



SoLearn

EPS PROJECT

*“Novel Methods for Education and Promotion
of Photovoltaics”*

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PRESENTATION OF THE TEAM

JORGE NAVARRO

“As a hardware development engineer in my last year of studies my role in the team is to create from zero to that device that we have to accomplish our goal purpose. I develop the technical part of the project, focusing on specs and taking advantages of experience working in engineering departments developing projects.

I came from Polytechnic University of Valencia in Spain, where I studied Industrial Electronics and Automatics Engineering and I chose this project because actually people do not know what renewables energies like solar can do in order to help them and we had an opportunity to demonstrate it in a fully creative way. “

VIOLETTE LE HIR

“I’m a French Student, in Management at Audencia Business School (Nantes). I chose this project because I’m really concerned about the environment issues and because I want to know more about photovoltaics and green energy myself.

My job in this team is the monitor and evaluator because I like to create strategy and evaluate the risks. In this project, I took care of the market analysis and the report writing mostly. I took part of the researches and the ideation process, to share my ideas and show my team some creativity.”

MAXENCE GAUDE

“I’m a French Student reading at the ENIT in France specialized in mechatronics.

I enrol in this project mainly because of the Design Thinking approach coupled with the energy field of application.

As a general engineer I can bring some knowledge to design a complete solution to make sure it’s realistic and then work on every aspect that can’t be done by other members not specialized in some aspects of our prototype.”

DAMIAN OLCZAK

“Currently I’m studying Information Technology at Lodz University of Technology. I also have a bachelor's degree in Applied Mathematics. As such, my contribution to the team mostly involved my knowledge of mathematical analysis and programming. I chose this project because I saw it as an interesting combination of different fields, and I wanted more experience with working in an interdisciplinary project.”

SZYMON KUZMINSKI

“I am a Polish Student of Business and Technology at Lodz University of Technology.

Since my field of studies cover the organizational and the technological side of the working environment, I was trying to connect all of the stakeholders providing them with knowledge and organizational support. That was also the reason why I choose this project. The interdisciplinary team helped me to understand how people from other fields of studies work and gave me the experience for the future.”

INTRODUCTION

The aim of this project “Novel Methods for Education and Promotion of Photovoltaics” is to make photovoltaics more popular. Katarzyna Znajdek and Maciej Sibiński trust us in this task. They have worked on photovoltaics technology for a long time and ask for our creativity and skills to work on this topic. As a tool to achieve the best results of the project we used the Design Thinking methodology, which will be described in further chapters.

"We proposed the open project entitled 'Novel methods for education and promotion of photovoltaics' in order to improve quality and increase the level of people's awareness concerning renewable energies. We want to promote the knowledge and educate new generations of Earth inhabitants about the topics which are connected with the protection of the planet. Free energy from the Sun is definitely one of the issues worth considering.

Apart from that we want to implement the Design Thinking methodology for the realization of the project. This method gives the students tools needed to undergo the project process and freedom in creative thinking of the solutions." Katarzyna Znajdek and Maciej Sibiński.

Nowadays, the commonly used energy in the world is the energy produced from the fossil fuels (81,7%). The sources are limited, therefore consumers want to change, but also because of the huge CO₂ release. The use of photovoltaics is one of the options to reduce this ecological impact, save money, and to become durable. However, people are not aware enough of its potential and efficiency.

Why are their thoughts so negative? Why do they think it is too expensive or too hard to install? We want to help by bringing a new way of education, where there is a big lack of knowledge.

Several solutions already exist, like the classic advertising campaigns by PV companies, some government movements (Uneca, COP21), associations (Solar Cookers International), initiatives from communities and study groups as ours.



These means are working slowly because there is not the right message, not the right way to lead it. Because it is too technical subject, people do not understand how it works and how they can use it, on their own. We have to analyse their questioning before trying to reach their mind. There is a whole process, so the information goes to the right point.

To develop our creativity and reach our target efficiently, we chose to work through the Design Thinking approach. Since we study in different fields, it seemed to be the best way to gather our knowledge and combine our skills.

“Design thinking is an iterative approach to problem solving that intentionally seeks out people with different perspectives, knowledge, skills and experience and has them work together to create a practical solution for a real-world problem. Design thinking uses a process-based approach to solve problems and like any process, it involves a series of steps that are carried out in a particular order to achieve a goal. In this case, the goal is to identify a solution that is capable of succeeding, can be carried out in a timely manner and is likely to be accepted by all stakeholders. The five steps in design thinking are empathize, define, ideate, prototype and test.” (1)

We started by the pre-empathize step, which is not included in the design thinking process. This step is meant to define the target. We all prepared post-its where we wrote words linked to the project's title. *What come to our mind reading the subject?* During the meeting we gathered everyone's ideas on a board thanks to a graph, as shown on the following picture. We draw two arrows and we placed out post-its depending on the level of importance and on the number of people concerned (few or a lot). The goal was to distinguish two target groups, but we only found one: **students and young adults, who are potential future home buyers or builders.**

LEARNING ABOUT PHOTOVOLTAICS

In the very beginning of the project, most of our team members had little knowledge and experience with photovoltaics. We knew that they were a source of renewable energy and all of us had interest in them, but we never had an opportunity to learn more about them.

As such, our supervisors offered to hold a few lectures and laboratories for us, where we would learn about the history of photovoltaics, how they are produced, how they work and predictions for their future. At the same time, they wanted to show us how the classes are conducted for students of related fields, so we would know the current methods of education on photovoltaics at Lodz University of Technology.

The lectures were conducted by Professor Maciej Sibiński. In total, the lectures took approximately 6 hours and were divided into 2 main parts:

- Optoelectronics: Solar Cells - Research and Development
- Renewable Energy Source: Solar Cells - Parameters and Application, BIPV

They touched upon several different subjects: construction and properties of solar cells, thin-film photovoltaic devices, designing PV installations, future trends in photovoltaics, various cells materials and production systems, and building-integrated photovoltaics (BIPV).

The general opinion by the team was that the quantity and variety of information presented was very good. It gave us solid understanding of fundamental concepts behind photovoltaics but did not overwhelm us with too much information. Opinions on possible recommendations varied between team members, due to different interests. For example, some felt that more in-depth information would be better, while others considered it as an advantage to motivate curious students into doing their own research.



The laboratories were conducted by Doctor Katarzyna Znajdek. The group performed 2 exercises: "Investigation of different configurations of the PV cells" and "Investigation of the PV module tilt angle on final relative conversion efficiency". During both of them we had work closely with photovoltaic modules consisting of mono-crystalline silicon solar cells and measured their characteristics under different laboratory conditions. For each we worked in the laboratory for approximately 1 hour and 30 minutes. We then created spreadsheets in which we calculated and derived values based on our measurements. Afterwards, we wrote reports on our observations and how they compared with theoretical values. One of the reports can be found in Appendix K.



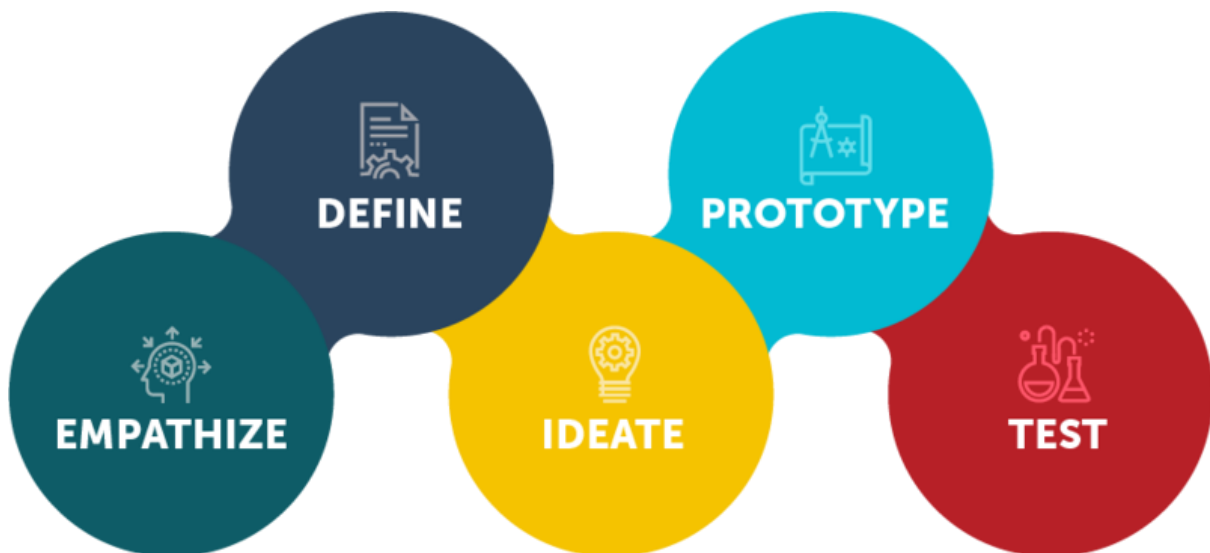
Figure 1: Team performing laboratory exercise

All team members were satisfied with laboratory work. It allowed us to witness effectiveness of photovoltaics in different conditions, including time of day, partial shadowing and connection arrangements. We learned that there is no one best photovoltaic installation and each can excel in suitable circumstances.

To sum up, we believe that current methods of teaching about photovoltaics are satisfactory. Their effectiveness depends on personal opinions and interests of individual students but provide general knowledge and solid foundations for further development.



EDUCATION AND PROMOTION OF PHOTOVOLTAICS THROUGH THE DESIGN THINKING APPROACH



1. EMPATHIZE

First step of Design Thinking process is to gain an empathic understanding of the problem or need we are trying to solve. This involves consulting with experts in the field, learning more about people who will be the target of our solution and immersing ourselves in the problem's environment. Before we could do all of that though, we had to decide our target group.

After learning the key fundamentals about photovoltaics, we began thinking about possible social groups we would like to target and then specify additional characteristics about them, such as their age, occupation, etc.

In our brainstorming sessions we came up with many different groups. Some of them are listed below, alongside simple descriptions why we considered them in the first place.

- Private companies - they have the capital for PV installations and they could promote themselves as environmentally conscious companies.
- Elementary school students - as everyone knows, children are our future, so educating and promoting them about photovoltaics would provide long-term benefits to the environment.
- University students - they begin their professional careers and will soon make decisions with their earnings, so it would be worth it to make them aware of benefits of photovoltaics.
- Senior citizens - as photovoltaics are a relatively modern invention, many members of the older generations possess little knowledge about them.
- People building or planning to build houses - convincing them to add photovoltaics installations to their current development plans would bring benefits quicker than other solutions.
- City council - coming up with a way for city officials to promote photovoltaics could potentially expose almost the entire population of that city to them.

We had several discussions trying to find the best group. We performed a series of eliminations based on different concerns, until we were left with only one. For example, working with groups like city council or private companies would be hard due to our lack of contact and experience in dealing with such institutions. In another case, while senior citizens know little about photovoltaics, we doubted if they would consider using them after they know more about them.



In the end, after much deliberation of pros and cons, we came to a conclusion that university students would be the best choice. We ourselves are students and know many others, so creating rapport and collecting data would be very easy.

1.1. Interviews

Having decided on our target group, we wanted to know more about them. We had two main methods of doing that: internet survey or in-person interviews. The former option would give us much larger sample size and would take considerably less time. The latter would allow us to gain much more personal insight, both from observation of non-verbal cues of our speakers and questions tailored specifically for them. We decided to go with the second option. We preferred to have smaller, but more in-depth explored, sample size. Moreover, people are much more likely to give false or inaccurate information in online surveys.

Before conducting the interviews, we prepared list of questions which we would ask every person we interviewed. Most of them are open-ended to encourage people to share their views and personal opinions on subjects. List of those questions can be found in the Table below.

1. Introduction of ourselves and of the project
2. What about you? Name/where are you from/occupation/what are you doing in your free time/what are you doing here...
3. Do you know any renewable energy?
4. Why do think there are important?
5. What do you know about PV?
6. Do you use PV? Or do you know people using PV?
7. Do you ever think about buying one? Why? (see if the problem is the money, if it's hard to find or to install)
8. Where did you learned about it? (school, media...)
9. Where do you discuss your point of view? (with friends, colleagues, on social medias...)
10. How do you think we can spread the info?

Moreover, we asked additional "casual questions" with the aim of making people feel more comfortable during the interview, so they would open up and answer the questions without hesitation. We conducted the interviews in 2 or 3 person groups with people around the International Faculty of Engineering. On top of that, each of us also conducted those interviews individually with our family, friends and acquaintance. Each interview took around 10 minutes.

1.2. Data sorting

After the interviews were conducted, we had to sort and analyse the obtained data. First of all, most of our audience was between 19 and 22 years old. Majority of them were from Poland, but we also had answers from people from France, Spain and Italy. Immediately we noticed that many people said very similar things. Depending on the question, we selected 2 or 3 most commonly given answers. Below is a list of the questions and answers we considered to be most important. Examples of interview answers can be found in the appendix (A).

- What do they know about photovoltaics?
 1. No knowledge, they didn't know it's about solar energy.
 2. Mistaking photovoltaics with thermal collectors.
 3. Solar panels on buildings.
- What are their experience with photovoltaics?
 1. No experience.
 2. Know someone who uses them.
 3. Know a location where they are used.
- Why are they not using them?
 1. It is not their decision.
 2. Too expensive.
 3. Tech complexity.
- How do you think we can spread the info?
 1. Social media.
 2. TV or radio campaign
 3. By simple and easy to understand visualizations.

1.3. Empathy map

With the data sorted and analysed, we proceeded to creating an empathy map of our target group. Firstly, we focused on the external characteristics: what our audience sees and hears about photovoltaics. As it turned out, people see solar panels quite a lot, but what they hear is often negative, that they are expensive, they are hard to install, and their maintenance is problematic. In fact, we can see photovoltaics quite often if we pay attention. There are those on roofs but also on smaller devices such as calculators, power banks or garden lights for example.

On the other hand, the internal characteristics were much more favourable. People **think and feel** that solar panels are helping the environment and that they lower the pollution. And although many people **say** that they would like to use them, they rarely do so.

As such, we can underline the consciousness of the environment consequences and the wish to consume better. But people think that technologies that support this idea are too hard to use. The empathy map created on the basis of the interviews is shown in Figure 2.

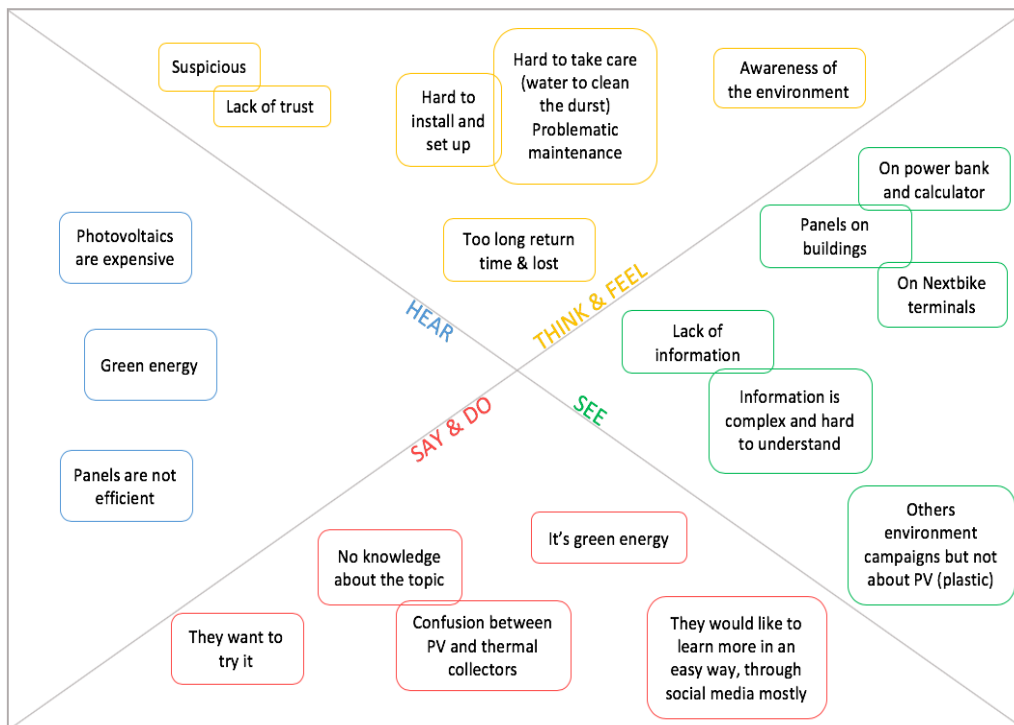


Figure 2. The empathy map.



2. DEFINE

This step involves synthesizing all the information that was gathered during the previous step and arriving at a group consensus that states what problem needs to be solved. The goal is to identify the scope and true nature of the problem, we call it the Point of View (POV).

The Point of View answers to the questions **who** our target is, **what** we want to share/educate and **why** we should. That is why we used the name Alex, suitable for a woman or a man. This will be the woman/man we want to reach during the test step at the end of the process of Design Thinking. Our goal is to create a solution completely fulfilling his/her needs according to the topic. We think Alex is like us at the beginning of the project, so it was easier to put ourselves in his/her shoes. After long discussion we formed the POV which is presented below. Our next task will be finding the best solution of such formulated problem taking into consideration all of the reasons and influencing issues.

Who

Alex, a student around 20 years old living in Łódź concerned about **environmental** issues needs to be **informed** in a simple way

What

about the greenest, easiest and cheapest **energy** source because Alex wants to be **aware** and **able**

Why

to make a **choice** but now Alex has a lot of **misconception** about **technologies**.

Other personas could have been possible, like people with more-decision making potential in their households, with more purchasing power, more aware of the electricity consumption or more directly concerned about the topic, but Alex is most curious and most able to communicate about it. Easier to reach through social media as well, because she/he is just like us. With that, we could focus on finding a solution most suitable for Alex, but at the same time keeping a broader audience in mind for future developments.

3. IDEATE

This step involves sharing ideas, even the craziest, the most expensive ones and the magical ones, and using each other's ideas as triggers for continuing the ideation process. The goal is to brainstorm solutions to the stated problem.

3.1. Ideas

Previously in the Definition step, the range of the problem has been narrowed to the need of Alex. In the Ideation stage the team had to seek for variety of ideas to solve the issue stated in the Point of View.

Each of the team members had to work on their own and, keeping in mind the obtained POV, find the possible solutions for the problem. All of the solutions had to be written on small cards called Post-It. Apart from real possible solutions team members had to look for at least 3 additional ideas each from specific category. The categories were called:

- Idea that need at least 1 Million Euro to realize,
- Idea that would cause troubles for your group or will be controversial,
- Idea that need a piece of magic or phantasy to come true.

Each of the team members had to produce at least 10 normal ideas. Adding to this the additional categories and multiplying by the number of people in the group theoretically we should obtain almost 100 ideas. In practice there were more than 100 dues to the fact that we had more than week for ideation and brainstorming.

During the meeting all the team members were sticking their notes with ideas to the board. When someone else had similar idea, they were obliged to add it nearby the existing one. In that way we grouped the solutions and could see which were brought up the most frequently. Moreover, if the ideas were not exactly the same, they could complement each other, so in that way the ideation process took advantage of the groupthink. In addition, created groups could be connected to create the more complex ideas for possible solutions. Figure 3 shows a whiteboard with our ideas.



Figure 3. Ideas grouped on a whiteboard.

3.2. Voting

Afterwards, previously estimated most frequent and bright ideas were noted down on the separate board. All together we had about 10 complex and quite detailed possible solutions, as for this stage of the process. Every person in the group had two votes that could be used for any of the solution proposition. Unfortunately, after first voting we came to the tie. The voting was repeated only on the two previously chosen ideas and at the end the winner was selected. Here are the 10 ideas we've selected:

1st idea: A public fountain with a PV cells on the side, equipped with plugs to charge phones or any devices. On the charger, people can find a QR code that leads them to an educational video or page to know more about PV.

2nd: A box with a PV cell on top connected to an application. This one analyses the information in live, calculating how many CO2 and money you're saving. Information can be

shared on social media to show others how efficient it is. This box is quite small and will serve as a simulator.

3rd: Design an installation where users could manually modify PV's orientation towards the sun using a joystick. This would be connected to an application or screen which would display the efficiency of the solar cell in current orientation.

4th: Create board games: a playful way to educate.

5th: Creation of a website with videos and links to educate about PV. This page will especially lead to a forum where people can interact together to get a lot of point of views and advices.

6th: Use the future to simulate and show what can change if we use PV or not. It can be interviews or a Virtual Reality Museum for example.

7th: Organize an international event with the creation of the “PV day”, a street PV festival.

8th: Reach the law to encourage and initiate the use of PV in public and private area.

9th: Write guides about PV, depending on the level of knowledge.

10th: A charging box in front of the IFE building. This box will contain a USB plug and a QR code. Will the students are charging their phones for example, they can scan the code which leads to a website or a page where information about PV are given.

The voting selection of the final idea to develop has couple of advantages. First of all, it is very creative process which benefits form working in a group, simultaneously giving equal chances for all participants to influence the whole process, final outcomes and also to show off a contribution. Secondly, it is a fair competition between ideas – every idea counts and has equal chances to come to the end. At the end, such an approach is not discriminating any of the ideas because even the most unreal or stupid ones can influence a creating process for others.

In the end, the group decided that best solution of the stated problem would be a device that will help future users of the solar panels to calculate amount of electricity and money saved due to the use of photovoltaics together with some information about the photovoltaics itself (2nd idea).

The minute of this meeting is available in appendix (B).

4. PROTOTYPE

This step involves creating a mock-up that conveys the essence of a proposed solution. An important goal of this step is to help the design team weed out unworkable or impractical solutions and focus attention on ideas that are likely to be approved by stakeholders. Figure 4 visualizes how our device would work and what elements would communicate with each other.

