel generator has been turned off. When the diesel generator is turned off he uses a capivara, a flashlight connected with a heavy battery that he carries into the forest.

If people have an emergency or needs medication he has to turn the generator on, he now hopes to be able to use the HiLight to save diesel.

Figure 9. Jonas with his capivara

Second interview opportunity

Didn´t participate.

D.2.3 Nova Esperanca – Rosimeire Garrido

Name	*Rosimeire Garrido*
Occupation	*Kasike (the leader of the community), and a crafts woman*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*4 hours per day*
Cost of energy per month	*R$25 per month for the community diesel generator and an extra R$20.50 per month for batteries for a flashlight and diesel for a lamp.*
Current electricity usage	*Television, cellphone charging and light*
Possible usage areas with extra electricity	*She would use it for food preservation and to make wood crafts*
Thinks she will use the HiLight for…	*For light and cellphone charging*
Water supply	*From the river, cleaned by chloride tablets*
Received equipment	*A HiLight and an octopus cable*

Figure 10. Rosimeire Garrido

First interview opportunity

As a leader of the community, Rosimeire, has to sign documents for the people of the community if they want to go to Manaus. The documents are often applications for different governmental programs that give aid to indigenous people. The only time that she has time to sign these documents is during the night, but then the diesel generator is not running so she hopes to be able to use the HiLight for this purpose since she has bad eyesight.

Second interview opportunity

Rosimeire was very happy with the HiLight. When she was working in the cassava root field she asked her children to take care of the HiLight, to bring it in if it started to rain etc. She didn´t get the charging of cellphones to work so she only used the HiLight for illumination.

During the interview we showed her how she could charge her cellphone, she thought the manual that was handed out was very hard to understand and she didn´t understand the part about charging devices even though she red it three times. She understood the part of shocking the battery, which she had to do three times.

She would like a manual with more pictures to make it easier.

She was also a little bit scared of using the button and the product since she didn´t want it to break.

The light was enough to light the whole room. She didn´t bring it outside since she was afraid it might break.

The HiLight replaced her diesel lamp and the batteries. She didn´t buy any diesel during the days she used the HiLight.

When using the diesel lamp she has a short wick so it won't produce so much soot. This makes the flame very sensitive to winds. Her children doesn´t want to sleep in the dark so she has the diesel lamp turned on. The wind often blow the light out so she has to go up during the nigh to re-light the lamp. She didn´t have to do this with the HiLight. The children also prefers it since it lights up the whole room instead of the diesel lamps that only gives a weak light.

She was very happy to use the HiLight as a light source instead of the diesel lamp that would put a lot of soot on her bed linens. She also used it to sign documents for the people in the community.

Since she is also studying in the community school she could use the HiLight for homework since the diesel generator was turned of when she got home.

Rosimeire said that everyone in the community would like to have a HiLight and she would be the first person in line to buy it. She prefers it to a diesel lamp.

Since the community doesn´t always have diesel, some nights are very dark.

During the rainseason she says that they have some sun but she´s not sure that the HiLight will work.

She would consider paying R$100 for a HiLight.

Waste disposal

Rosimeires husband don´t like to throw batteries in the nature so they collect batteries in a box that they bring to a community nearby where Secretary of Health collects them and take them to Manaus.

Table 6. Rosemeire Garrido

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	4	8	
2	6	8	
3	8	4	
4	9	8	
5	9	8	
6	9	7	
7	8	6	
8	9	6	
9	9	6	
10	8	6	
11	9	7	
12	9	6	
13	9	6	
14	9	7	
15	9	6	
16	9	6	

D.2.4 Nova Esperanca – Ugulina Garrido

Name	*Ugulina Garrido*
Occupation	*Midwife*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*4 hours per day*
Cost of energy per month	*R$25 per month for the community diesel generator plus an extra R$2.50 for one liter of diesel for her lamp*
Current electricity usage	*Television, refrigerator and to charge the cellphone*
Possible usage areas with extra electricity	*Other household appliances such as a washing machine and a refrigerator*
Thinks she will use the HiLight for…	*For light and charging her cellphone.*
Water supply	*From the river, cleaned by chloride tablets*
Received equipment	*A HiLight and an octopus cable*

Figure 11. Ugulina Garrido

First interview opportunity

Ugulina claims that the big problem is that they, in her family, have to choose who can charge their cellphone every night. When she delivers babies, sometimes in the middle of the night, she has a diesel lamp. It has happened that she delivers the baby, right after refilling the diesel lamp, with diesel on her hands.