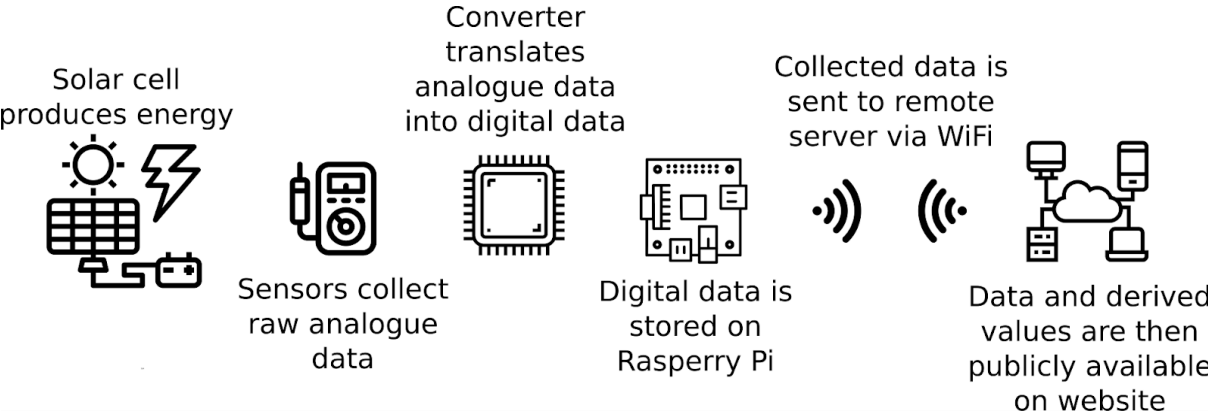


Figure 4. Simple visualization of data collecting device.

4.1. Hardware

4.1.1. Introduction

We decided to create a box with a solar cell on top that would act as a system for collecting data about production of solar energy in a given place. Its main function is to collect current, voltage and temperature that the cell is producing through the day and make an estimation about the total power production of solar panel installation in a given place. This would inform our customer how profitable the installation would be from them.



As such, we wanted a device that would be able to acquire and store the data from the solar cell, and then send that data so it can be presented in simple and accessible manner. Thus, we decided on using a Raspberry Pi Zero W - a small, single-board computer, with built-in Wi-Fi module. While small, it is a very powerful tool which would allow us to collect the data into an SD card and then send it wirelessly to a remote server, where it could be accessed from anywhere in the world through a website.

For acquiring we needed sensors for measuring voltage, current and temperature. Using current and voltage in a direct current resistive circuit, we can obtain the electric power based on Joule's and Ohm's laws.

$$P=IV=I^2R=V^2/R$$

During the project development we had two options for sensors: use two different sensors to measure voltage and current separately or a single one that would measure both at the same time. From our knowledge and research, we came to a conclusion that we would use INA260 which has the ability to measure power, current and voltage, and also converts the analogue data into digital data. There are two main reasons why we decided to implement only a single circuit. First, it uses i2C communication. It communicates straight with the Raspberry with a pull up resistor by protocol. Second, it was cheaper. We wanted to limit the cost of our project and buying several different sensors and an AD converter would be more expensive.

4.1.2. Choosing components

As mentioned previously, the selection of the INA260 was for its main features, the key one being the communication through i2C protocol. In order to have a lecture of our different parameters and transmit them to our main core for storage the data, we have to implement a master-slave communication as the i2C bus standard requires.



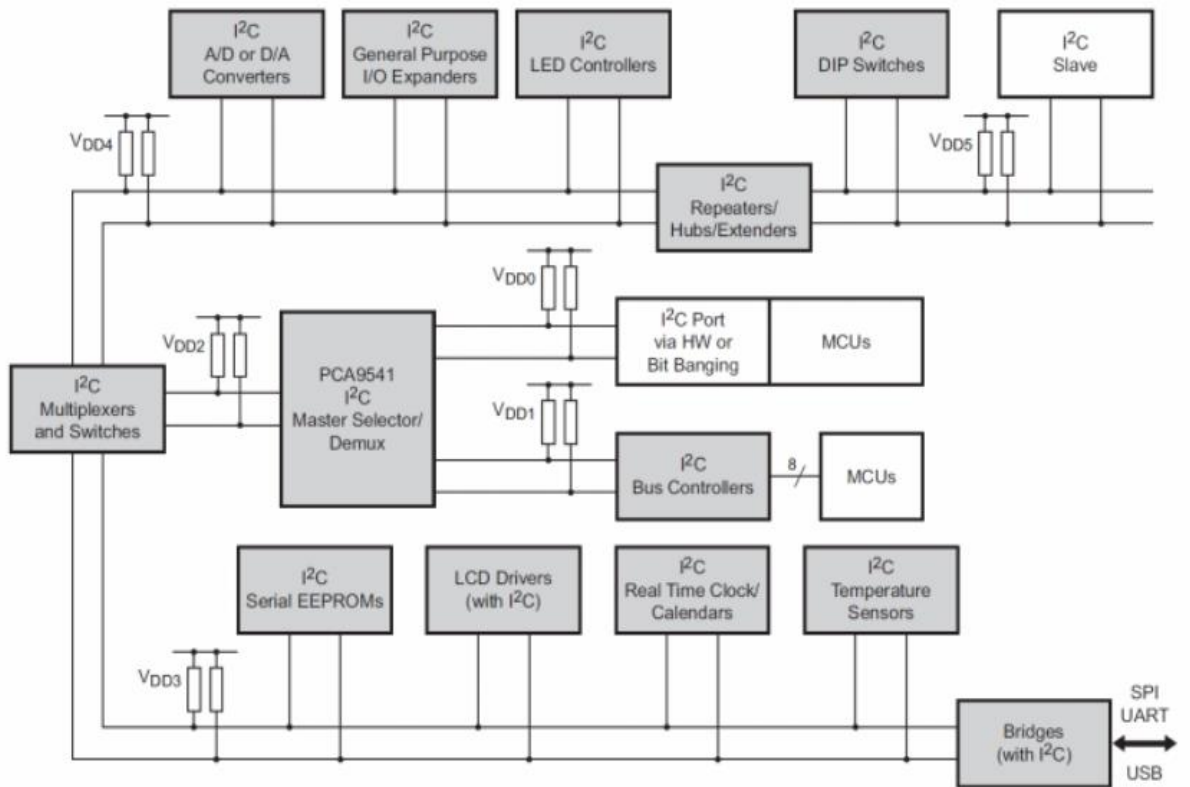


Figure 5. Scheme of an I²C bus connection from <https://i2c.info/i2c-bus-specification>

“The I²C bus uses two wires: serial data (SDA) and serial clock (SCL). All I²C master and slave devices are connected with only those two wires. Each device can be a transmitter, a receiver or both. Some devices are masters – they generate bus clock and initiate communication on the bus, other devices are slaves and respond to the commands on the bus. In order to communicate with specific device, each slave device must have an address which is unique on the bus. I²C master devices (usually microcontrollers) don’t need an address since no other (slave) device sends commands to the master.”

Calculation for pull-up resistance on I²C bus:

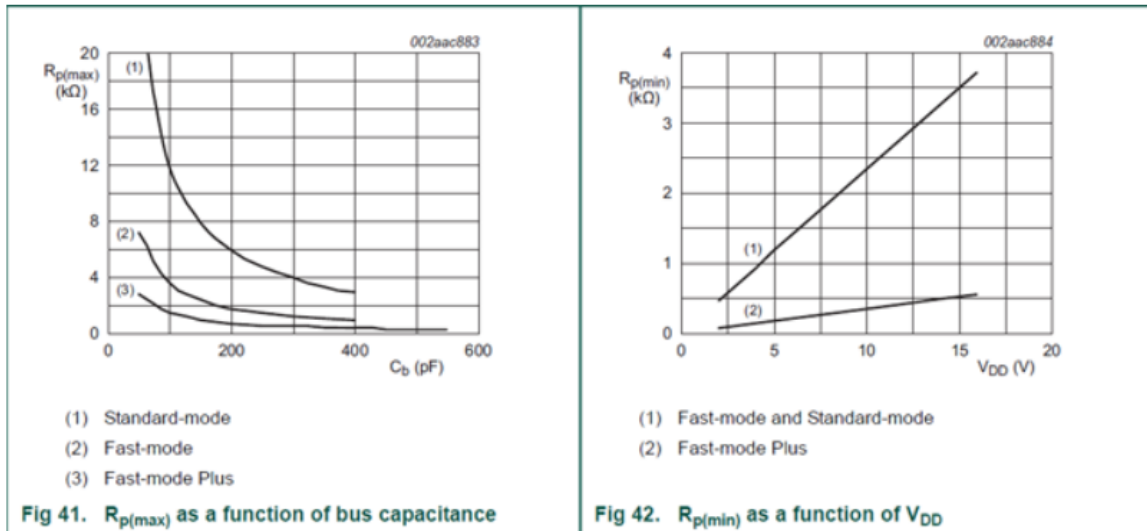
$$\text{Freq} < 100\text{kHz} \implies R_{\min} = \frac{V_{cc} - 0.4\text{V}}{3\text{mA}}, R_{\max} = \frac{1000\text{ns}}{C_{\text{bus}}}$$

$$\text{Freq} > 100\text{kHz} \implies R_{\min} = \frac{V_{cc} - 0.4\text{V}}{3\text{mA}}, R_{\max} = \frac{300\text{ns}}{C_{\text{bus}}}$$

In our case for transmit data, 100kHz will be enough. Cbus is the bus capacitance for out pin, usually is about 10pF for more we have to see on pi Zero w datasheet and pinout.

It makes sense that higher frequencies require lower resistance pull-ups: a lower resistance will charge/discharge the cable's capacitance faster, which results in steeper edges. With the wider pulses of lower frequencies a less steep edge won't influence the pulse's shape as much.

Therefore the [I2C specification](#) gives maximum values for the pull-up resistors as a function of bus capacitance for three speed classes:



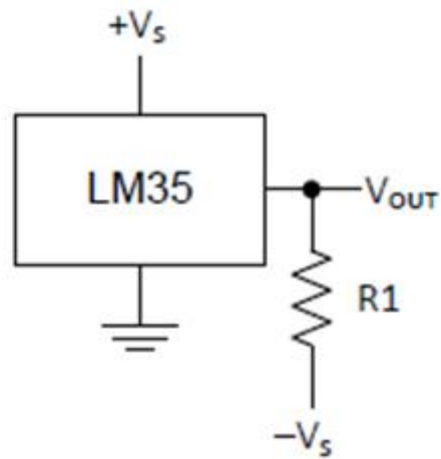
The minimum values are defined in function of the bus voltage, and should limit the current through the drivers.

Figure 6 Resistance for I²C communication

For our application and making calculations, pull up resistor of 4.7 kOhm will be enough.

For temperature sensing we decided to use LM35 - a very popular temperature sensor that works well for temperatures up to 150°C. It has a linear output, each mV corresponds to a change in temperature and we can adjust the scale by input supply. For our application, for example, every change of 6mV is a change of one Celsius degree and that is controlled through our Raspberry Pi.





Choose $R_1 = -V_s / 50 \mu\text{A}$
 $V_{\text{OUT}} = 1500 \text{ mV at } 150^\circ\text{C}$
 $V_{\text{OUT}} = 250 \text{ mV at } 25^\circ\text{C}$
 $V_{\text{OUT}} = -550 \text{ mV at } -55^\circ\text{C}$

Figure 7. Full-range centigrade temperature sensor

For a complete range of temperature, we have to fix resistance value. For typical applications it is not necessary. More information is described in datasheets of the components which are attached to the report.

Output signal, marked as V_{out} , is analogue signal in mV. Its value depends on the temperature obtained by the sensor.

At this point we faced an issue in data acquisition. If we look at the pinout of Raspberry Pi Zero, we will see something which is attached to Figure 8.

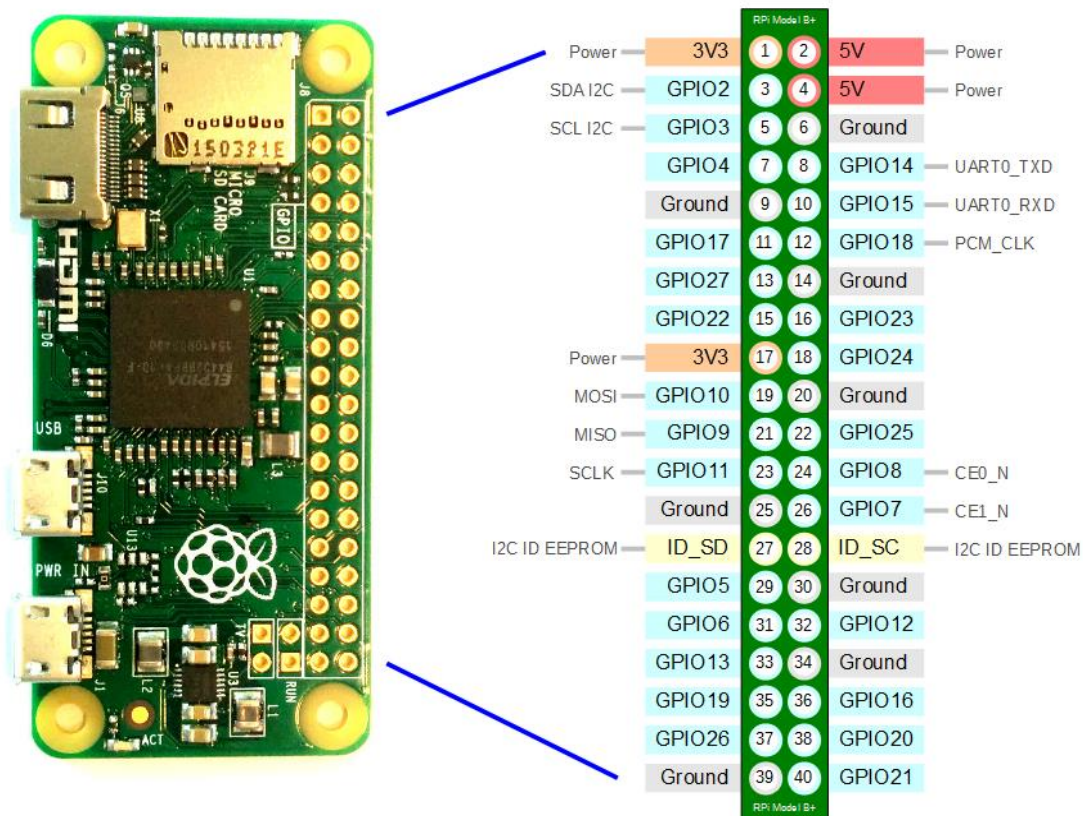


Figure 8. Description of pins in Raspberry Pi Zero W.

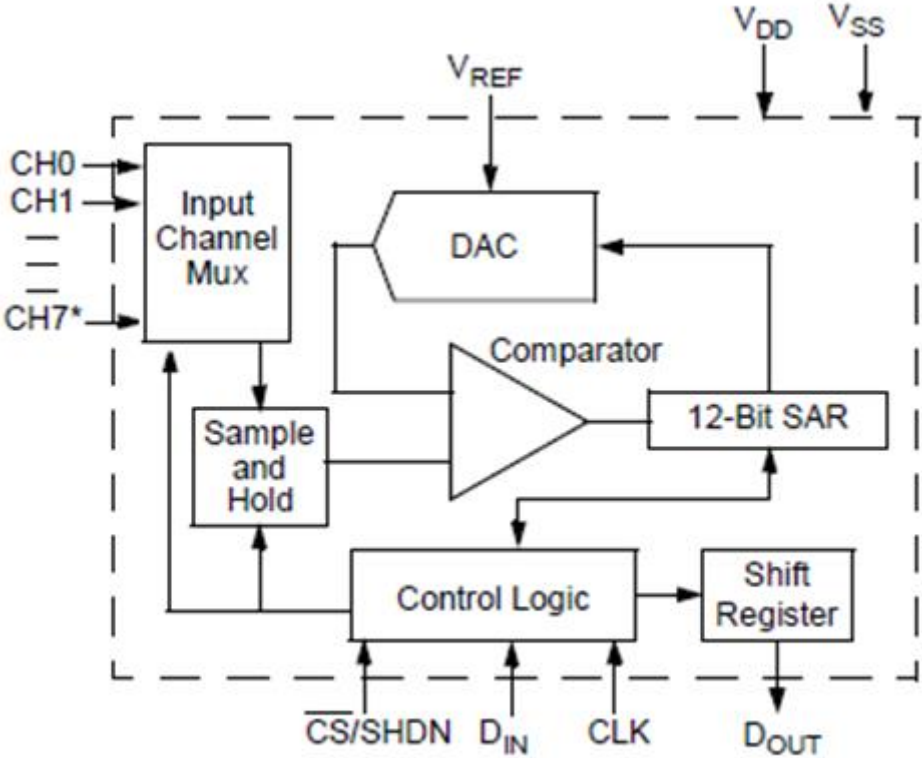
There are General Purpose Input Outputs, but none of them is for analogue inputs. Raspberry Pi Zero W does not have built-in analogue to digital converter. To fix this problem, we had to add an analogue-to-digital converter to our design, so we could send digital data to the Raspberry through SPI communication. The best option for this was a model MCP3204. The last two digits of it correspond to the number of its analogue inputs, so in this case it is 4.

The Microchip Technology Inc. MCP3204/3208 devices are successive approximation 12-bit Analog-to-Digital (A/D) Converters with on-board sample and hold circuitry.

The MCP3204 is programmable to provide two pseudo-differential input pairs or four single ended inputs. The MCP3208 is programmable to provide four pseudo-differential input pairs or eight single ended inputs. Differential Nonlinearity (DNL) is specified at ± 1 LSB, while Integral Nonlinearity (INL) is offered in ± 1 LSB (MCP3204/3208-B) and ± 2 LSB (MCP3204/3208-C) versions.



Communication with the devices is accomplished using a simple serial interface compatible with the SPI protocol. The devices are capable of conversion rates of up to 100 kSPS. The MCP3204/3208 devices operate over a broad voltage range (2.7V - 5.5V). Low current design permits operation with typical standby and active currents of only 500 nA and 320 μ A, respectively.



* Note: Channels 5-7 available on MCP3208 Only

Figure 9. Functional Block Diagram

As seen in the block diagram, with 4 connections typical for SPI configuration as chip select (CS), D_{in} (data input), CLK (clock signal) and D_{out} (Data output) the device is able to communicate with Raspberry Pi and provide the temperature measurements needed for our application.



PDIP, SOIC, TSSOP

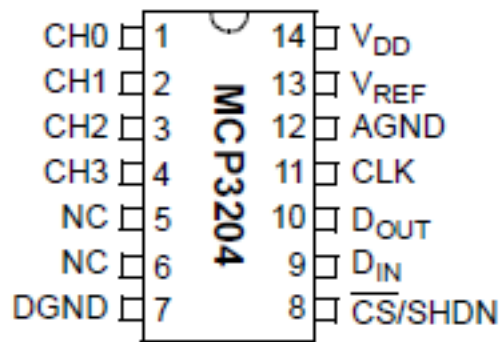


Figure 10. The pin description for the Integrated circuit

Charging function:

To charge the circuit's battery with energy produced by the solar cell, we implemented an IC called SPV1040 from ST MicroElectronics. This device has a 4.2 V output that goes directly to the battery providing charge and the description for the component is the following:

Figure 1: Block diagram

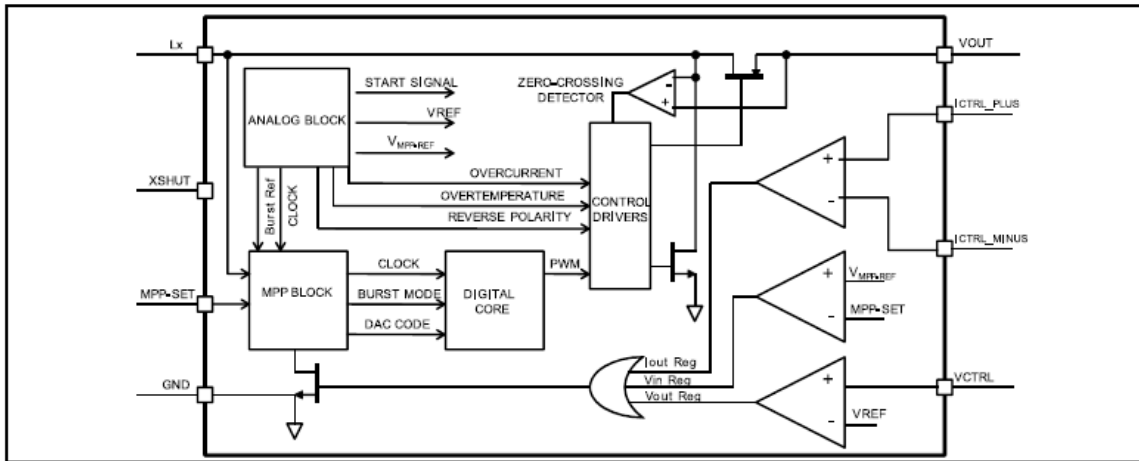


Figure 2: Simplified application circuit

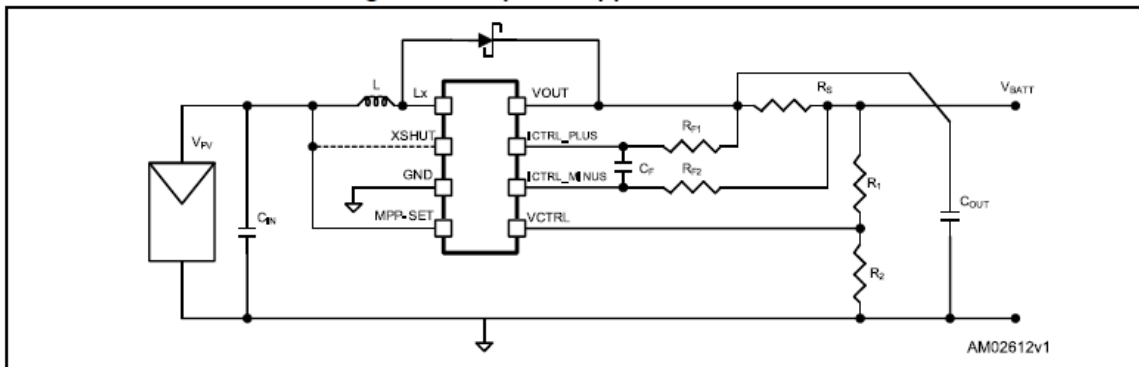


Figure 11 Block diagram

The SPV1040 is a monolithic, high efficiency, low voltage, self-powered DC-DC converter that operates over a 0.3 V to 5.5 V DC input voltage range and provides a single output voltage. The device provides regulated output voltage and current by sensing the VCTRL feedback of the external resistor divider and the voltage drop on the external sense resistor R_s , respectively. High efficiency is ensured by low power consumption in any working mode and by the embedded perturb and observe MPPT algorithm.

The SPV1040 guarantees its own safety and application safety by stopping the N-channel power switch in case of overcurrent or over temperature conditions.

4.1.3. Schematics

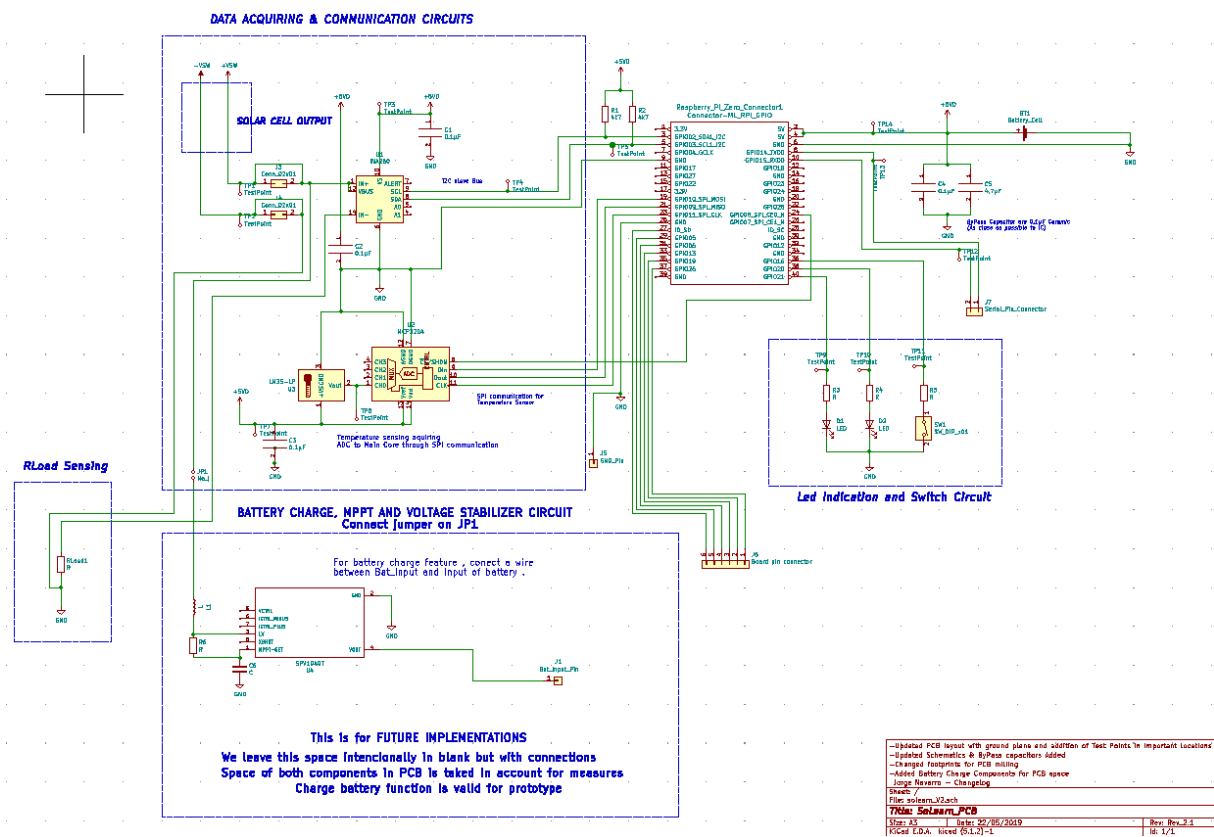


Figure 12. Final schematic of the printed circuit board.

Taking all that into consideration and taking into account the limitations we had in mind, the schematic development began in order to organize the components in a schematic drawing sheet. Development of design was made through KiCad - an open-source tool made for hardware developers and designers. The schematic itself is presented in Figure 12.

4.1.4. Creation of PCB

For the development of the project using KiCad we created two main planes in a biplane configuration. The bottom one is connected to ground as a ground plane, the top one corresponds to +Vcc on 5V.

Cooper areas are designed in order to have future implementations in working conditions available. Figure 13 contains the top layer of the printed circuit board (PCB), while Figure 14 contains the bottom layer (GND plane). Figure 15 shows a 3D model of PCB.

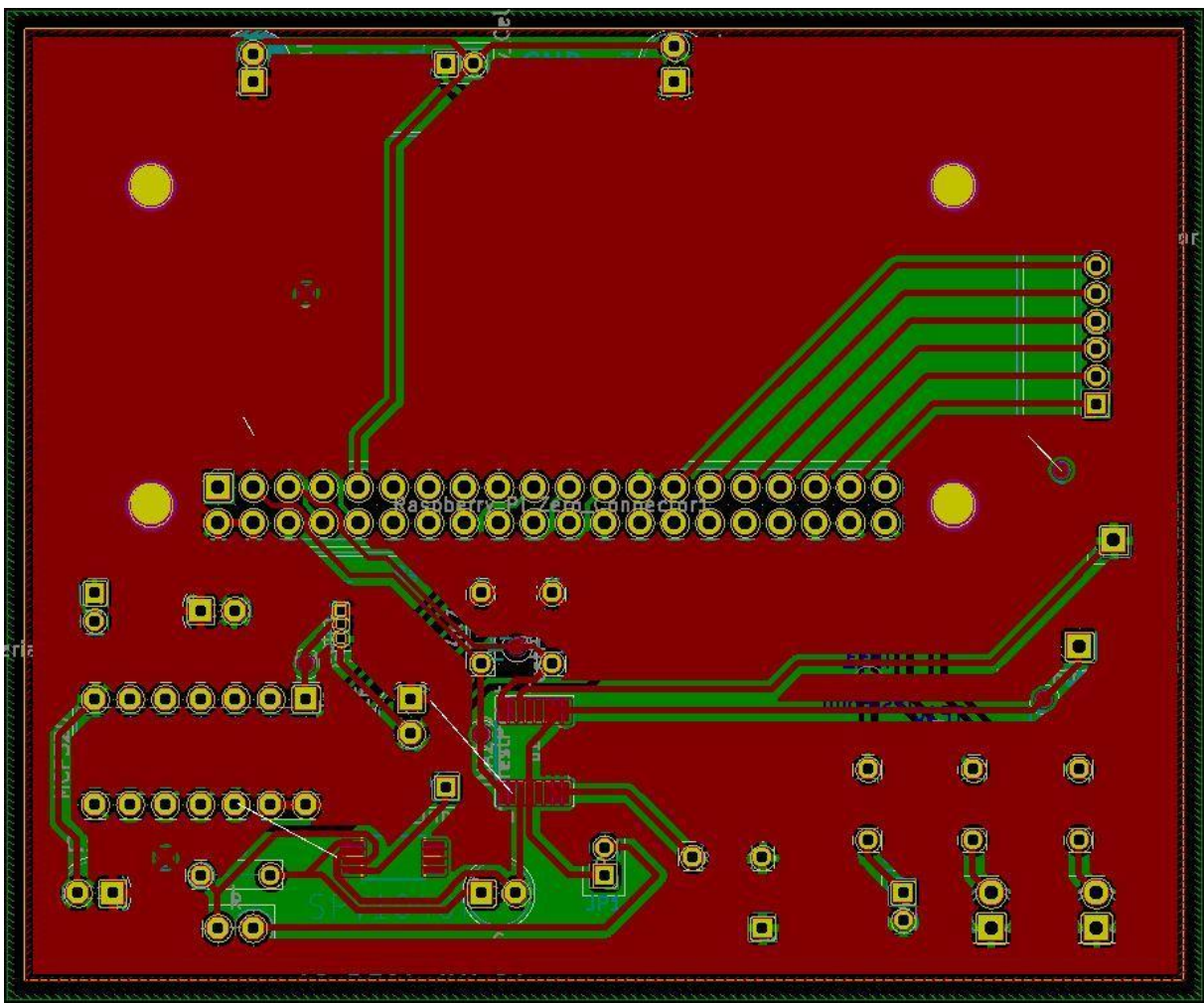


Figure 13. Top layer of the printed circuit board.

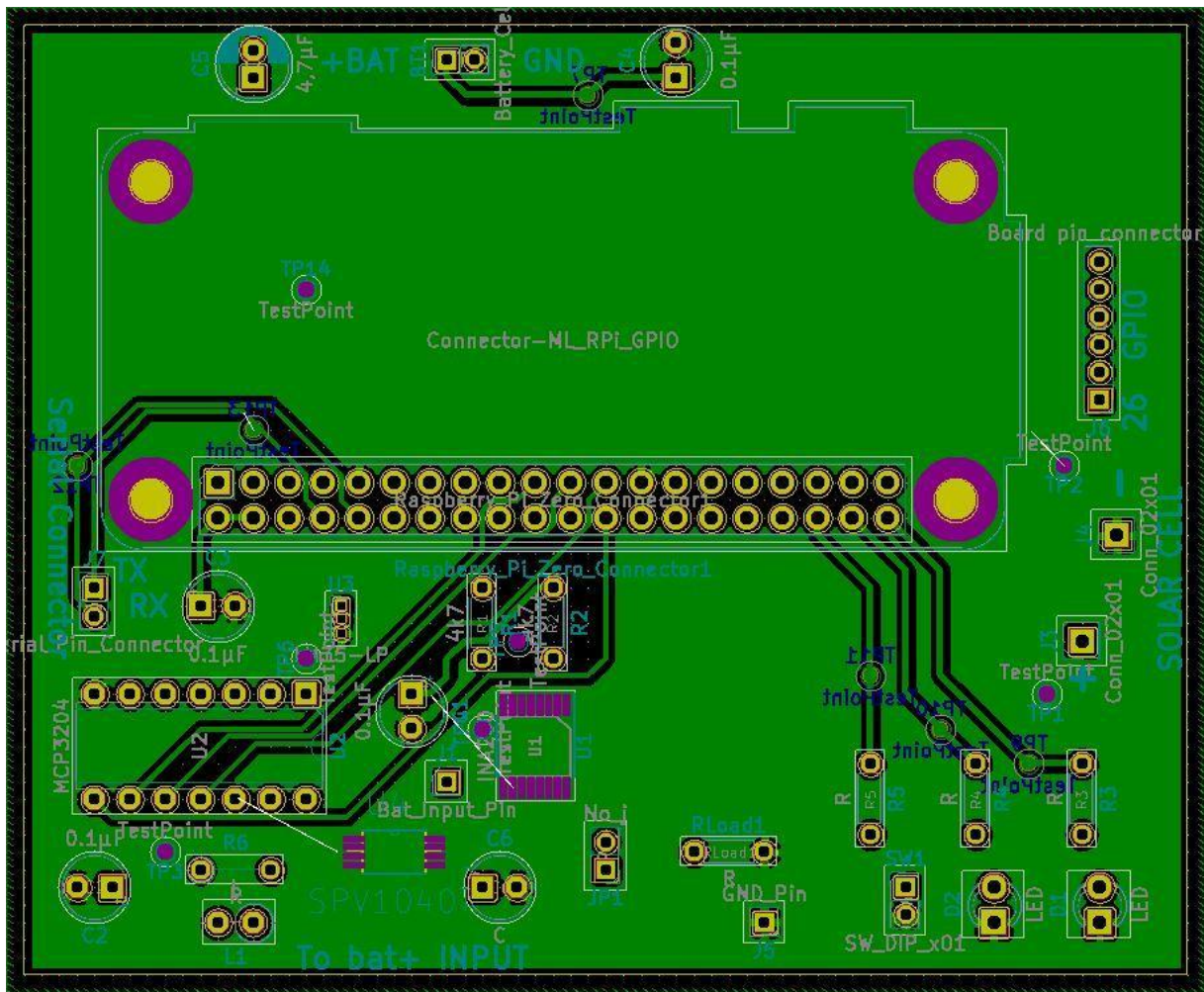


Figure 14. Bottom layer of the printed circuit board.

The distribution of the connections on the board aims for saving as much space as possible with annotations of the important components. Two layer design is for maintain one as a supply area and other for ground as ground plane, this kind of design for pc base typical in two layers configuration where we don't have bias connections and the thickness of the board is considerable due to the manufacturing process, the solar mask is not added on pads on this kind of design due to cost. It is necessary to say that in version 2 of the PCB the design could change and became more professional giving the schematics and planes to a manufacturer of PCB and being careful with pads and planes, remember here that this electronic design is only a prototype.



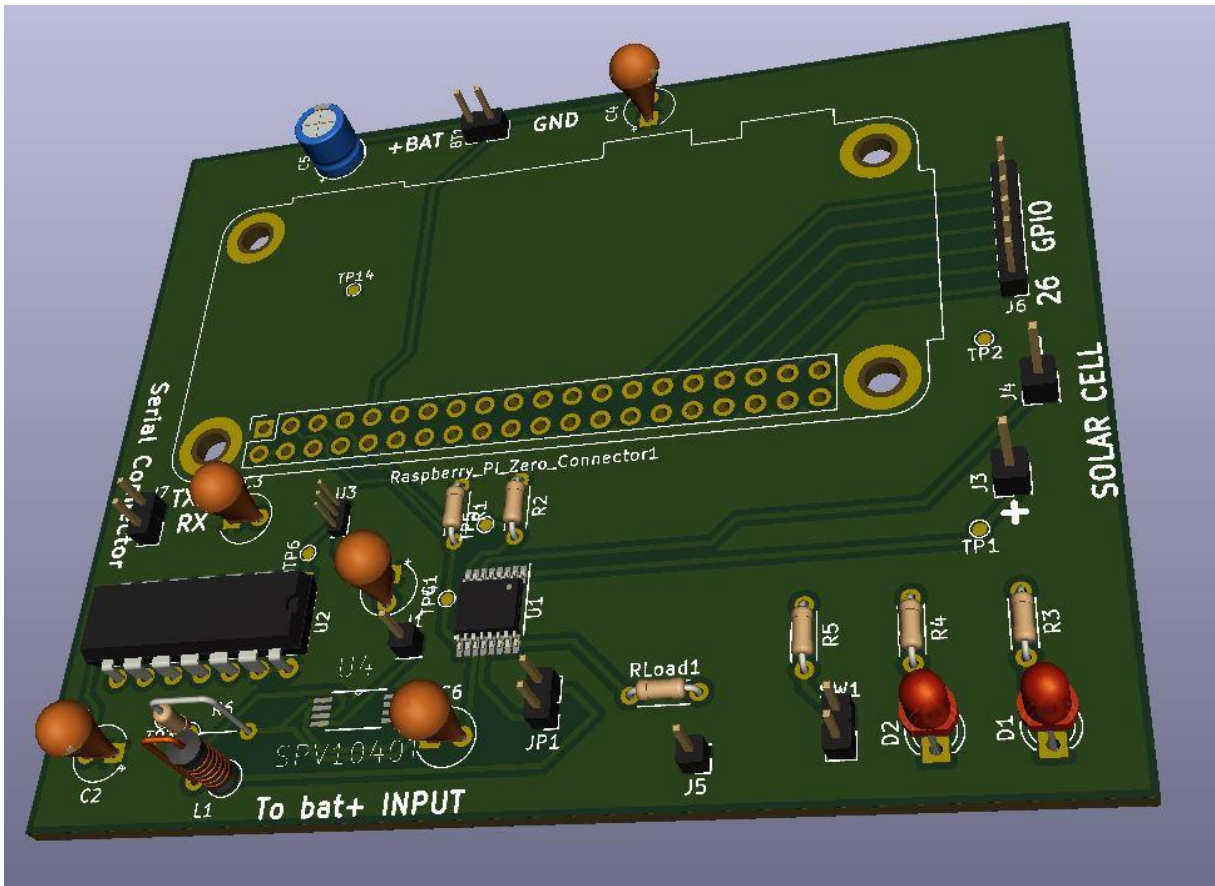


Figure 15. 3D model of the printed circuit board.

The pins for the board are of the same measure as the ones on Raspberry Pi.

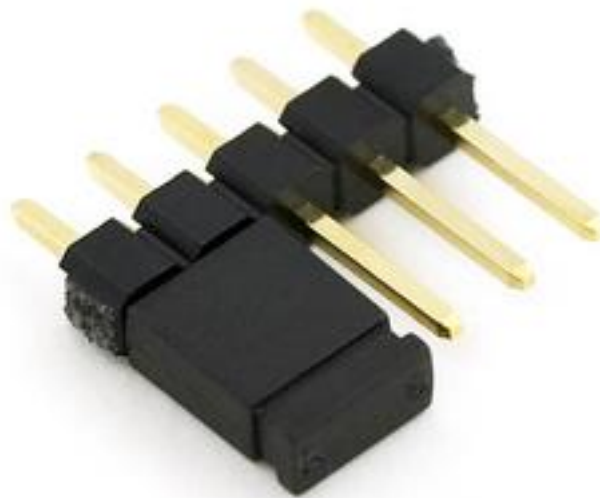
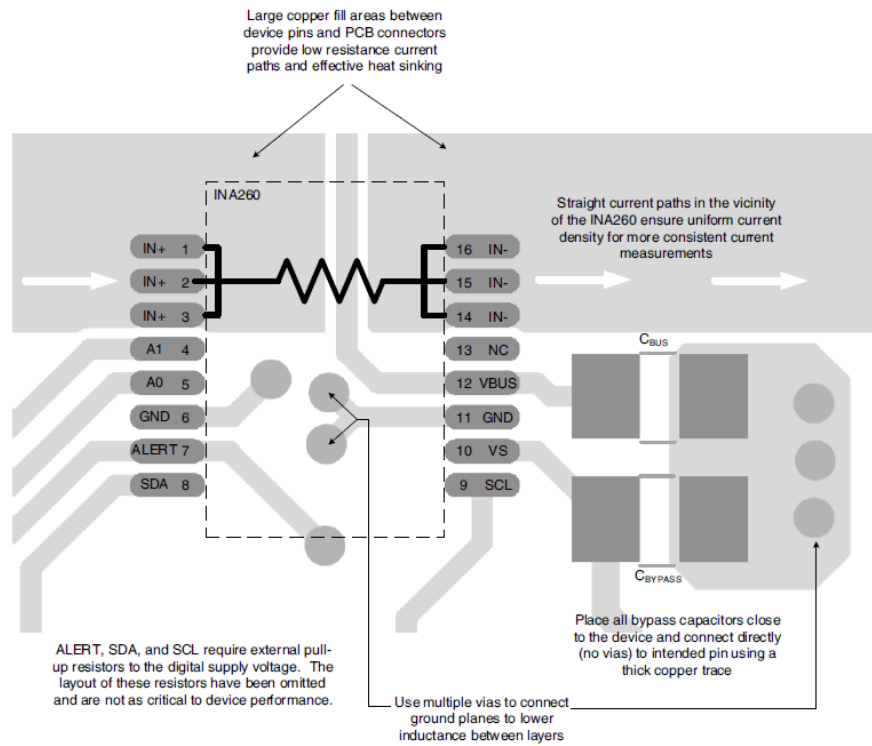


Figure 16. Solder pins for the PCB mill.

All manufacturer settings for components were done while taking into account the recommendations of datasheets. Below is an example of location for bypass capacitors on the main board.



Copyright © 2016, Texas Instruments Incorporated

NOTE: Connect the VBUS pin to the power supply rail.

Figure 17. INA260 layout configuration.

Following manufacturer requirements for bypass capacitors and connexions on the board we start to create the PCB with milling techniques, and the result was the following:

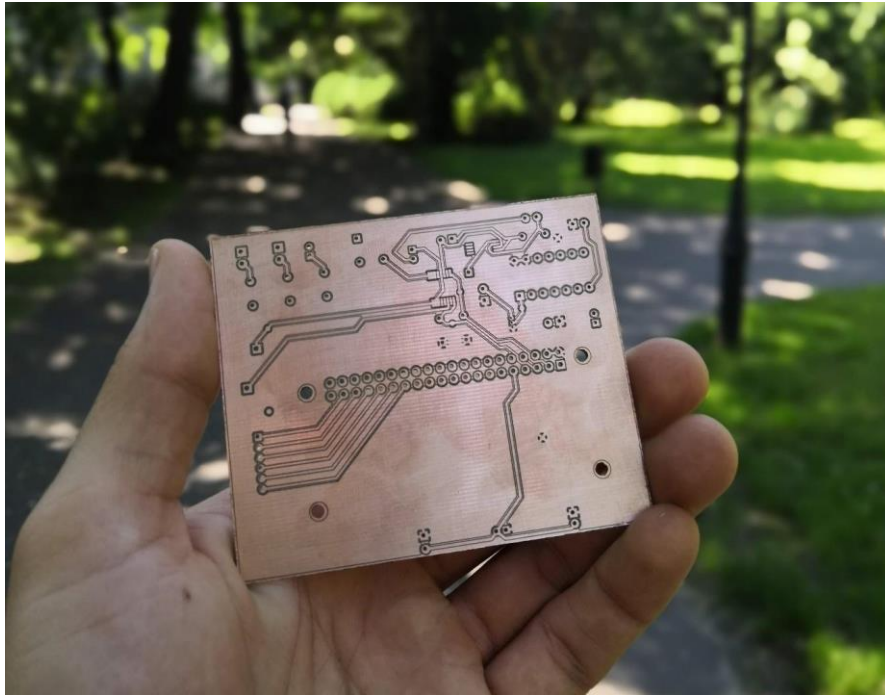


Figure 18. Final printed circuit board prototype after milling.