Second interview opportunity

Ugulina said that the HiLight and the project is a blessed thing that came to her to replace her diesel lamp.

She used the HiLight to charge her sons cellphone and then mainly for light.

She would charge the HiLight for about 4 hours per day and then use it in the house as a lamp on the lower setting between 22:00 and 05:00. She was very happy with the light since it illuminated the whole room. She didn´t use her diesel lamp during this period.

She´s not sure on how it would work during rain season.

Ugulina says that a product like the HiLight would be very useful to improve peoples lives, especially to avoid the diesel lamp. She also thinks that the HiLight would be very useful when helping with delivering babies. She had to kickstart the device twice during the trial period. When the community doesn´t have diesel to use the generator they could gather around the HiLights.

Table 7. Ugulina Garrido

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
Every day	4	7	

D.3 Terra Preta

Name of community	*Terra Preta*
Location	*Terra Preta is part of Àrea de Proteção Ambiental (APA) Margem Esquerda do Rio Negro, 54 km from Manaus, 4 hours by a motorboat.*
Number of households	*36*
Important structures of the community	*Community Center, medical center, church, farinha house and a school*
Energy supply	*The diesel generators specifications is 55kVA and has 75 HP.*
Energy consumption	*1600 liters of diesel per month. They pay R$ 2.50 per liter. They get 1000 liters of diesel from the Municipality of Manaus. The remaining 600 liters are paid by the households that pay R$ 25 per month.*
Energy availability	*The diesel generator runs for 11 hours per day: 4 hours in the morning, 2 hours in the afternoon and 5 hours during the evening and night.*
Main energy use areas	*The energy is used mainly for fridges for food preservation, pump for the water well, production of handcrafts, televisions and washing machines.*
Water supply	*The community has a well that they use for water which they clean with chloride tablets*
Future energy plan	*The community is in the plan for isolated systems until 2023. The plan means that the upgrade of the system will be paid by Eletrobrás.*

Figure 12. Microclimate of Terra Preta

Terra Preta has a diesel generator that is turned on in the morning for the school and the morning classes. When it is turned on the energy is also used to charge cellphones, listening to radio and cooling water. The diesel generator also runs during the night when the community has night classes for adults. The school also receives students from other communities.

When the generator is turned off for the night, about 10.30 pm, the community members use small diesel lamps as a light source. They claimed that the smoke from the lamps made it hard to breathe and they would like to avoid this light source if possible.

Sometimes when tourists visit their community, they ask to charge their cellphones. It is not possible to turn on the whole diesel generator system for this purpose and they hope to be able to help with this with their HiLights. Maybe this creates an extra income for the people of the community.

One of the members of the society is paid to take care of the water of the community. Some of the houses have their own water tanks that fill up with rainwater, but they also have a well and shared water tanks.

Microclimate

Terra Preta has many open areas and are in this way suitable for solar panels.

Date of interviews
First interview opportunity: 13th of September 2013
Second interview opportunity: 10th of October 2013

D.3.1 Terra Preta – Clodoaldo Silva Aleixo

Name	*Clodoaldo Silva Aleixo*
Occupation	*Health agent*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*11 hours per day*
Cost of energy per month	*R$25 for the community diesel generator and an extra R$9 per month for flashlight batteries*
Current electricity usage	*Cooling of water, food preservation, watching television, and two electrical drills used for souvenir production. He makes an ice cream called GinGin that he sells for R$ 0.5 to other people in the community.*
Possible usage areas with extra electricity	*He would like to invest the extra electricity in equipment that would make it possible for him to sell snacks and food.*
Thinks he will use the HiLight for…	*Use the light when making handcrafts, charge the batteries for his radio, charge the cellphone*
Water supply	*From a well*
Received equipment	*One HiLight*
Considered reasonable price for a HiLight	R$ 200

Figure 13. Clodoaldo Silva Aleixo

First interview opportunity

Clodoaldo works as a health agent in the morning and as a souvenir manufacturer during the afternoon. If he gets extra time during the night he uses it to fish. When he goes out to fish he uses a lantern with batteries that lasts for three to four hours. He hopes that the HiLight will make him able to stay and fish for a longer time, have extra light and be able to charge his cellphone more often. If he got access to extra energy he would be able to work extra with wood manufacturing, such as making doors and windows.