Figure 18 contains a photo of printed circuit board, right after the milling process.
Figure 19 contains the circuit fully connected to Raspberry Pi.



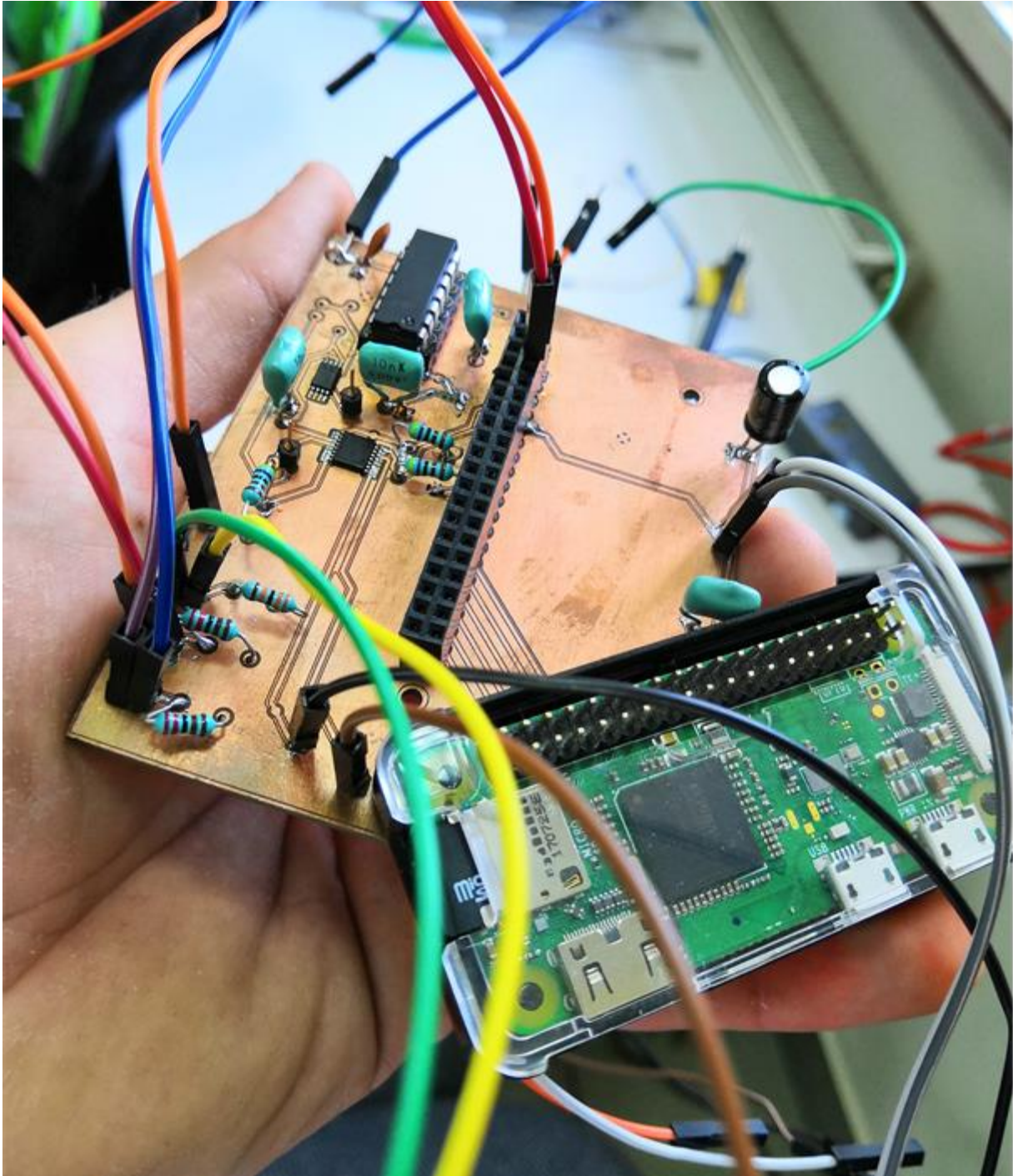


Figure 19. Board with components soldered on it.

As we can see in the picture, some of the components are very small and required much precision during soldering. Thankfully, professor Łukasz Ruta helped us put them in place.

4.2. Box design.

The box has been designed with the purpose of fix all the components necessary to the data acquiring having in account that we have to minimize as maximum as possible all the spaces .

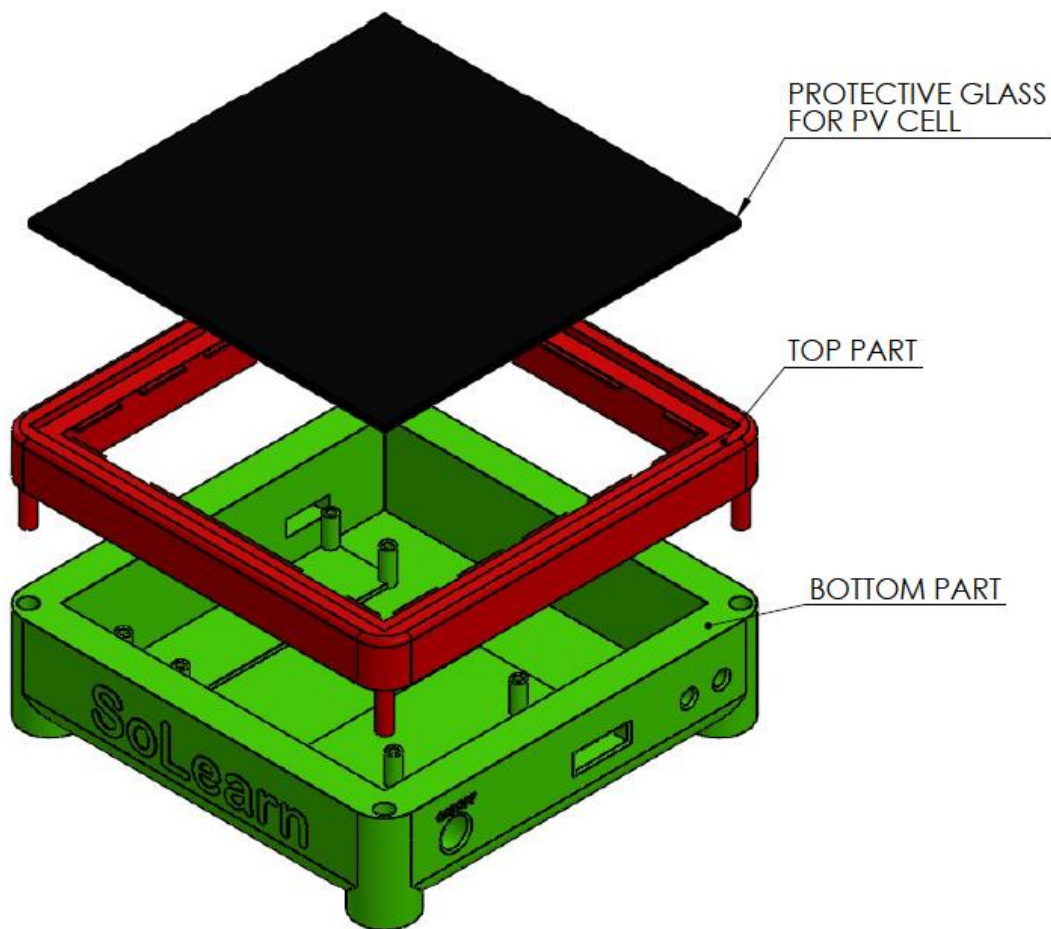


Figure 20. Solar box prototype.

Inside the box is attached through screws the main core raspberry included in our PCB and the battery board as well, both have correspondent holes for programming and charge, also a switch on button and two led indicators.

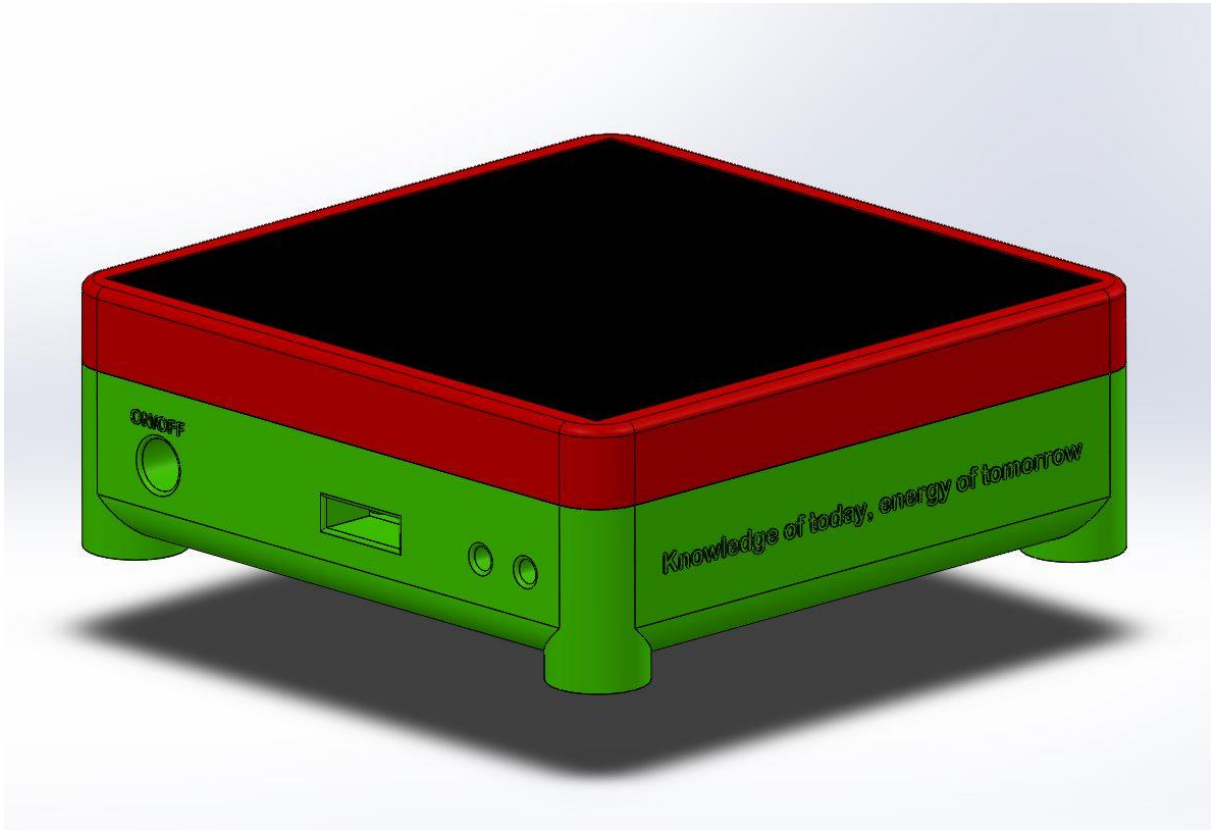


Figure 21. Assembly of box final model

Extruded to the surface, it is the SoLearn name and the slogan of the project, as well the ON/OFF button for the switch. The rounded corners and borders are with intention of let the people put in hard places and make the box more compact effect.

We decided to make a relieve with the slogan, name and some connections because the aspect of the engraved version on 3D printer was not as legible as the extruded one, apart from that the look that it gives to the design is more professional.



The following picture is a section view in order to be able to see inside the box:

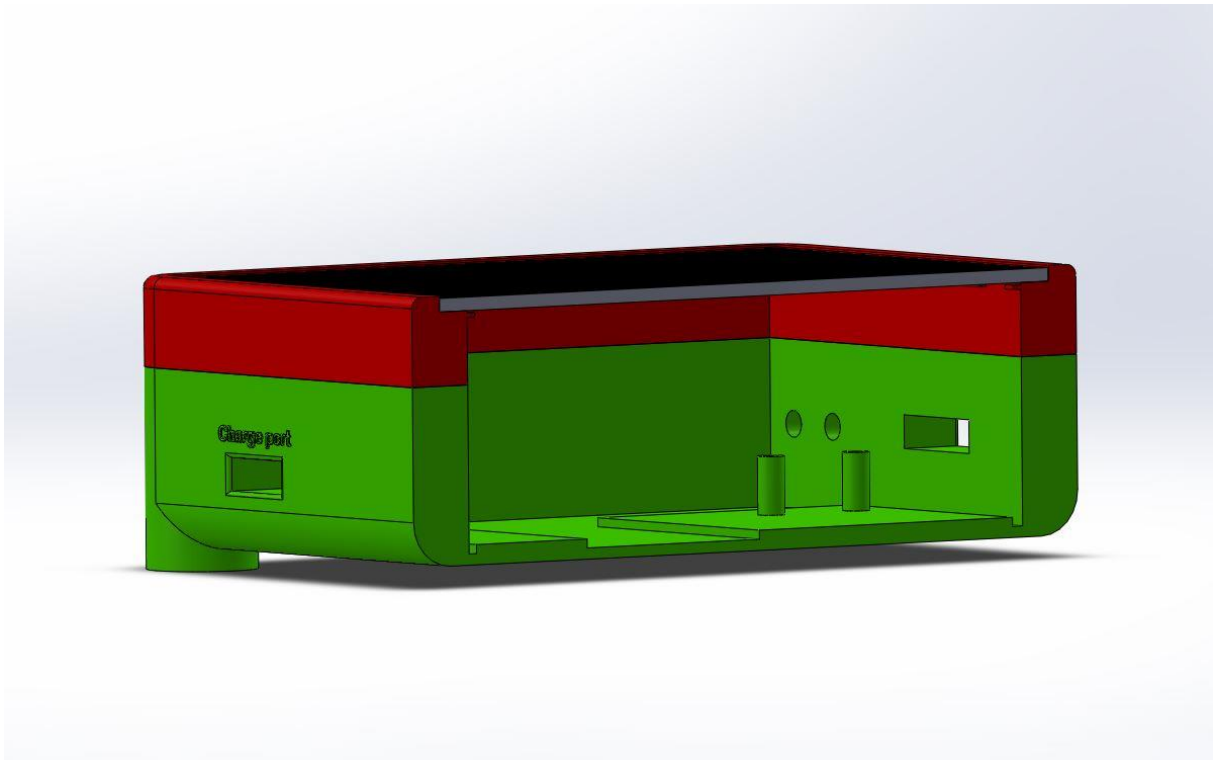


Figure 22. Section view of box

All the box has been printed in 3D, the complete time to achieve both parts including top and bottom was about 20 hours of print, in the printing process we had to repeat the top side print due to problems with printer and retraction materials, all was created in abs because has to be on the exterior of a building and PLA is not suitable for this applications. Here a photo of the printer in the laboratory working on the box:

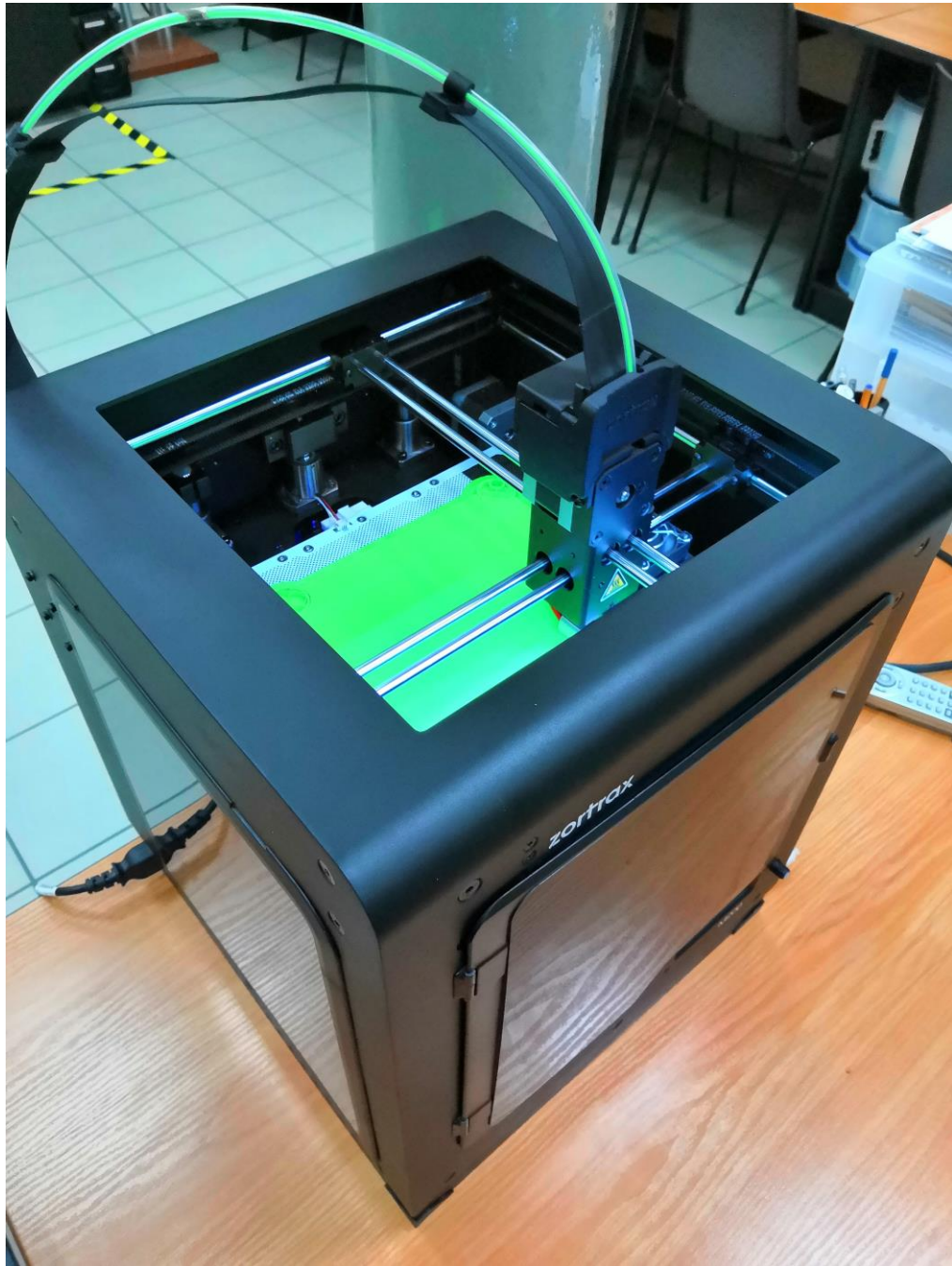


Figure 23. 3D printer working on the box

It is necessary to say that a final version or a professional one will be made in other materials, recyclable as possible and with smooth surface with some marks for grip.

4.3. Software

In this chapter we will present all the processes from the signal reception by the sensors to the display of the data and other features on the webpage. To achieve this task we used a Raspberry Pi, an open-source microcomputer running a Linux operating system called Raspbian^[2] (Raspberrypi.org, 2019).

From the Point of View defined in the definition step of Design Thinking process we can extract that Alex wants to learn, but has a lot of misconceptions about technologies. Moreover, so do more and more people about their privacy, that is why we have used only open source tools to do the software design. Under these licenses (MIT or GNU for instance) we can freely use those tools and share our system made with them and also modify them which means we have a total control of the technologies we are using and so do the users^[3] (Opensource.org, 2019).

The operation of the system is divided in three phases: data acquisition (with the Raspberry Pi), data storage (on the Raspberry Pi or on another server) and data display (with a web page).

The methodology we have used in order to have a working prototype and to be able to work in parallel on the electronic hardware was the following:

- First, we are building a “demo” web page to validate it with pre-made data
- Then we are simulating the acquisition of data on the raspberry pi and we add the web page on it so it can be seen on a private network (e.g. an internet box) and it shows the real data stored.
- To finish we are using another server to send the data on it and the web page is visible on internet.

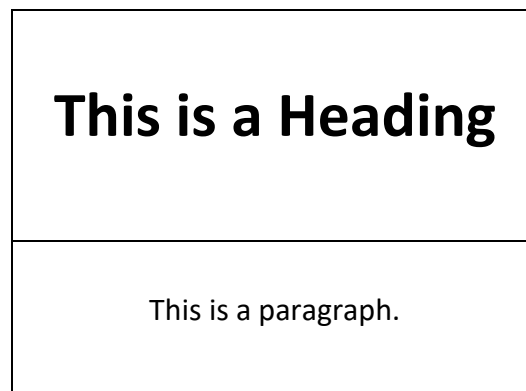
Thanks to these steps we can offer an agile solution: the prototype will be able to work without an internet connection, on a small network or on the internet.

4.3.1. Web page

4.3.1.1. Structure

We developed our web page thanks to the website W3schools (w3schools.com, 2019) powered by the W3C consortium that “defines an Open Web Platform for application development [...] available on any device. Although the boundaries of the platform continue to evolve, industry leaders speak nearly in unison about how HTML5 [...] CSS, SVG, WOFF, the Semantic Web stack, XML, and a variety of APIs.”^[4] (W3.org, 2019).

A web page is composed of at least one language: HTML (Hyper Text Markup Language). HTML5 is the standard markup language to describe the structure of web pages represented by tags like <...> to label pieces of content such as heading, paragraph, images, and so on so the browsers can render this content^[4] (W3.org, 2019). This is what internet looked like at the beginning:



The CSS (Cascading Style Sheets) was introduced to describe how HTML elements are displayed on screen (sizes, fonts, colors, behaviours), it can be present on the HTML file between en <style>...</style> tags or stored in CSS files^[4] (W3.org, 2019). With the same example:



The last language we need to design our web page is the JavaScript to program the behaviour of our web page. For example, it can change the colors, sizes, etc... of elements when click on a button, make calculations, receive inputs from people like text, numbers, date and process them. It can be presented on the HTML file between en `<script>...</script>` tags or stored in JS files^[4] (W3.org, 2019).

To design our web page we could have used a framework (e.g. Bootstrap or WordPress) that does pre-made blocks for website but we did it in pure HTML5, CSS and JavaScript to be more free and to be sure to control everything we do (for instance use cookies to collect data if we use their services).

4.3.1.2. Template

The first versions of the web page were done with HTML5 and CSS until the following template was accepted:

- The web page must be divided in thematic parts: one for the name of the project, one for a graph to display data, one for the social networks, one to show the actual value of the power generated, one to convert an electrical power and convert it into the time of use of home appliances and into particles of CO2 saved.
- The web page must have a navigation bar which will be always present and where we have to click to go to the different part of the web page.
- These parts have to scale automatically for the various size of screen (and for when the browsers are resized).
- The webpage must use images royalty free.
- The webpage must be modern and elegant.
- The webpage must work properly on mobile phones.

4.3.1.3. Web page contents

The first part of our webpage is the name of our project (dynamically positioned with the size of the browser). It is designed to be simple, elegant and minimalist (see Appendix A for the code of the webpage).



Figure 24. Screenshot of the title page.

We can see the menu at the top of the viewport, it is “fixed” to the webpage, in CSS it means it will be at the same position while we scroll. When we hover an icon, it became yellow (#EDC00E in HTML format and we will keep the same yellow in all the website) and black. Then the user just has to click to go to the part is interested in.



Figure 25. Screenshot of the menu.

The second part of the page is used to show the actual power generated by the system as well as the temperature. We display the temperature because it's affecting the efficiency of the solar cells. When the temperature is defined partially as cold (less than 10°C) it appears on blue, until 30°C in white and after in red (e.g. the screenshot below). The power is always displayed in white, but we add a chevron: it can be pointing to the top in



green when the system produces more than the previous value or in yellow pointing at the bottom when it produces less. These values are updated every second to let the time of the system to send them and to keep them readable. To do so we read these values by reading them into a file with AJAX. AJAX (Asynchronous JavaScript And XML) it is not a programming language but a technique to access data from a server to the webpage without reloading the page^[4] (W3.org, 2019).

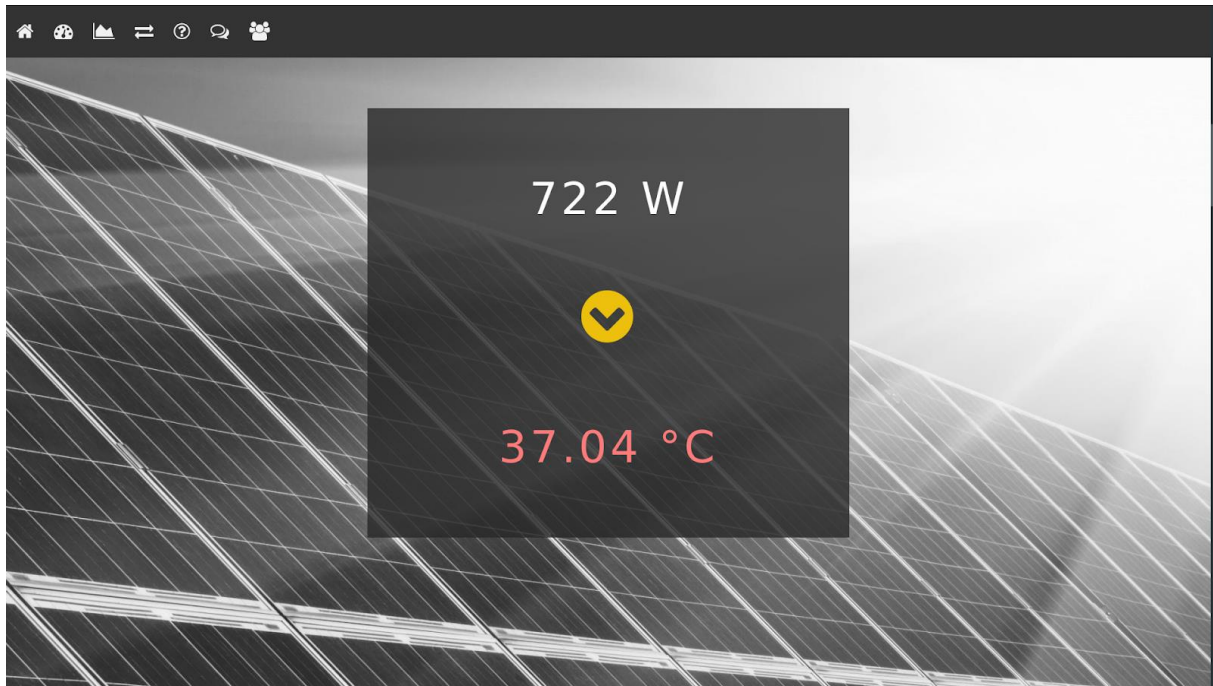


Figure 26. Screenshot of the application displaying the actual values.

Then the user scrolls (or click on the menu) to find the part where the data: by default, we are requesting the data for the actual day, if there is no data the page is empty (e.g. the screenshot below). To do so we are using an AJAX and PHP.

We use AJAX to send the data from the day chosen by the users (e.g. the screenshot below) or the one by default to the PHP script. PHP7 is a free scripting language used on the server and not on the “browser”, it means the calculations or other jobs programmed or done by the server and not by the computer or the phone of the user^[4] (W3.org, 2019). We used it to search in the folder of the server where the data are stored and return them on the CSV format. CSV (comma-separated values) is a widely used format to exchange data designed by IBM^[7] (IBM FORTRAN, 1972), it is well-known to be used easily with spreadsheet

software, our idea is that people who wants to used and analysed their data will do it with Microsoft Excel or LibreOffice Calc. If they are more experienced, they can parse the data with homemade scripts or with libraries of function added to languages by default (e.g. PHP or Python). If they do not exist, it returns a value to show this information and we will use it with JavaScript later.

If the data exist, we display them thanks to a library under the MIT license called Chart.js. But first we have to parse them to transform them for CSV string into arrays. For example, three measures for the fifth of May from 1PM to 3PM made the system looks like: date, time, value of the current, value of the voltage, value of the power, value of the temperature.

```
2019-05-18,13:00:00,1,5,5.2,26
2019-05-18,14:00:00,1,5.5,5.6,27
2019-05-18,15:00:00,1,6,6.3,28
```

First, we separate the measures when we find a carriage return (detected by `\n`) to have an array filled with our different measures:

```
Array = [ "2019-05-18,13:00:00,1,5,5.2,26", "2019...,27", "2019...,28" ]
```

For each of the values in the array we extract the date, time, current value, voltage value, power value, temperature value by separating them with the `“,”` used by the CSV format.

```
Array_of_the_first_measure = [ "2019-05-18", "13:00:00", "1", "5", "5.2", "26" ]
```

Then we create the arrays used by Chart.js to make the point in the chart: one for the x-axis and one for the y-axis. To create the array of the power (in the y-axis) we just add the fifth value of the array (e.g. `Array_of_the_first_measure`). And to do the second array we are using the same method to add the date (first value) and the time (second value) into the x-axis array.

```
Array_of_x-axis = [ "2019-05-18 13:00:00", "2019-05-18 14:00:00", "2019-05-18 15:00:00" ]
```

```
Array_of_y-axis = [ "26", "27", "28" ]
```

With this we can inject these arrays into the script used to create the chart. In this script we also found the options we have used by looking into the documentation of the library to change the colors, to add the function to show the values of a point when we move the mouse close to it and other details. All these options are interpreted with files of the library: we can have these files on our server, or we can use them stored by the developers. The first option allows us to change the files (MIT license allow it) but we do not need it and the second option involved storage space saved so we used this one.

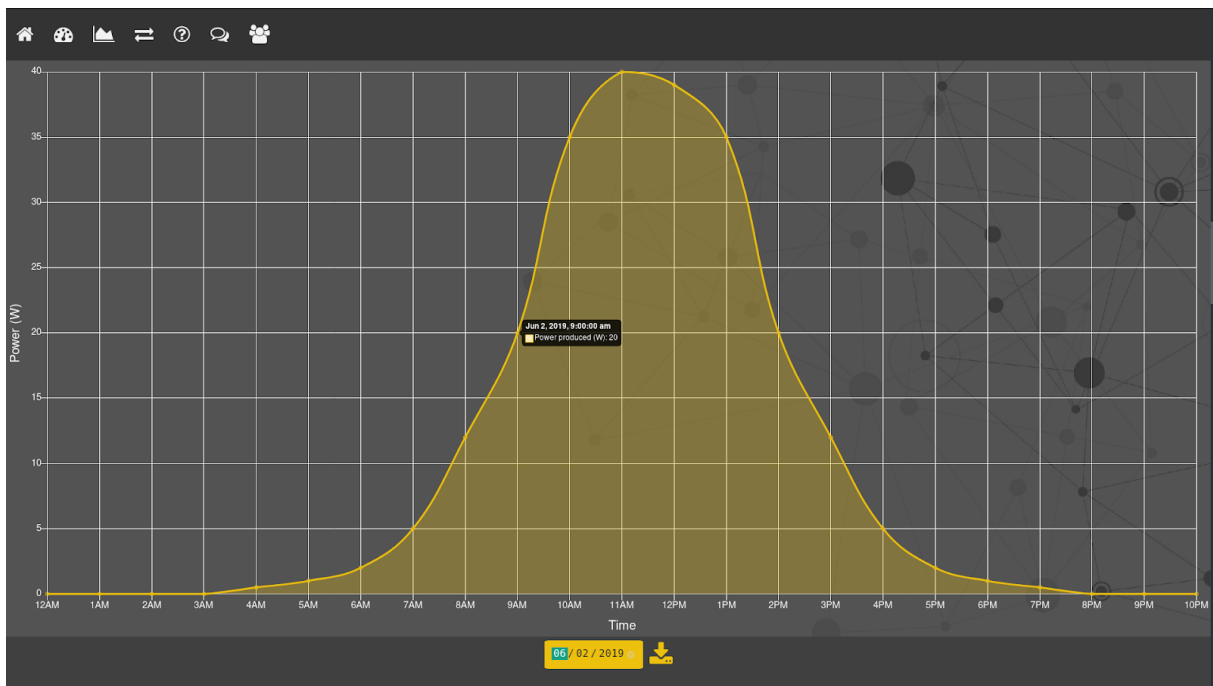


Figure 27. Screenshot of the application displaying the chart when there is data.

Moreover, if the data exist, we add a button so the user can download them (see appendix C. Screenshot of the application displaying the chart before downloading data.) as a CSV file and with date automatically generated.

If the data are not in the folder, we display nothing (e.g. the first screenshot) and the button to download disappears.

The following part of the webpage is the “converter”. The user enters a value of power and a number of hours with the keyboard or by clicking on the boxes to increase or decrease the values with a step of 50 for the power and 0.25 (equals to 15 minutes) for the time. Then the values of use of home appliances particles saved and the amount of money possibly saved by using photovoltaic energy is automatically updated. The user can also change the kind of home appliance used for the comparison with the yellow arrows. The system is used for the particles saved. Moreover, we add a mechanic to help users understand what these particles are by adding description of the one selected when hovering the text.

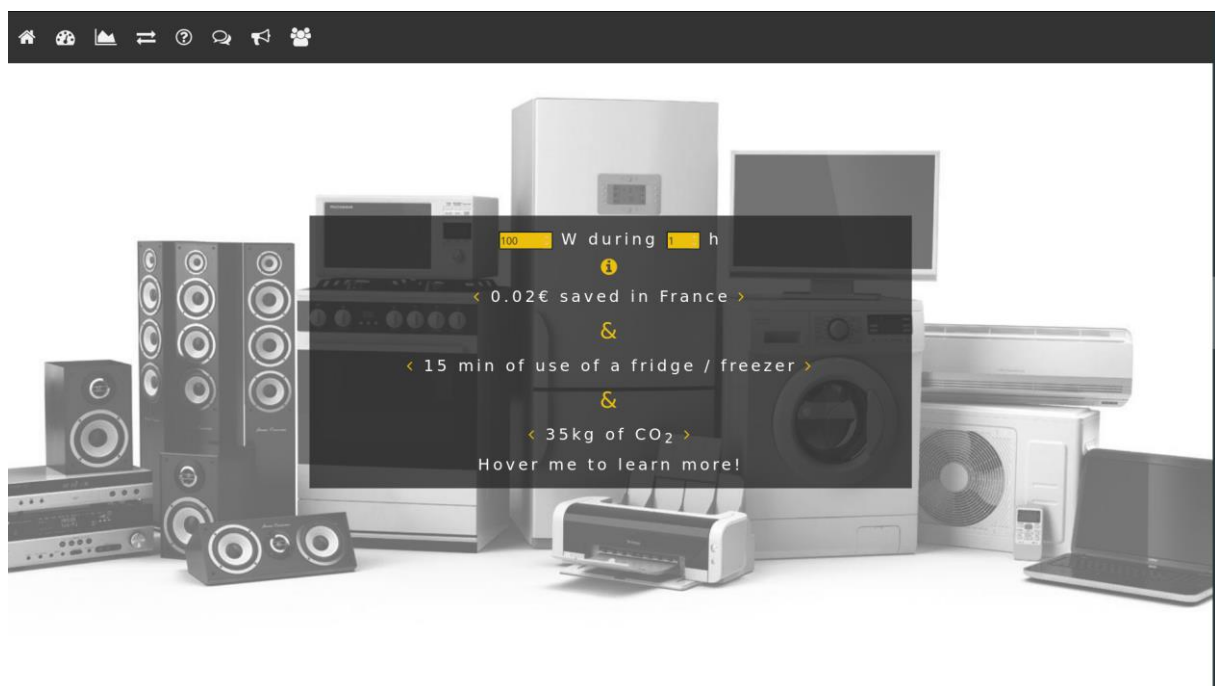


Figure 28. Screenshot of the converter application.

Our methodology of converting the energy generated into time of use of different most likely used devices by our persona was to research flats of IFE students, and list the home appliances and their consumption. Afterwards, we calculated the average and transformed it into a coefficient.

Moreover, we provide more direct way of converting the power produced into money saved in countries our team members come from: France, Poland and Spain. The number given is national average, as the exact prices will vary depending on the provider. (Ec.europa.eu, 2019)

We also provided a converter that shows how much of a given pollutant release is prevented by producing energy by solar cells in comparison to the same amount of energy produced by thermal plants using coal. We focused on 5 pollutants which have the highest impact on environment and human health: carbon dioxide, carbon monoxide, sulphur dioxide, nitric oxides and particulates.

To calculate the production of each pollutant for 1 Watt per hour, we used materials given by our coordinators and documents provided by Polish Ministry of Environment (Energia.eco.pl, 2019). Table 1 contains calculated production of pollutants per unit of power.

Table 1. Calculated amounts of pollutant production.

Pollutant	Amount produced for 12 Megawatts per hour in kilograms	Amount produced for 1 Watt per hour in kilograms
CO ₂	4400	3.67×10^{-4}
SO ₂	3.06	2.55×10^{-7}
Nox	8	6.67×10^{-7}
CO	10	8.33×10^{-7}
Particulates	5.4	4.50×10^{-7}

Afterwards, we conducted research on the specific effects on the environment and human health of each of those compounds. We condensed them into short descriptions and display them on the website, so our customer can learn about their impact and realize how much of them can be prevented by switching to solar energy.



The next parts of the webpage are no longer about data and numbers concerning the energy but more about education and communication beginning with a page to show the users how the product they are using is working as the Point of View guiding us to do. We did not add space with links for articles, Wikipedia or YouTube videos about photovoltaic energy to let the user makes the research if he or she wants to learn more about specific aspects of this energy. Moreover, the reflex 'the search it on internet' is well used and we do not want to impose what the user could learn.

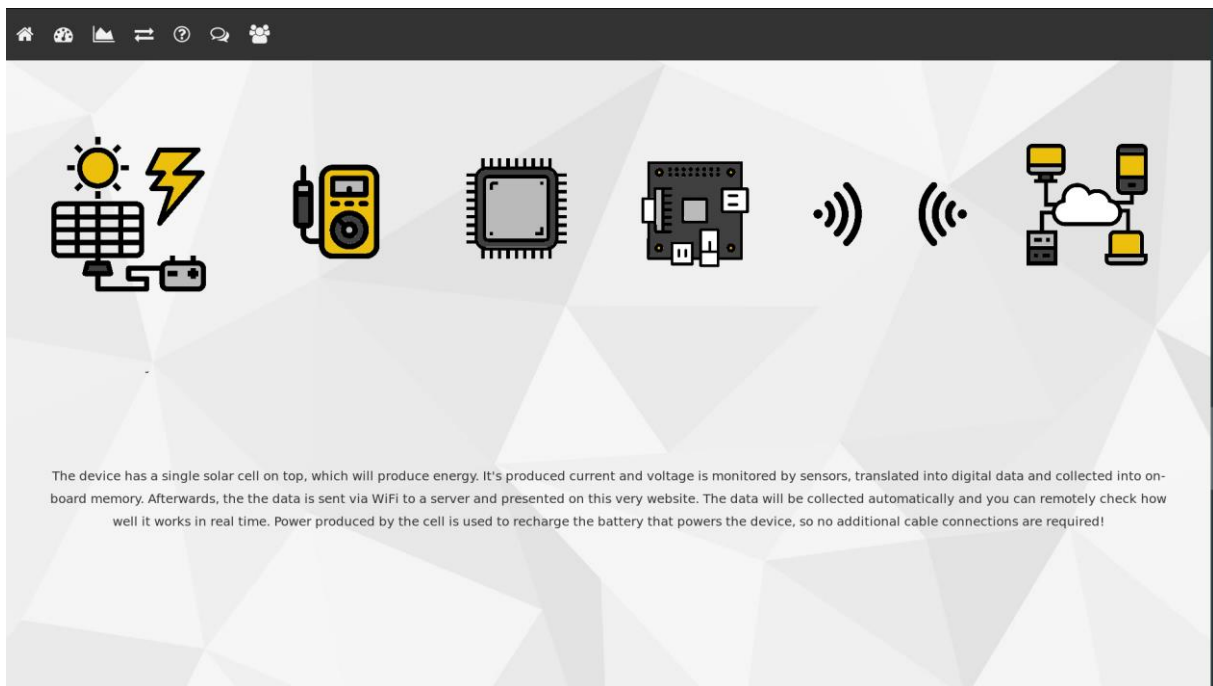


Figure 29. Screenshot of the part of the web page explaining the system.

The next page is used to share the project on social networks, we have the two most used for the moment but if other brands propose API (application programming interface) to share the website we will be able to add them. The idea is to share the link of the website with pre-made text.

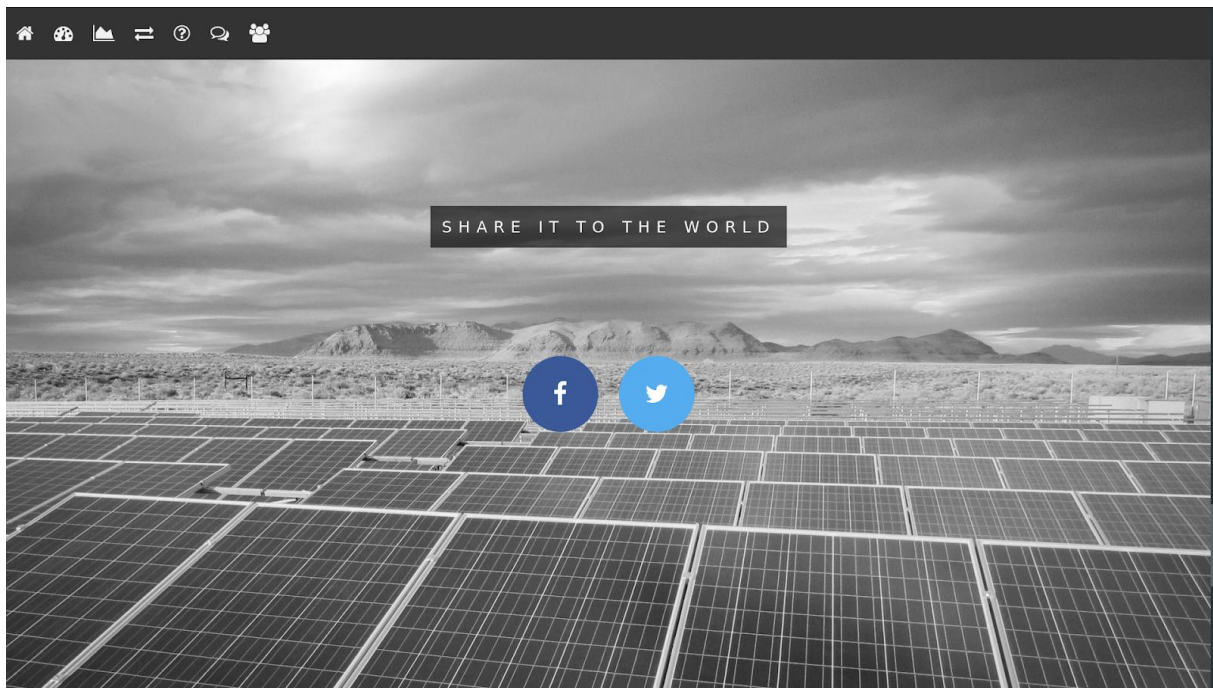


Figure 30. Screenshot of the part for the social networks.