Second interview opportunity

Didn´t participate.

Table 8. Clodoaldo Silva Aleixo

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	4	3	1
2	6	3	1
3	4	4	1
4	6	4	1
5	8	3	1
6	6	2	1
7	6	2	1
8	8	3	1
9	8	3	1
10	8	3	1
11	6	2	1
12	6	1	1
13	6	1	1
14	5	1	1
15	5	1	1
16	7	3	1

D.3.2 Terra Preta – Felliciano Serafin

Name	*Felliciano Serafin*
Occupation	*Farmer*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*11 hours per day*
Cost of energy per month	*R$25 per month for the community diesel generator and an extra R$6 per month for batteries for a flashlight*
Current electricity usage	*Cooling of water and food preservation.*
Possible usage areas with extra electricity	*To be able to work with handcrafts*
Thinks he will use the HiLight for…	*To charge his cellphone*
Water supply	*From a well*
Received equipment	*One HiLight*
Considered reasonable price for a HiLight	*R$200*

Figure 14. Felliciano Serafin

First interview opportunity

Felliciano works with farinha production during the day. In the afternoon he leaves the community for fishing. At sunset he is usually still at the river and uses the moon as a light source when he goes home. He thinks he will use the HiLight to charge cellphones and other small devices and to have as a light source during the night.

Second interview opportunity

Didn't participate.

Table 9. Felliciano Serafin

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	6	3	1
2	6	3	1
3	6	3	1
4	6	3	1
5	6	3	1
6	8	4	1
7	5	3	1
8	5	3	1
9	7	4	1
10	7	3	1
11	7	3	1
12	6	2	1
13	6	2	1
14	6	2	1
15	6	2	1
16	6	2	1

D.3.3 Terra Preta – Rafael J. Bruno

Name	*Rafael J. Bruno*
Occupation	*Leader, and health agent of Terra Preta*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*11 hours per day*
Cost of energy per month	*R$25 for the community diesel generator and an extra R$6 for diesel for a diesel lamp*
Current electricity usage	*Cooling of water and food preservation.*
Possible usage areas with extra electricity	*To extend his work with fruit pulp that he can sell*
Thinks he will use the HiLight for…	*To charge his cellphone and replace the diesel lamp*
Water supply	*From a well*
Received equipment	*One HiLight and an octopus cable*
Considered reasonable price for a HiLight	R$ 120-150

Figure 15. Rafael J. Bruno

First interview opportunity

Rafael thinks he will use the HiLight mainly to charge his cellphone since he is both the leader and health agent of the community. These positions make it very necessary for him to be reachable for the other people in the community that calls him about everything. He would like to see more products like the HiLight since they, in the community, have had some problems with diesel leakage. The leakages generate health problems for the inhabitants of the community since they swim in the river, drink its water etc.

Second interview opportunity

Rafael was the only person from Terra Preta, who received a HiLight, which participated in the second interview opportunity. Since he is the leader of Terra Preta he still had a good understanding of how the other three people used the product and what they thought about it.

Rafael said that as soon as they got back from the meeting in Caioé where they received the HiLight he summoned the community members of Terra Preta to tell them about the product and to teach them how to use it.

Since only Rafael received an octopus cable, they would take turns in using it during the day. When the second interview opportunity took place, the other people from Terra Preta who received a HiLight were in Manaus to buy 3 more cables.

He mainly used the HiLight for charging his cellphone and for illumination after the diesel generator was turned of at 22.00. The light was strong enough to illuminate the whole room. Other usage areas were charging of batteries and radio that the community members use. Since he also works as a health agent he said the HiLight would be very useful for emergencies, though no emergency occurred during this time. He considers the light to be a little bit to weak for childbirths for which he would need a stronger light and bigger battery. But he prefers using the HiLight over a diesel lamp when he treats sick people so that they don´t have to breath the smoke from the lamps when they already feel ill.