When we click on the button for Twitter for instance, we have this sentence ready, but the user can add some comments about how much power was created. These APIs are used by the company so if the user is already connected with its account the link generated will change the language (e.g. the screenshot below with a French account) automatically.

Quoi de neuf ?

Find out how much solar energy you can produce on: <https://solearn2019.com/>

Tweeter

Figure 31. Screenshot of the Twitter page after clicking on the button.

The next application in the website is a text area so the users can give us feedback about the system, the webpage or new ideas to improve our solution (see appendix D. Screenshot of the application used to get feedbacks).



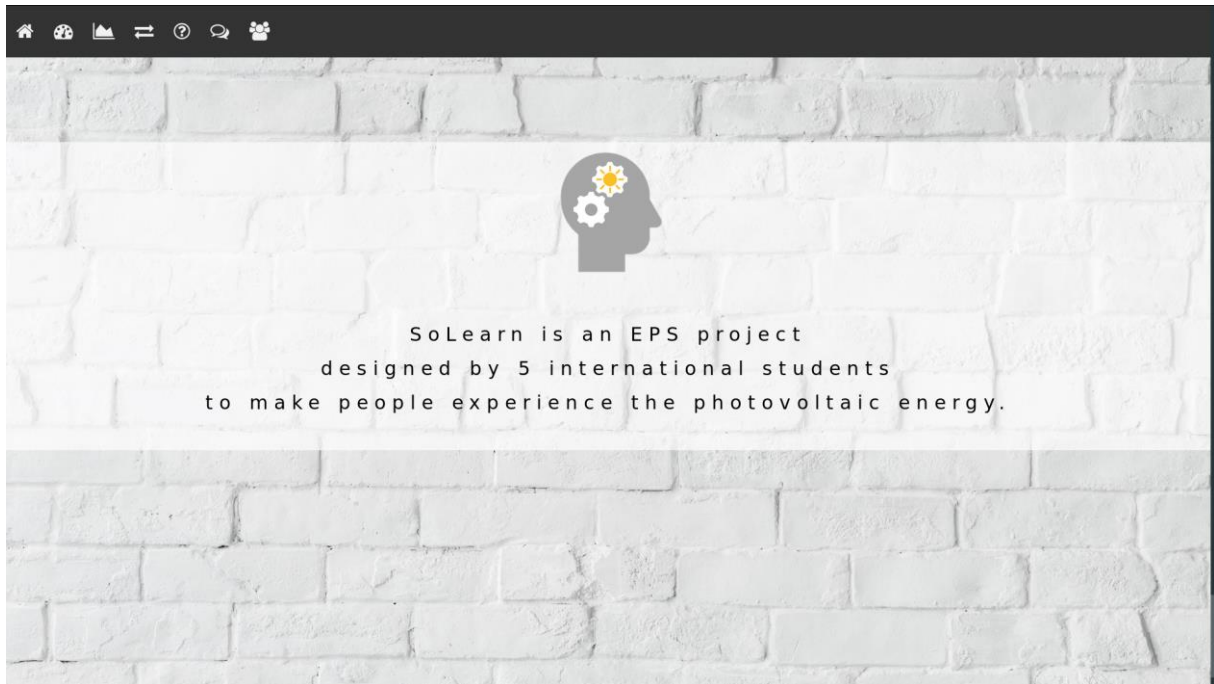


Figure 32. Screenshot of part of the website where the project is explained.

The last part of the website is used to present the project.

4.3.1.4. Mobile version

One important feature of the website is the utilization on smartphone so people can access the system everywhere and every time. The main change is the menu at the bottom, all the other changes are for the size of the fonts and to adapt the position and the layout of the elements of the webpage:



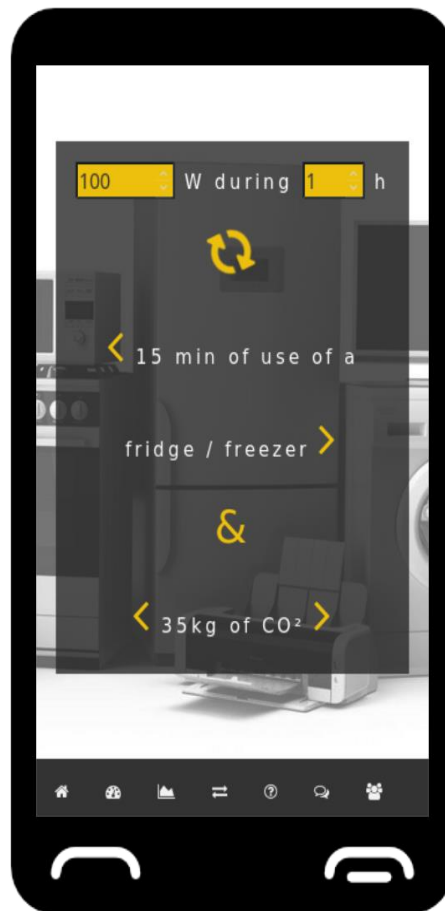


Figure 33. Montage with a screenshot of the converter application on a smartphone.

All these changes are made from the CSS code: first we declare the size of the viewport minimum or maximum to change the properties wanted. For example, to change the menu for the phone (their viewport is less than 400 pixels) our code is:

```
@media (max-width: 450px) {
```

The final code can be seen in Appendix G.

4.3.2. Raspberry Pi Zero W

We choose the Raspberry Pi Zero W because it is a powerful tool because it is a microcomputer so it means it can be used to make a server. It is a cheap, open source, efficient and small solution (its size is 65mm × 30mm × 5mm) with WIFI chipset already integrated (2.4 GHz) (Raspberrypi.org, 2019).

4.3.2.1. Setting up

The fact that we are using the Raspberry Pi as a server made us install the lightest operating system as possible: Raspbian Stretch Lite (derived from the famous Linux distribution Debian).

To add files (e.g. scripts, programs, images) on the Raspberry we need to access it thanks to SSH (Secure SHell), a protocol “that enables secure system administration and file transfers over insecure networks” (e.g. an internet box) from the computer used to develop the programs and the website to the Raspberry Pi® (Ssh.com, 2019). To activate this protocol, we used a trick to force it to be enable (by default is disabled for security reason because the username “pi” and the password “raspberry” of the raspberry are the same for everyone who install a Raspbian operating system). To do so we are adding an empty file named “ssh” in the boot partition. Then we are adding the name of the Wi-Fi network and its password in a specific file so we can connect with SSH:

```
$ sudo nano /etc/wpa_supplicant/wpa_supplicant.conf
```

“Sudo” means we are executing as “root” (it is the same as “administrator” for Mac or Windows) and nano is a simple text editor to add the information of the network:

```
network={  
    ssid="name_of_the_network"  
    psk="password_of_the_network"  
    key_mgmt=WPA-PSK
```



```
}
```

After transferring the operating system from our computer to a SD card, we plug this card the Raspberry Pi and turn it on. Then we try the command “nmap” to see what is the IP address of the Raspberry Pi from 192.168.1.0 to 192.168.1.255 (by experience we know it will be in this range):

```
$ nmap -sn 192.168.1.0/24
```

The terminal prompt the answer “192.168.1.7” then we try the following command to see if the SSH is working:

```
$ ssh pi@192.168.1.107
```

The terminal asks for the password (“raspberrypi”) and we are connected in the Raspberry Pi. After that we update the system, enable ssh at every start up and we change the password:

```
$ sudo apt-get update
```

```
$ sudo apt-get upgrade
```

```
$ sudo systemctl enable ssh
```

```
$ sudo raspi-config (a menu popup and then we type the new password)
```

While this menu is open, we also enable SPI protocol communication and I²C protocol communication as well because we will need them to receive data from the sensors.

The Raspberry Pi is now ready for the installation of the tools needed for the website:

- Apache: Apache Web Server is an open-source web server creation, deployment and management software maintained by the Apache Software Foundation[®] (Apache.org, 2019). We will use it to use the Raspberry Pi as server of the webpage to test all the mechanics before having a dedicated server.
- PHP: the PHP is required to test our webpage on the Raspberry Pi.
- Python is already installed by default, but we need to install the libraries used in our programs (for example to use the I²C and SPI communication protocols). Python is an open source scripting language widely used and versatile managed by the Python Software Foundation[™] (Python.org, 2019).

4.3.2.2. Hosting the webpage

The most important file we have to transfer into the folder for the web page is our file with the code of HTML5, CSS and JavaScript. We named it index.html because it is a standard: when we connect to the IP address where the webpage is the content shows first as to be called index.html or index.php. Our website is an only composed of one page so in the folder only one .html file is present. Then we add the pictures used in the page and the file with the PHP7 scripts. This file has to be in the same folder for security reason: only scripts on the same folder of the .html can be executed (only administrator should have access to the server). Then we create a folder called “measures” where all the data will be stored. To test the webpage, we have created data for the first and the second of June to test if the chart scripts are working properly. In the main folder we are adding a file where the values of the actual power and temperature will be stored. To simulate the acquisition of the data from the sensors we made two Python scripts. The first will create a random measure and store it in a csv file name after the day when the acquisition has been done. The second one is used to write random values in the file that shows the actual values of power and temperature. We have used three libraries to it: datetime, random and csv.

First, we have to tell the system what language is used (here python3) and what libraries are used. Then we are creating the variable of the path where the data are stored. The algorithm is very basic with these scripts: we create four random values simulating the

sensors, we are saving the date and the time and we add this six information with the CSV format: date, hour, I, U, P, T in the next line of the file. If there is no file for this date it is created or we add the line after the others:

```
#!/usr/bin/python3
import random
import datetime
import csv
#variables
path='/path/' #where to save the data
#Simulation of the signals:
i='{0:01.2f}'.format(random.uniform(0, 1))
u='{0:01.2f}'.format(random.uniform(0, 12))
p='{0:01.2f}'.format(float(i)*float(u))
t='{0:01.2f}'.format(random.uniform(10, 25))
#Storage in a CSV file:
dt=str(datetime.datetime.now())
date=dt[0:10]
time=dt[11:19]
file=path+date+'.csv'
with open(file, 'a+', newline='') as f:
    writer = csv.writer(f)
    writer.writerow([date,time, i, u, p, t]) #date, hour, I, U, P, T
f.close()
```

The second script is very similar: we are creating two values and we stored them in a file but this time we are writing over the old one:

After that we have everything ready to test our webpage but we need to access it, so we are looking the Raspberry Pi IP address on the local network with the bash command:

```
$ ping raspberrypi.local
```



The answer was 192-168-1-XXX depending on the network we were connected to. We only have to type this IP address into any browser, and we had access to the webpage.

To simulate the actual values changing all the time we executed a bash script that executes our python script.

The script asks for the number of times if we want to change the values, then it executes our second python script and show on the terminal the values so we can compare with the ones displayed on the web page.

4.3.2.3. Acquiring the data from the sensors

The sensors are using to different protocols (SPI and I²C) so the program is designed to send a signal for the first sensor (the temperature sensor for example), wait 0.2 second to avoid to many operations, then the second signal is sent. The acquisition of the measures is done thanks the libraries create especially for the seniors by their manufacturer. After the measures, the program writes the values into the file for the actual values (power and temperature) and into the CSV file of the current day after waiting some minutes (by default we chose 15 minutes between each measures).

4.3.3. Server

The server used is running on Debian, the same operating system used on the Raspberry, so the setup was the same and we just had to move all our files from the Raspberry Pi to the server with one command line. Thanks to this server, the webpage can now be reached with a regular URL. The transfer of the data between them is accomplished by adding in the python program the transfer of the files from the Raspberry Pi to the server after the acquisition thanks to a SSH function (see appendix F). Code for acquisition and transfer of the data.

4.3.4 Future improvements

In the last paragraphs, we showed how we built a working prototype and the following ideas are various ways to improve our solution for the software side of the project:

- Using a GSM networks instead of Wi-Fi to extend the area of use of the system
- Using more PHP to relieve phones and computers of certain calculations
- The Raspberry Pi is an amazing tool to develop powerful solution but by designing our own microcomputer it will be possible to have a solution using less energy. This solution is interesting if it's possible to divide R&D costs by selling a lot of products
- The development of a small software to setup the system (choosing between a local or an internet broadcast, changing the settings of the network, changing the amount of measures for instance)
- Using a database to store the data of all the users on the same server, so it will be needed to have a system of accounts
- Using cookies and other information available on browsers to propose the information for the country where the user is living and using the right language automatically
- Working on new features on the website to make it easier to use and more understandable. A small tutorial can be added to top it all.



5. TEST

This step involves presenting the prototype to the target. The goal is to solicit feedback that will let the design team know if they have successfully solved the problem or whether they need to go back to the drawing board and repeat steps.

This step is one of the most important because we finally have opinions about our work and achievements to improve them. Thanks to the consumers' feedback, we could have corrected and upgraded our prototype. Because we were running out of time, we couldn't reach our target a second time to ask their points of view. It's also a step where communication strategy is important, how to reach our target? How to make them react? As the prototyping phase was long and more difficult than we thought, we couldn't anticipate the tests.

To sum up what we want to test, the SoLearn final offer is a box connected to a website to simulate and calculate the money and CO₂ savings. On top of this box, there is a PV cell recording all data and sending it live to the user depending on the sun exposition. The main goal of our project is to educate people about PV, so the website presents soft explanations and knowledge.

Therefore, in the meanwhile, we analysed the photovoltaics market to make sure we have opportunities to grow and a problem to solve.

On one side, it's obvious that the market is growing fast for renewable energies (Appendix I shows the repartition of production between different renewable energies), same for the use of photovoltaics. This evolution is especially due to the decrease of prices of silicon PV cells over time: 76\$/Watt in 1977 against 0,30\$/Watt in 2015. Appendix J is a graph which show the actual use of photovoltaics in different countries. Appendix K shows the evolution and estimation of this use in the future.

On the other side, a huge part of this change is due to the role of governments. It is really important because they encourage the installation and use of photovoltaics thanks to financial incentives. Such policies are implemented to promote national or territorial energy

independence, high tech job creation and reduction of carbon dioxide emissions which cause climate change.

On top of all, consciousness about changing our way of consumption is growing, people are more curious, they are looking for the greenest option.

All of those points are added in the following SWOT:

<p>STRENGTHS</p> <ul style="list-style-type: none"> ○ Huge increasing market: \$91.3bn in 2018, from a niche market to a general electricity source ○ Money saver ○ Easy to install ○ Price of electricity and gas are growing: energy accounts for 8.5% of household budgets in 2017, up to 0.2 percentage points from 2016 ○ Technology efficiency is growing, such as the photovoltaics themselves: global solar photovoltaic capacity has grown from around five gigawatts in 2005 to an approximately 306.5 gigawatts in 2016 ○ Our product is cheap to produce ≤ 500 zloty (the components are cheap and easy to find) ○ Large target: companies, students, adults, government, builders, architects... 	<p>OPPORTUNITIES</p> <ul style="list-style-type: none"> ○ Green trends: PV recognize as a renewable energy ○ Laws and helps are going in favour of a green consumption: the self-consumption bonus, 0% of bank eco-loans, local aids, bonuses for energy, eligibility to have solar panels for free, grants in case of renovation (of course it depends on the country) ○ Easy to communicate thanks to the huge use of social medias
<p>WEAKNESS</p> <ul style="list-style-type: none"> ○ Bad image, people think it's not efficient ○ Depending on the weather, this dependence scares people ○ Hard to understand or hard to found easy explanations ○ Lot of maintenance 	<p>THREATS</p> <ul style="list-style-type: none"> ○ Others green energy such as water or wind ○ Difficulties to change habits of people, especially when it comes to change house parts ○ Regarding the law: we have to be careful of the urbanism rules of the town or the city (on the appearance of the houses or if it's a co-propriety, or for the laying)



The key point of our solution is that it is suitable for a wide amount of people, not only for Alex. We can reach PV companies, interesting in offering a test to their future consumers to convince them about the efficiency and educate them about PV. Our final product is a way of communication and marketing, it sells the product itself. Architects and house builders must be interested as well, to test the sun orientation or the house capacity. The product will give them the answer either they should install PV cells on the roof or not. We can also sell the product to the government, make it a compulsory step in the building process or in renovation initiatives.

Different marketing strategies can be used, adapted to each target. Either a law proposition for the government, or a demonstration video for the constructors, or street marketing actions for the students, giving them practical guides, or going door to door for the older one, or advertising campaign in specialized magazines in architecture for example.

Testing and selling our idea would be the following steps to be entrusted to our supervisors or to a specialized company after evaluating its price.

The testing part can be easy, thanks to the counter on the website, it shows the number of visits. There is also a corner where people can send feedbacks, through Facebook account or through contacts information where they are welcome to give advices, recommendations or tell us their complains.



CONCLUSIONS

First of all, we are grateful for being part of the EPS Project. It was a great project with a real problematic and goals. It was the first time that we worked in an international team with professionals' teachers and searchers and with a budget. This project was a great source of knowledge.

It wasn't really easy in the first place, because we come from different countries, with different work cultures. The fact that we come from many fields, was both a problem and an asset to our team. It was hard to combine all of our interests in one project. Because we study in different fields, we wanted to go in different directions - creativity, engineering, business, electronics, and software. Moreover, our project had too big scope in scope for Design Thinking approach in the given time-frame for it.

Nonetheless, the chance to work in an interdisciplinary team was a very interesting and valuable experience, because in our professional careers we will without a doubt work in similar conditions.

Additionally, we learnt a new approach of work, the Design Thinking approach. This working method was new to each of us, so we learnt how to think in a creative way. But we also learnt how difficult it can be. After all, we didn't focus enough on the consumer's point of view. Especially between the third and fourth steps: ideate and prototype. We should have asked their opinion, do more interaction with them to obtain feedback about our ideas. Maybe the ideas vote shouldn't be performed by us but them. What is sure, is that we will use this method in our future projects, knowing the difficulties and pitfalls. In fact, we did not have enough time to finish our project. But maybe with a better time management, we could have done the first two steps quicker. We used the two first months to empathize and define, which was too much. Two months were not enough to ideate, prototype and test our ideas. In the best-case scenario, we would have done several prototypes, regarding the remarks and feedback of final users.



We also know much more about photovoltaics now than when we started the project, thanks to prof. Sibinski's lectures and dr Znadjek's exercises. We are now knowledgeable about PV's technicalities, efficiency and their possible futures.

Other than photovoltaics, we had a chance to combine many different technologies into one working device – custom printed circuit boards with sensors, embedded systems with Raspberry Pi, server setup and data transferring, website creation with the use of HTML, JavaScript and PHP, and data visualization.



APPENDIX

APPENDIX A. Notes of few interviews

1st interview:

Mateo – 19 – Lodz

Student + programming /ride bike/skateparks

- Energy from the sun, green
- Why important? Limited resources on earth > we have to find other ways to collect energy
- “photovoltaics?” collect energy from the sun, heat the plate and the energy is stored in some capacitors
- Exp? No solar panels at home, he saw some outside like black barrel with water (sun heat the water) + lives in a house
- Reasons not using? His parents chose the house, it was built 20 years ago so it wasn't popular
- How should we spread the message? Campaigns and adverts
Awareness is being trendy (mostly about not using plastic anymore)

e-mail: mateusziantadeusz@wp.pl

Feelings: scared, stressed when we ask the question why not using

2nd interview:

Lika – 26 – Georgia

Internship in IFE SAO until August + reading articles on political economics (student in the humanitarian field) /drink

- Sun, wind, pressure of water
- Why important? Any source to produce energy > we will be in shit without renewable energy
- PV? Nothing
Solar panels > on top of the buildings, it heats water and produce energy
- Exp? Her grandmother uses it in her summer house in Georgia
Lives in an apartment
- Why not using? In the future
depends > cheaper than electricity but maybe difficult to install when the house is already built
- Learned about it in school (not through adverts)
- How to spread the msg? not with students, between adults, adverts from companies

Email: likanodarishrili@gmail.com

Feelings: Enthusiastic, even if she was not really aware

3rd interview:

Piotr – 21 – Lodz

Student in computer science (TCS?) + watch movies

Pawel – 21 – Lodz

Student – read books

- Sun, wind, water, nuclear?
- Why important, because it's cheaper, ecologic and efficient. / running out of energy
- PV? X
solar panels were expensive but getting cheaper, people don't know about it/ not really efficient 15% maybe 30%
- Exp? Calculator, power bank
- Why not using? Not responsible of the house energy consumption / parents don't know
- They learned about it on internet (1 in school)
- How to spread? Show to older people how it works and that it exists (30 or 40+)

Feelings: Curious, enthusiastic, open and interested

4th interview:

Gabriela – 20 – Lodz

Work in a restaurant / student + riding horses

Enthusiastic, eco-freak

Gasha – 20 – Lodz

Student in biotechnology

Not interested at all (busy)

Lucas – 20 – Rabien

Student in computer science + football, volleyball

In between

- Solar, water, wind, biofuel
- Important because we are running out of unrenewable energy. We have to take care of our earth
- Solar panels need a lot of water to be cleaned. No idea of what there are made of
- No experience, but see it in the street like for Nextbike
- Why not using? Pretty expensive, live in a flat, not so much sun in Poland
- Learn that they exist at school
- How? Money from the government so house can use it + some companies in the web

E-mail : gabich@vp.pl withowshi@gmail.com gosiaturmanek11@gmail.com

5th interview:

Jonathan – 21 – Paris

Student in computer science + music (guitar, piano, singing)

- Solar, wind, water
- Yes important, we don't have enough technologies to produce so we need to find other ways
- Solar panels during his studies (2 years ago)
- No one in his family/friend has some PV
Why? Don't really know how to use them
Lives in a house
- Big source of energy, for sure we need it, but doesn't know how it works but he will use some in the future
- How to spread info? Try to make adverts on the social medias, in order to reach young people and students because it's the future

Email: jonathan.pham27@yahoo.fr

Feelings: Not comfortable with the interview



APPENDIX B. Minutes of the Ideate step's meeting

Organization Name: <u>Lodz University of Technology (TUL)</u>
Department Name: <u>EPS Project</u>
Day, Date: <u>07.05.2019</u>
Time of Meeting: <u>12:00</u>
Meeting Location: <u>IFE Room 11</u>
Minutes prepared by: Violette
Aim of the meeting: IDEATE step of Design Thinking
Attendees: Maxence, Jorge, Damian, Szymon, Violette
Supervisors: dr inż. Katarzyna Znajdek, dr. hab. inż. Maciej Sibiński, prof. PŁ
Meeting summary:
IDEATE > gather ideas on board: we prepared before 10 ideas each + 9 crazy ideas (involving magic, 1M\$ and troubles) > sort out big combined ideas We had different groups of ideas = gadgets / guide / education / Virtual Reality / ... 1. fountain PV + charger + social media QR, (education) 2. Box (+ phone app in live): info about saving CO2, money, social posts (« oh I saved xxx today/this week ») lead to community 3. Joystick > manual settings + charger 4. Games (without computer) 5. Web page (videos, links...) forum 6. future: interviews, VR museum 7. International event (PV Day > street PV festival) 8. Law/initiative for usage of PV 9. guide

10. charging box

>vote

1. III

2. III

3. I

4. I

9. I

10. I

>>2nd vote => **2nd idea**

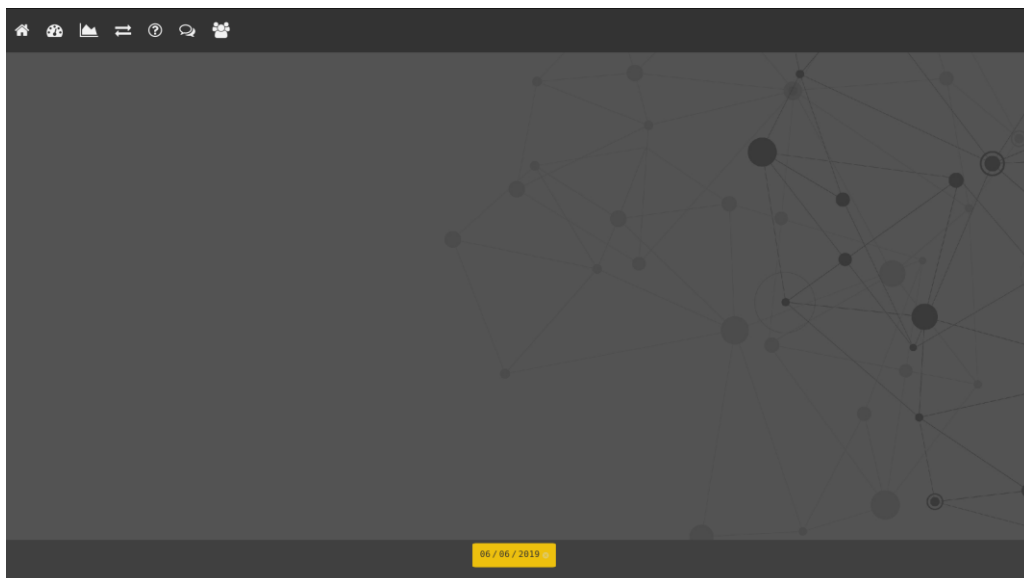
For next time (Thursday 9.05 at 12) > PROTOTYPING

Think of the design and then materials/components

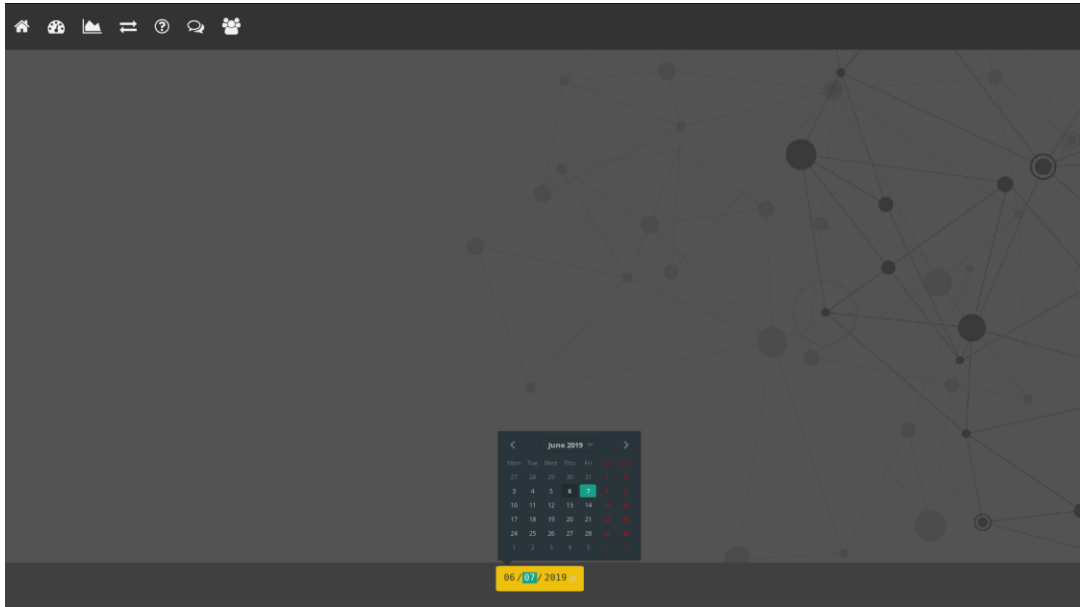
Think about costs/budget and things we can ask to buy, for example:

- 1 small panel
- Micro controller: esp

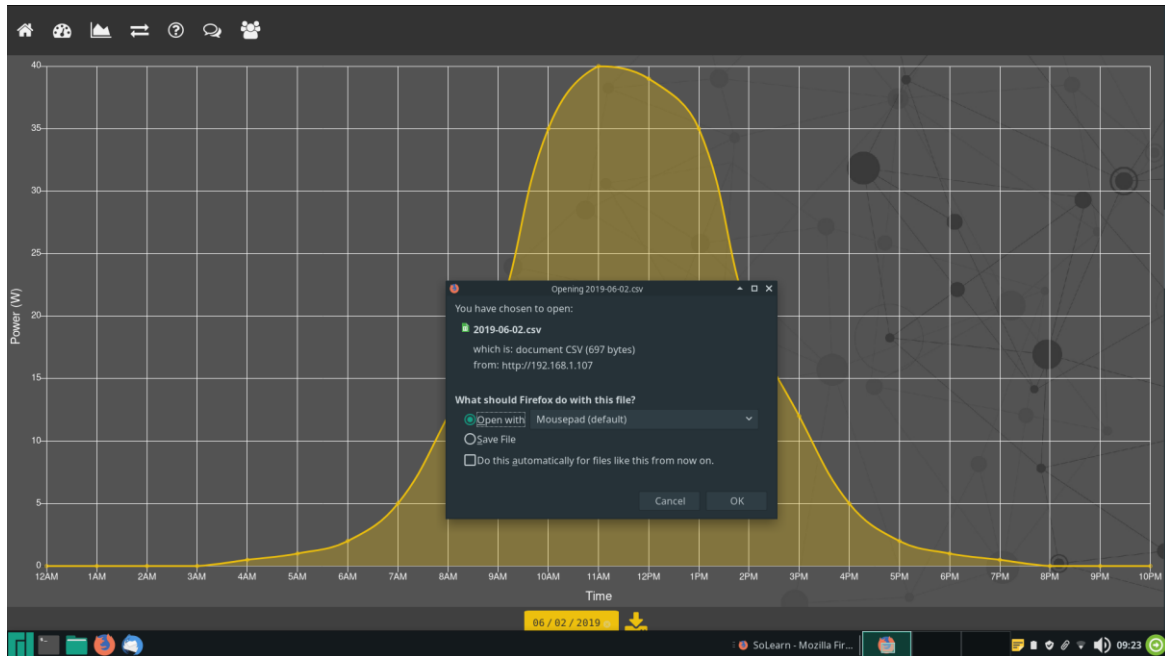
APPENDIX C. Screenshot of the application displaying the chart when there is no data.



APPENDIX D. Screenshot of the application displaying the chart when the user chooses a day.



APPENDIX E. Screenshot of the application displaying the chart before downloading data.



APPENDIX F. Code for acquisition and transfer of the data.

```
#!/usr/bin/python3
```

```
import datetime
```

```
import time
```

```
import csv
```

```
import os
```

```
import random
```

```
#variables
```

```
cron = 15
```

```
path_rpi='/var/www/html/'
```

```
path_server='/var/www/solearn/'
```



```

#functions
def date_to_str(date):
    dt = str(date)
    date = dt[0:10]
    time_hms = dt[11:19]
    time_hm = dt[11:16]
    return(date, time_hms, time_hm)
def ssh(path_file, path_server):
    os.system('sshpass -p "<::SoLearn::>" scp -r
'+path_file+' root@solearn.lgtech.ovh:'+path_server+'.')

#Script
acquisition_cron = datetime.datetime.now() + datetime.timedelta(minutes = cron)
while True:
    #Get time
    date, acquisition_time, current_time = date_to_str(datetime.datetime.now())
    #get the values
    # Simulation
    current = '{:01.2f}'.format(random.uniform(0, 1))
    voltage = '{:01.2f}'.format(random.uniform(0, 12))
    power = '{:01.2f}'.format(float(current) * float(voltage))
    temperature = '{:01.2f}'.format(random.uniform(10, 25))
    #save actual_values.txt
    with open(path_rpi + 'actual_values.txt', 'w+', newline='') as f:
        f.write(power + "," + temperature)
        f.close()
    # send actual_values.txt

```

```

ssh(path_rpi + 'actual_values.txt', path_server)
#cronjob
if datetime.datetime.now() >= acquisition_cron:
    print('csv+1')
    #save data cron
    path_csv = path_rpi + date + '.csv'
    with open(path_csv, 'a+', newline='') as f:
        writer = csv.writer(f)
        writer.writerow([date, acquisition_time, current, voltage, power,
temperature])
        f.close()
    #send data cron
    ssh(path_csv, path_server + 'measures/')
    #new cron
    acquisition_cron = datetime.datetime.now() + datetime.timedelta(minutes =
cron)
    #wait
    time.sleep(1)

```

APPENDIX G. code of the web page (CSS, HTML5, JavaScript)

```

<!DOCTYPE html>
<html>
<head>
<title>SoLearn</title>
<meta content="text/html;charset=utf-8" http-equiv="Content-Type">
<meta content="utf-8" http-equiv="encoding">

```



```

<link href="logo.png" rel="shortcut icon" >
<meta name="description" content="Track your photovoltaic production">
<meta name="author" content="SoLearn">
<meta name="viewport" content="width=device-width, initial-scale=1.0">
<style>
body, html {
  height: 100%;
  margin: 0;
  font: 400 15px/1.8 "Lato", sans-serif;
  color: #777;
}
/*----- Menu -----*/
.navbar {
  overflow: hidden;
  background-color: #333;
  position: fixed;
  top: 0;
  width: 100%;
  z-index: 500;
  font-size: 30px;
}
.navbar a {
  float: left;
  display: block;
  color: #f2f2f2;
  text-align: center;
  padding: 14px 16px;
  text-decoration: none;
}
.navbar a:hover {
  background: #EDC00E;
  color: black;
}
.fa-home, .fa-dashboard, .fa-area-chart, .fa-exchange, .fa-question-circle-o, .fa-comments-o, .fa-group {
}
/*----- Background images -----*/
.bgimg-0, .bgimg-1, .bgimg-3, .bgimg-4, .bgimg-5, .bgimg-6 {
  position: relative;
  background-attachment: fixed;
  background-position: center;
  background-repeat: no-repeat;
  background-size: cover;
  min-height: 100%;
}
.bgimg-2 {
  position: relative;
  background-attachment: fixed;
  background-position: center;
  background-repeat: no-repeat;
  background-size: cover;
  min-height: 92%;
}
}

```

```

.bgimg-0 {
  background-image: url("sp3.jpg");
}
.bgimg-1 {
  background-image: url("sp2.jpg");
}
.bgimg-2 {
  background-image: url("Background-website-01.jpg");
}
.bgimg-3 {
  background-image: url("hd.jpg");
}
.bgimg-4 {
  background-image: url("Background-website-02.jpg");
}
.bgimg-5 {
  background-image: url("Background-website-03.jpg");
}
.bgimg-6 {
  background-image: url("Background-website-04.jpg");
}
/*----- 1st page -----*/
.caption {
  position: absolute;
  left: 0;
  top: 25%;
  width: 100%;
  text-align: center;
  color: #000;
}
.caption span.border {
  background-color: rgba(0, 0, 0, 0.65);
  color: #fff;
  padding: 18px;
  font-size: 70px;
  letter-spacing: 10px;
}
/*----- Production -----*/
.fa-spinner {
  color: #505050;
}
.fa-chevron-circle-up {
  color: #bfff00;
}
.fa-chevron-circle-down {
  color: #EDC00E;
}
.caption_production {
  position: absolute;
  left: 30%;
  right: 30%;
  top: 15%;
}

```

```

width: auto;
text-align: center;
color: #000;
}
.border_production {
background-color: rgba(40, 40, 40, 0.8);
color: #fff;
padding: 10px;
font-size: 70px;
letter-spacing: 5px;
}
@media (max-width: 1024px) {
.caption_production {
left: 5%;
right: 5%;
top: 10%;
}
}
@media (max-width: 1300px) {
.caption_production {
left: 15%;
right: 15%;
top: 15%;
}
}
/*----- Data -----*/
.caption_data {
position: absolute;
left: 0;
top: 0;
width: 100%;
height: 100%;
text-align: center;
color: #000;
background-color: rgba(40, 40, 40, 0.8);
}
.fa-download {
color: #EDC00E;
background-color: none;
}
input {
margin: .4rem 0;
}
.note {
font-size: .8em;
}
#calendar {
background-color: #EDC00E;
color: #333333;
border: 10px solid #EDC00E;
border-radius: 5%;
}

```

```

canvas {
  -moz-user-select: none;
  -webkit-user-select: none;
  -ms-user-select: none;
  display: block;
  position: relative;
  top: 0;
  left: 0;
  right: 0;
  bottom: 0;
  width: 200px;
  height: 200px;
}
.center {
  display: flex;
  align-items: center;
  justify-content: center;
}
/*----- Converter -----*/
.fa-refresh,.fa-angle-left ,.fa-angle-right {
  color: #EDC00E;
  font-size:40px;
}
.fa-refresh:hover, .fa-angle-left:hover, .fa-angle-right:hover {
  opacity: 0.7;
}
#in_power {
  width: 5em;
  background-color: #EDC00E;
  color: #333333;
}
#in_time {
  width: 3em;
  background-color: #EDC00E;
  color: #333333;
}
.caption_converter {
  position: absolute;
  left: 25%;
  right: 25%;
  top: 30%;
  width: auto;
  text-align: center;
  color: #000;
}
.border_converter {
  background-color: rgba(40, 40, 40, 0.8);
  color: #fff;
  padding: 15px;
  font-size: 25px;
  letter-spacing: 5px;
}

```

```

/*----- Tooltip -----*/
.tooltip .tooltiptext {
  visibility: hidden;
  width: 600px;
  background-color: #202020;
  color: #fff;
  font-size: 20px;
  text-align: center;
  border-radius: 6px;
  padding: 5px 0;
  border: solid 3px #EDC00E;
  /* Position the tooltip */
  position: absolute;
  z-index: 1;
  bottom: 10%;
  left: 20%;
}
.tooltip:hover .tooltiptext {
  visibility: visible;
}
.tooltip2 .tooltiptext2 {
  visibility: hidden;
  width: 300px;
  background-color: #202020;
  color: #fff;
  font-size: 20px;
  text-align: center;
  border-radius: 6px;
  padding: 5px 0;
  border: solid 3px #EDC00E;
  /* Position the tooltip */
  position: absolute;
  z-index: 1;
  bottom: 10%;
  left: 25%;
}
.tooltip2:hover .tooltiptext2 {
  visibility: visible;
}
/*----- Phones -----*/
@media (max-width: 1200px) {
  .caption_converter {
    left: 5%;
    right: 5%;
    top: 20%;
  }
}
/*----- Learn more -----*/
.graph_learnmore {
  padding-top: 100px;
  padding-bottom: 100px;
  width: 16%;
}

```

```

}
/*----- Social network -----*/
.fa {
}
.fa-facebook:hover, .fa-twitter:hover {
  opacity: 0.85;
}
.fa-facebook {
  background: #3B5998;
  color: white;
  padding: 40px;
  font-size: 70px;
  width: 40px;
  height: 40px;
  text-align: center;
  text-decoration: none;
  border-radius: 50%;
  margin: 10px;
}
.fa-twitter {
  background: #55ACEE;
  color: white;
  padding: 40px;
  font-size: 70px;
  width: 40px;
  height: 40px;
  text-align: center;
  text-decoration: none;
  border-radius: 50%;
  margin: 10px;
}
#sn {
  text-align: center;
  position: absolute;
  left: 0;
  top: 50%;
  width: 100%;
  font-size: 40px;
}
.caption_sn {
  position: absolute;
  left: 0;
  top: 30%;
  width: 100%;
  text-align: center;
  color: #000;
}
.caption_sn span.border_sn {
  background-color: rgba(0, 0, 0, 0.65);
  color: #fff;
  padding: 18px;
  font-size: 25px;
}

```

```

    letter-spacing: 10px;
}
/*----- Feedback -----*/
.caption_feedback {
    position: absolute;
    left: 0;
    top: 30%;
    width: 100%;
    text-align: center;
    color: #333333;
    padding: 0px;
    font-size: 25px;
    letter-spacing: 10px;
}
#input_feedback {
    background-color: rgba(237, 192, 14, 0.45);
    color: #333333;
}
.fa-send-o {
    color: #333333;
}
.fa-send-o:hover {
    opacity: 0.7;
}
/*----- About us -----*/
.caption_us {
    position: absolute;
    left: 0;
    top: 20%;
    width: 100%;
    text-align: center;
    color: #000;
    background-color: rgba(255, 255, 255, 0.65);
}
.caption_us p.border {
    background-color: rgba(0, 0, 0, 0.65);
    color: #fff;
    padding: 18px;
    font-size: 30px;
    letter-spacing: 10px;
}
/*----- Template -----*/
h3 {
    letter-spacing: 5px;
    text-transform: uppercase;
    font: 20px "Lato", sans-serif;
    color: #111;
}
/*----- Responsiveness -----*/
@media (max-width: 800px) {
    .bgimg-0, .bgimg-1, .bgimg-2, .bgimg-3, .bgimg-4, .bgimg-5, .bgimg-6 {
        background-attachment: scroll; /* Turn off parallax scrolling */
    }
}

```

```

}
}
/* Phones */
@media (max-width: 450px) {
/*-- Menu --*/
.navbar {
font-size: 12px;
top: auto;
bottom: 0;
}
/*-- 1st page --*/
.caption span.border {
padding: 18px;
font-size: 50px;
letter-spacing: 8px;
}
/*-- Production --*/
.caption_production {
position: absolute;
left: 0;
right: 0;
top: 0%;
}
.border_production {
padding: 2px;
font-size: 50px;
letter-spacing: 2px;
padding-bottom: 250px;
}
/*-- Data --*/
.bgimg-2 {
min-height: 75%;
}
/*-- Converter --*/
fa-refresh,.fa-angle-left ,.fa-angle-right {
font-size:20px;
}
.caption_converter {
left: 5%;
right: 5%;
top: 10%;
}
.border_converter {
padding: 0px;
font-size: 15px;
letter-spacing: 3px;
}
.tooltip .tooltiptext {
width: 300px;
font-size: 10px;
bottom: 10%;
left: 10%;
}

```



```

}
.tooltip2 .tooltiptext2 {
  left: 10%;
}
/*-- Social Network --*/
.caption_sn {
  position: absolute;
  left: 0;
  top: 25%;
  width: 100%;
  text-align: center;
  color: #000;
}
.caption_sn span.border_sn {
  background-color: rgba(0, 0, 0, 0.65);
  color: #fff;
  padding: 10px;
  font-size: 17px;
  letter-spacing: 4px;
}
#sn {
  top: 35%;
  font-size: 20px;
}
.fa-facebook {
  padding: 20px;
  width: 20px;
  height: 20px;
  margin: 10px;
}
.fa-twitter {
  padding: 20px;
  width: 20px;
  height: 20px;
}
/*-- Feedbck --*/
.caption_feedback {
  left: 0;
  top: 10%;
  font-size: 20px;
  letter-spacing: 5px;
}
/*-- About Us --*/
.caption_us {
  top: 0%;
  bottom: 0%;
}
.caption_us p.border {
  padding: 10px;
  font-size: 20px;
  letter-spacing: 5px;
}
}
}