Felliciano, one of the other people in the community that received a HiLight, used it for fishing instead of his flashlights.

During the test period he didn´t experience any difficulties with the HiLight. He saw that the red light was turned on a few times and he would then take the HiLight inside for the rest of the day for it to cool off. He also had to kick start it once but found all the answers to these problems in the manual which he thought was good.

He said that he once charged the HiLight from 06.00 to 16.00, until it was fully charged. He then used the light on the strongest setting from 22.00 to 04.00, when it turned off. Rafael therefore means that the battery, even when fully charged didn't last for 10 hours as said.

He thinks he will be able to charge it during the rain season when the sun comes out. But sometimes days will pass without him being able to charge because of the drizzly rain.

There will also be a problem with the humidity in the air he thinks based on his experience with other electronics such as cellphones. Other rain seasons he had problems with moisture that penetrates electronic products so they get moldy and breaks. He has had this problem with cellphones, flashlights and batteries.

Some of the people in the community replaced their single-use batteries with re-chargeable batteries that they charged with the HiLight. Since it is forbidden to throw batteries in the nature, Rafael said that this was a very good solution.

Rafael says that normally the community collects all the single-use batteries from the families and takes them in a box to FAS for them to take care of the batteries. He thinks the HiLight would be an environmental benefit for the Amazonian region in substituting the batteries.

The families in Terra Preta would usually buy three batteries per family per week for a price of R$1.50 each. This would make them save R$18 per month with a HiLight.

As suggestions on improvements he said that he would like the product to be bigger. He also thinks that the evaluation time should be longer than one month as it was in this case. It would be better to do the evaluation after one year.

Also, he claimed that this year is different from other years since the dry season has had much more rainy days than normal.

Rafael thinks that they would need one HiLight per household for it to be useful for everyone in the community. He also urges that a big solar system would be of much greater use to the whole community. He doesn´t think that the Brazilian government would buy this product for people. He would consider paying R$300-400 for the product.

Table 10. Rafael J. Bruno

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	6	3	1
2	6	3	1
3	7	4	2
4	7	2	2
5	7	3	1
6	6	2	1
7	7	2	1
8	7	3	1
9	7	3	2
10	4	1	1
11	4	1	1
12	4	2	1
13	6	2	1
14	6	3	1
15	6	3	1
16	6	2	1

D.3.4 Terra Preta – Samuel Aleixo

Name	*Samuel Aleixo*
Occupation	*Responsible for the diesel generator and water supply of Terra Preta*
Energy supplier	*Community diesel generator*
Number of hours with electricity	*11 hours per day*
Cost of energy per month	*R$25 per month for the community diesel generator and an extra R$5 per month for diesel for a diesel lamp*
Current electricity usage	*Cooling of water, watching television and food preservation.*
Possible usage areas with extra electricity	*To be able to work with handcrafts*
Thinks he will use the HiLight for…	*To charge his cellphone*
Water supply	*From a well*
Received equipment	*One HiLight*
Considered reasonable price for a HiLight	R$ 200


Figure 16. Samuel Aleixo

First interview opportunity

Samuel thinks he will use the HiLight to charge his cellphone. Since he is responsible for the community’s diesel generator, if there is a problem he wants to be able to call Manaus for help. Today, if the diesel generator breaks, he can´t charge his cellphone and therefore not call for help.

Second interview opportunity

Didn´t participate.

Table 11. Samuel Aleixo

Day	Number of hours charged by the sun	Number of hours using the lamp	Number of charged cellphones
1	8	5	2
2	5	3	1
3	7	3	1
4	6	4	2
5	6	2	1
6	4	2	1
7	8	6	2
8	5	3	1
9	5	4	1
10	7	4	1
11	3	2	1
12	8	6	2
13	6	3	1
14	4	3	1
15	5	2	1
16	7	3	1

Appendix E: Interview guide first visit

Community characteristics

- Where is the community located?
- How far is it from Manaus? How long does it take? What is their way of transportation?
- What is the estimated population size?
- Does the community have a community center/church/school/health center/farinha production?

Can you explain what a regular day looks like for you?

Energy consumption at the moment

- What is the energy used for? (church, school etc.)
- How much is spent on energy (liters or Reals)

Water usage

- How do they get hold of the water? (rain, pump, river?)
- How do they clean the water?

What would they like to use the energy for?

- Would it generate social/economical/environmental/health improvements?

Appendix F: Interview guide second visit

General comments on the HiLight

Usage areas

- Tasks
- How did you use the HiLight during this period (charge/use)?
- What did you charge?
- Did you help other members of the community?
- Problems/difficulties
- Suggestions for improvements of the product
- Suggestions on other usage areas

Usage during rain season

Economy

How much can you save on energy, if using HiLight?

Would you still like to buy a product like this? Price?

Where would you go to buy/look for this product?

Could the HiLight bring any benefits to you and your community/Amazon Region?

- Social/Health/Environmental
- Short/Long term

What do you think about the HiLight as a single energy source for a community?

What do you think about a stationary solar power system (100 % solar power) compared with the diesel system you have today?

Waste disposal

Appendix G: Questionnaire for HiLight Testers

Please fill out this form before testing the HiLight

1. Name

   ____

   Name of community ______________________ Occupation ______________________

2. Do you have electricity in your community?

   If **YES**,

   a. How often do you use the electricity?

   ____

   b. What do you use the electricity for?

   ____

   c. What is the cost of electricity per month?

   ____

   d. For what would you need extra electricity?

   ____

3. Do you have a cellphone?

   If **YES**,

   a. How do you charge it?

   ____

   b. How often do you charge the cell phone?

   ____

c. If you pay to charge your cell phone, how much do you have to pay for each charge?

4. What light source do you use today?

5. How much do you pay to get that light?

6. How/For what tasks do you plan to use the HiLight?

Thank you for filling out this questionnaire!

Appendix H: Manual of the HiLight

1. General information about the product:

1 On/Off button

2 USB-port for charging devices

3 Micro-USB entrance for charging the HiLight

4 Solar cells

5 Battery indicators

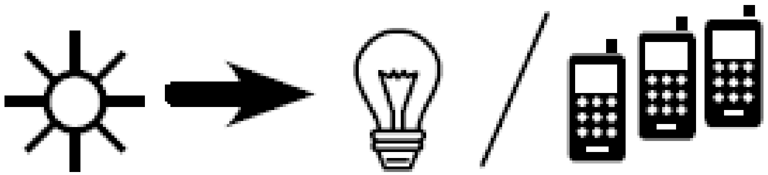
1 Strap

2 LED-lamp

2. Instructions for usage of the product

To charge the HiLight, place the HiLight fully in the sun with no parts of the solar cells shaded.

When the green lights are flashing, the HiLight is charging.



10 hours of charging in the sun

Enables use of the lamp for 10 to 20 hours or to charge 2 to 10 cellphones

3. Battery indicators

- Press and hold the On/Off button for one second to distinguish the battery level of the HiLight indicated by the green lights.
  0 = empty
  1 = partially empty (less than 30%);
  2 = around half (30 – 60%);
  3 = more than half (60 – 90%);
  4 = full (90 – 100%).

4. Using the lamp

- Press the On/Off button once for light up to 20 hours.
- For a stronger light, which will last up to 10 hours, press the On/Off button twice.
- To turn off the light, press the button three times.

When using the lamp, it will flash three times to indicate that the battery is running low.

5. How to charge your device with the HiLight

- Connect your device with the HiLight via an USB-cable
- Press the On/Off button for one second until the green lights turns on
- The HiLight will charge your device when the green lights are lit
- Unplug your device when it´s fully charged or when only one green light is lit on the HiLight
- You can charge your device at the same time as the HiLight is charging from the sun

6. Care

Make sure that the HiLight doesn´t get wet.

7. Problem solving

Problem	Solution
1. The red light is on	The HiLight has been overheated, put it in the shade.
2. The HiLight isn´t charging (the green light doesn't come on) even though it´s placed in the sun. 3. The lamp isn´t functioning 4. The HiLight isn´t charging my devices	i. Connect the USB-cable with the USB to the charged HiLight ii. Connect the uncharged HiLight to the micro-USB iii. Press the On/Off button on the charged HiLight for one second 
5. The HiLight got wet by rain or dropped into water	Remove the orange cover and disconnect all devices from the HiLight. Do not charge it from the sun. Turn of the light. Put in a dry place.