```

```

</style>
</head>
<body onload="convert();today();data(calendar.value, 0);show_actual_values()">
<!-- Add icon library -->
<link rel="stylesheet" href="https://cdn.jsdelivr.net/npm/font-awesome@4.7.0/css/font-awesome.min.css">
<!-- Menu -->
<div class="navbar">
  <a href="#home"><i class="fa fa-home"></i></a>
  <a href="#production"><i class="fa fa-dashboard"></i></a>
  <a href="#data"><i class="fa fa-area-chart"></i></a>
  <a href="#converter"><i class="fa fa-exchange"></i></a>
  <a href="#learn more"><i class="fa fa-question-circle-o"></i></a>
  <a href="#social"><i class="fa fa-comments-o"></i></a>
  <a href="#feedback"><i class="fa fa-bullhorn"></i></a>
  <a href="#about us"><i class="fa fa-group"></i></a>
</div>
<!-- First page -->
<div id="home" class="bgimg-1">
  <div class="caption">
    <span class="border">SoLearn</span>
  </div>
</div>
<div style="color: #777;background-color:white;text-align:center;padding:50px 80px;text-align: justify;">
  <h3 style="text-align:center;">How it works</h3>
  <p>Have you ever considered using solar panels at your home or workplace, but wondered how efficient it would be and how much benefit would it bring to you? We have a simple solution for your - a SoLearn device that you only need to install in place of your choice and it will do all the job for you. Scroll or use the menu to find how much you produce and track your production!</p>
</div>
<!-- Production -->
<div style="position:relative;">
  <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align: justify;font-size: 25px;">
    <p>Actual values</p>
  </div>
</div>
<div id="production" class="bgimg-0">
  <div class="caption_production">
    <div class="border_production">
      <p id="actual_power">Initialisation...</p>
      <a><i id="arrow" class="fa fa-spinner fa-spin" style="font-size:96px"></i></a>
      <p id="actual_temperature"></p>
    </div>
  </div>
</div>
<!-- Data -->
<div style="position:relative;">
  <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align: justify;font-size: 25px;">
    <p>Data</p>
  </div>
</div>

```

```

</div>
<div id="data" class="bgimg-2">
  <div class="caption_data">
    <canvas id="myChart"></canvas>
    <script src="https://cdnjs.cloudflare.com/ajax/libs/Chart.js/2.8.0/Chart.bundle.min.js"></script>
  </div>
</div>
<div class="center" style="background:#505050;">
<input type="date" id="calendar" oninput="data(calendar.value, 1)" value="today" style="margin-right:10px;">
<a href="path_csv" download="" id="dl_a" style="text-decoration:none;font-size:40px"><i id="button_dl" class="fa fa-download" style="font-size:40px"></i></a>
</div>
<!-- Converter -->
<div style="position:relative;">
  <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align:justify;font-size: 25px;">
    <p>Converter</p>
  </div>
</div>
<div id="converter" class="bgimg-3">
  <div class="caption_converter">
    <div class="border_converter">
      <input type="number" id="in_power" value="100" min="0" step="100" onchange="convert()"><a> W during </a><input type="number" name="time" id="in_time" value="1" min="0" step="0.25" onchange="convert()"><a> h</a>
      <div class="tooltip2"><i class="fa fa-info-circle" style="font-size:30px;color:#EDC00E"></i>
        <span class="tooltiptext2" id="tooltiptext_cell"></span>
      </div>
      <!-- money saved -->
      <a onclick="decrease_count0()"> <i class="fa fa-angle-left"></i></a>
      <a id="counter_money">Money</a>
      <a onclick="increase_count0()"> <i class="fa fa-angle-right"></i></a><br>
      <!-- & -->
      <a style="color: #EDC00E;font-size:36px;">&</a><br>
      <!-- time home appliances -->
      <a onclick="decrease_count1()"> <i class="fa fa-angle-left"></i></a>
      <a id="counter_home_appliances">Home appliances</a>
      <a onclick="increase_count1()"> <i class="fa fa-angle-right"></i></a><br>
      <!-- & -->
      <a style="color: #EDC00E;font-size:36px;">&</a><br>
      <!-- particles saved -->
      <a onclick="decrease_count2()"> <i class="fa fa-angle-left"></i></a>
      <a id="counter_particles">Particles saved</a>
      <a onclick="increase_count2()"> <i class="fa fa-angle-right"></i></a>
      <div class="tooltip">Hover me to learn more!
        <span class="tooltiptext" id="tooltiptext_particles"></span>
      </div>
    </div>
  </div>
</div>
</div>
<!-- Learn more -->

```

```

<div style="position:relative;">
  <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align:
    justify;font-size: 25px;">
    <p>Learn more</p>
  </div>
</div>
<div id="learn more" class="bgimg-4">
  
  
  
  
  
  
  <p style="text-align:center;padding-left:50px;padding-right:50px;padding-top:5px;padding-
    bottom:5px;font-size:25px;color:#303030">The device has a single solar cell on top, which will
    produce energy. It's produced current and voltage is monitored by sensors, translated into
    digital data and collected into on-board memory. Afterwards, the the data is sent via WiFi to a
    server and presented on this very website. The data will be collected automatically and you can
    remotely check how well it works in real time. Power produced by the cell is used to recharge
    the battery that powers the device, so no additional cable connections are required!</p>
</div>
<!-- Social networks -->
<div style="position:relative;">
  <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align:
    justify;font-size: 25px;">
    <p>Social networks</p>
  </div>
</div>
<div id="social" class="bgimg-1">
  <div class="caption_sn">
    <span class="border_sn">SHARE IT TO THE WORLD</span>
  </div>
  <div id="sn">
    <a
      href="https://www.facebook.com/sharer/sharer.php?u=https%3A//solearn2019.000webho
      stapp.com"><i class="fa fa-facebook"></i></a>
    <a id="twitter_link" href=""><i class="fa fa-twitter"></i></a>
  </div>
</div>
<!-- Feedback -->
<div style="position:relative;">
  <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align:
    justify;font-size: 25px;">
    <p>Feedback</p>
  </div>
</div>
<div id="feedback" class="bgimg-6">
  <div class="caption_feedback">
    <p>Please tell us what you think:</p>
    <textarea id="input_feedback" rows="10" cols="35">
  </textarea>
</div>

```

```

    <br><a id="feedback_button" onclick="write_feedback()"><i class="fa fa-send-o" style="font-
        size:36px"></i></a>
</div>
</div>
<!-- About us -->
<div style="position:relative;">
    <div style="color:#ddd;background-color:#404040;text-align:center;padding:1px 80px;text-align:
        justify;font-size: 25px;">
        <p>Learn more</p>
    </div>
</div>
<div id="about us" class="bgimg-5">
    <div class="caption_us">
        
        <p class="border" style="background-color:transparent;color: #000000;">SoLearn is an European
            Project Semester system<br>designed by 5 international students<br>to make people
            experience the photovoltaic energy<br>
            made in 2019.</span>
    </div>
</div>
<!-- Legal mentions -->
<div style="position:relative;">
    <div style="color:#ddd;background-color:#000000;text-align:center;padding:30px 80px;text-align:
        justify;">
        <p>Legal mentions</p>
    </div>
</div>
<!-- SCRIPTS -->
<script>
/*----- Power -----*/
var actual_temperature = 0;
var v_old;
var v_new;
var values;
var a = setInterval("show_actual_values()",1000);
function show_actual_values() {
    /*-- AJAX --*/
    var xhttp = new XMLHttpRequest();
    xhttp.onreadystatechange = function() {
    if (this.readyState == 4 && this.status == 200) {
        var values = this.responseText;
        var values = values.split(",");
        v_new = values[0];
        actual_temperature = values[1];
    }
    }
    xhttp.open("GET", "actual_values.txt", true);
    xhttp.send();
    /*-- Temperature --*/
    document.getElementById("actual_temperature").innerHTML = actual_temperature + " °C";
    document.getElementById("actual_temperature").style.color = "white";
    if (actual_temperature < 10) document.getElementById("actual_temperature").style.color = "#62A0FF";
}

```

```

if (actual_temperature > 29) document.getElementById("actual_temperature").style.color = "#FF7C7C";
/*-- Power --*/
/*v_new = ~~ v_new;*/
document.getElementById("actual_power").innerHTML = v_new + " W";
if (v_new > v_old){
    document.getElementById("arrow").className = "fa fa-chevron-circle-up";
} else {
    if (v_new < v_old){
        document.getElementById("arrow").className = "fa fa-chevron-circle-down";
    } else {
        document.getElementById("arrow").className = "fa fa-spinner fa-spin";
    }
}
v_old = v_new;
}
/*----- Data -----*/
var chart;
function graph() {
    /*----- graph -----*/
    var ctx = document.getElementById('myChart').getContext('2d');
    chart = new Chart(ctx, {

        // The type of chart we want to create
        type: 'line',
        // The data for our dataset
        data: {
            labels: data_date, /* data_date OR time_values */
            datasets: [{
                label: 'Power produced (W)',
                backgroundColor: 'rgba(237, 192, 14, 0.3)',
                borderColor: 'rgb(237, 192, 14)',
                data: data_power /* data_power OR power */
            }]
        },
        // Configuration options go here
        options: {
            legend: {
                display: false,
            },
            responsive: true, // false
            maintainAspectRatio: false,
            title: {
                display: false,
                fontColor: '#FFFFFF',
                fontSize: 40,
                text: 'Power production (W) vs. time of the day.'
            },
            tooltips: {
                mode: 'index',
                intersect: false,
            },
            hover: {

```

```

    mode: 'nearest',
    intersect: true
  },
  scales: {
    xAxes: [{
      type: 'time',
      time: {
        unit: 'hour'
      },
      displayFormats: {
        hour: 'HH:mm'
      },
      display: true,
      gridLines: { color: "#FFFFFF" },
      scaleLabel: {
        display: true,
        fontColor: '#FFFFFF',
        fontSize: 20,
        labelString: 'Time'
      },
      ticks: {
        fontColor: '#FFFFFF',
        fontSize: 15,
      }
    }],
    yAxes: [{
      display: true,
      gridLines: { color: "#FFFFFF" },
      scaleLabel: {
        display: true,
        fontColor: '#FFFFFF',
        fontSize: 20,
        labelString: 'Power (W)'
      },
      ticks: {
        fontColor: '#FFFFFF',
        fontSize: 15,
      }
    }],
  },
  layout: {
    padding: {
      left: 0,
      right: 0,
      top: 100,
      bottom: 0,
    }
  }
});
}
/*-- set the value of the calendar to be today --*/

```

```

function today() {
    var date = new Date();
    var year = date.getFullYear();
    var month = date.getMonth() + 1;
    if (month < 10) month = "0" + month;
    var day = date.getDate();
    if (day < 10) day = "0" + day;
    var today = year + "-" + month + "-" + day;
    document.getElementById('calendar').value = today;
}
var data_csv = "";
var data_power = [];
var data_date = [];
function data(str, p){
    data_power = [];
    data_date = [];
    if (typeof(chart) != "undefined") {
        chart.destroy();
    }
    var xmlhttp = new XMLHttpRequest();
    xmlhttp.onreadystatechange = function() {
    if (this.readyState == 4 && this.status == 200) {
        if (this.responseText == "No data for this day.") {
            if (p == 1) window.alert("No data for the day "+calendar.value);
            var x = document.getElementById("button_dl");
            x.style.display = "none";
        } else {
            var x = document.getElementById("button_dl");
            x.style.display = "block";
            document.getElementById("dl_a").href = "measures/"+calendar.value+".csv";
            document.getElementById("dl_a").download = calendar.value+".csv";
            /*-- data are existing --*/
            var xhttp = new XMLHttpRequest();
            xhttp.onreadystatechange = function() {
            if (this.readyState == 4 && this.status == 200) {
                var data_csv = this.responseText;
                var data_csv = data_csv.split("\n");
                var data_csv_length = data_csv.length;
                var i = 0;
                var csv_array;
                var csv_day;
                var csv_time;
                if (typeof(data_csv[data_csv_length-1]) != "undefined") data_csv.splice(data_csv_length-1, 1);
                data_csv_length = data_csv.length;
                while (i < data_csv_length) {
                    /*-- values of power --*/
                    var data_i = data_csv[i];
                    csv_array = data_i.split(",");
                    data_power = data_power.concat(Number(csv_array[4]));
                    /*-- values of day --*/
                    csv_day = csv_array[0];
                    csv_day = csv_day.split("-");
                }
            }
            }
        }
    }
}

```



```

var year = csv_day[0];
var month = csv_day[1];
var day = csv_day[2];
/*-- values of time --*/
csv_time = csv_array[1];
csv_time = csv_time.split(":");
var hour = csv_time[0];
var min = csv_time[1];
/*-- --*/
data_date = data_date.concat(new Date(year,month,day,hour,min));
i++;
}
graph();
}
}
xhttp.open("GET", "measures/"+calendar.value+".csv", true);
xhttp.send();
}
}
}
xmlhttp.open("GET", "data.php?d=" + str, true);
xmlhttp.send();
}
/*----- Converter-----*/
document.getElementById("tooltiptext_cell").innerHTML = "The cell used on the system has dimensions
of 15x15 cm and generates the nominal power of 1,5W";
var count0 = 0;
var count1 = 0;
var count2 = 0;
function convert() {
/*---- energy ----*/
var power = document.getElementById('in_power').value;
var time = document.getElementById('in_time').value;
var energy = time * power;
var energy = ~~ energy;
/*---- money saved ----*/
if (count0 == 0) { //France
var avg = 0.0001799;
var money = power * time * avg;
money = money.toFixed(2);
document.getElementById("counter_money").innerHTML = money + "€ saved in France";
}
if (count0 == 1) { //Poland
var avg = 0.0006;
var money = power * time * avg;
money = money.toFixed(2);
document.getElementById("counter_money").innerHTML = money + "zł saved in Poland";
}
if (count0 == 2) { //Spain
var avg = 0.0002477;
var money = power * time * avg;
money = money.toFixed(2);
}
}

```

```

document.getElementById("counter_money").innerHTML = money + "€ saved in Spain";
}
/*---- conversion home appliances ----*/
if (count1 == 0) {
var power_ha = 400;
var t_ha = energy / power_ha;
var t_ha = min_hour(t_ha);
document.getElementById("counter_home_appliances").innerHTML = t_ha + " of use of a fridge /
freezer";
}
if (count1 == 1) {
var power_ha = 150;
var t_ha = energy / power_ha;
var t_ha = min_hour(t_ha);
document.getElementById("counter_home_appliances").innerHTML = t_ha + " of use of a 25" TV";
}
if (count1 == 2) {
var power_ha = 1400;
var t_ha = energy / power_ha;
var t_ha = min_hour(t_ha);
document.getElementById("counter_home_appliances").innerHTML = t_ha + " of use of a dishwasher";
}
if (count1 == 3) {
var power_ha = 400;
var t_ha = energy / power_ha;
var t_ha = min_hour(t_ha);
document.getElementById("counter_home_appliances").innerHTML = t_ha + " of use of a desktop
computer";
}
if (count1 == 4) {
var power_ha = 110;
var t_ha = energy / power_ha;
var t_ha = min_hour(t_ha);
document.getElementById("counter_home_appliances").innerHTML = t_ha + " of use of a laptop";
}
if (count1 == 5) {
var power_ha = 8;
var t_ha = energy / power_ha;
var t_ha = min_hour(t_ha);
document.getElementById("counter_home_appliances").innerHTML = t_ha + " of use of a phone
charger";
}
/*---- conversion particles ----*/
if (count2 == 0) {
var coef = 0.353;
var prevented = power * coef * time;
var prevented = ~~ prevented;
document.getElementById("counter_particles").innerHTML = prevented + "kg of CO<sub>2</sub>";
document.getElementById("tooltiptext_particles").innerHTML = "Carbon dioxide is one of the most well
known greenhouse gases. Since the age of industrialization, its concentration in Earth's
atmosphere raised by approximately 43%. Fossil fuels, deforestation and animal husbandry are
main causes for increased production of CO<sub>2</sub>.";
}

```

```

}
if (count2 == 1) {
var coef = 0.000245;
var prevented = power * coef * time;
var prevented = prevented.toFixed(2);
document.getElementById("counter_particles").innerHTML = prevented + "kg of SO<sub>2</sub>";
document.getElementById("tooltiptext_particles").innerHTML = "Sulfur dioxide is a toxic gas that affects
human, animal and plant health. It occurs naturally during volcanic eruptions, but is also
produced during combustion of fossil fuels contaminated with sulfur compounds. Since 1970s,
there has been a steady reduction in its emissions, but many developing countries struggle with
lowering their emissions. Since it travels through the atmosphere with prevailing winds, sulfur
dioxide emissions are not a local problem.";
}
if (count2 == 2) {
var coef = 0.00065;
var prevented = power * coef * time;
var prevented = prevented.toFixed(2);
document.getElementById("counter_particles").innerHTML = prevented + "kg of nitrogen compounds";
document.getElementById("tooltiptext_particles").innerHTML = "Family of nitric oxides has a wide range
of effects. First, they are enablers for reactions that produce acid rains. Secondly, they react
with ozone and thus deplete the ozone layer. Thirdly, long-term exposure to nitrogen dioxide
damages human immune system and impairs respiratory functions. Short term exposure
causes headaches and nausea.";
}
if (count2 == 3) {
var coef = 0.00082;
var prevented = power * coef * time;
var prevented = prevented.toFixed(2);
document.getElementById("counter_particles").innerHTML = prevented + "kg of CO";
document.getElementById("tooltiptext_particles").innerHTML = "Carbon monoxide is a gas slightly less
dense than air that's flammable. It combines with hemoglobin to produce carboxyhemoglobin,
which impedes oxygen distribution in animals. Simply put it's highly toxic and is the most
common type of fatal air poisoning in many countries. Exposure to carbon monoxide might
cause significant damage to heart and nervous system. Moreover, it can affect the fetus of
pregnant women exposed to it.";
}
if (count2 == 4) {
var coef = 0.00044;
var prevented = power * coef * time;
var prevented = prevented.toFixed(2);
document.getElementById("counter_particles").innerHTML = prevented + "kg of particulates";
document.getElementById("tooltiptext_particles").innerHTML = "During the burning of fossil fuels,
microscopic solid and liquid matter is produced. That matter affects both human health and
climate. Health effects include birth defects, higher risk of lung cancer and chronic respiratory
illness. Climate effects include smog, changes to local precipitation (e.g. increased rainfall) and
changes to incoming solar radiation.";
}
}
function min_hour(t) {
var h = 0;
if (t < 1) {
var t = t*60;
}
}

```

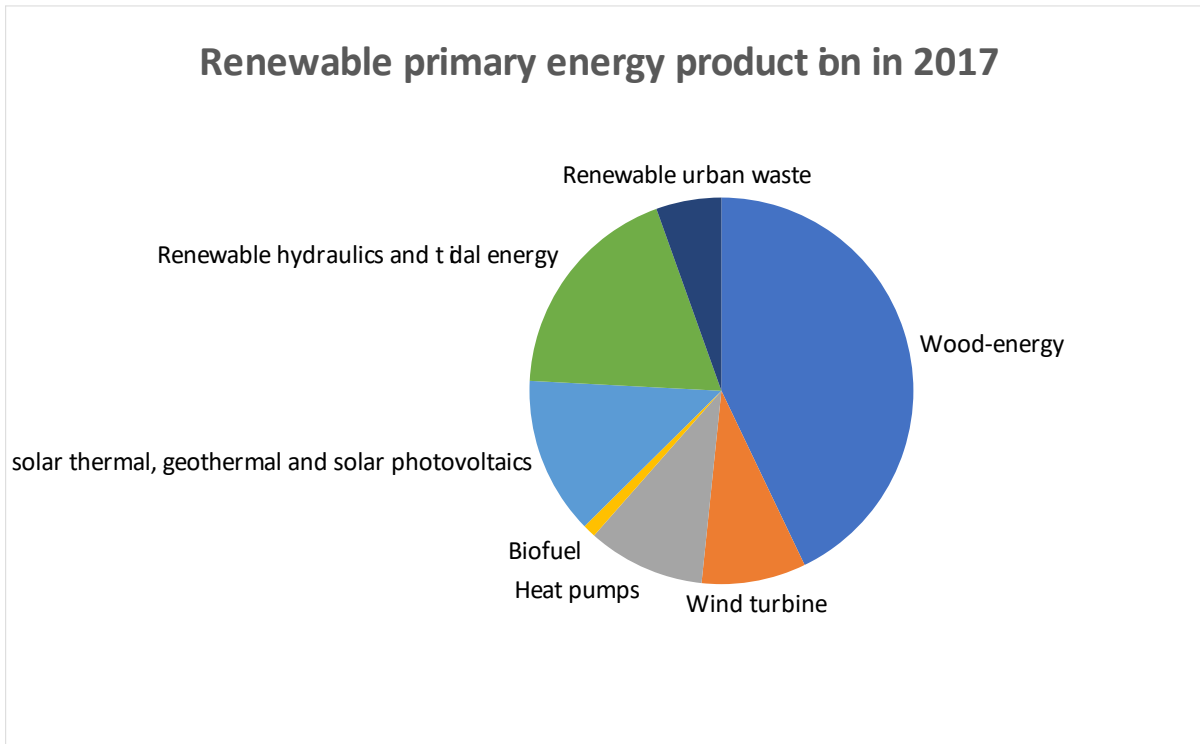
```

    var t = ~~ t;
    str_hour = t + " min";
} else {
    while (t > 1) {
        t = t - 1;
        h++;
    }
    t = t*60;
    t = ~~ t;
    if (t == 60) t= 59;
    str_hour = h + " h " + t + " min"
}
return str_hour;
}
/*---- buttons conversion modes ----*/
function increase_count0() {
    count0 = count0 +1;
    if (count0 > 2) count0 = 0;
    convert()
}
function decrease_count0() {
    count0 = count0 -1;
    if (count0 < 0) count0 = 2;
    convert()
}
function increase_count1() {
    count1 = count1 +1;
    if (count1 > 5) count1 = 0;
    convert()
}
function decrease_count1() {
    count1 = count1 -1;
    if (count1 < 0) count1 = 5;
    convert()
}
function increase_count2() {
    count2 = count2 +1;
    if (count2 > 4) count2 = 0;
    convert()
}
function decrease_count2() {
    count2 = count2 -1;
    if (count2 < 0) count2 = 4;
    convert()
}
}
/*----- Feedbacks -----*/
var str;
function write_feedback() {
    var str = document.getElementById('input_feedback').value;
    var xmlhttp = new XMLHttpRequest();
    xmlhttp.onreadystatechange = function() {
        if (this.readyState == 4 && this.status == 200) {

```

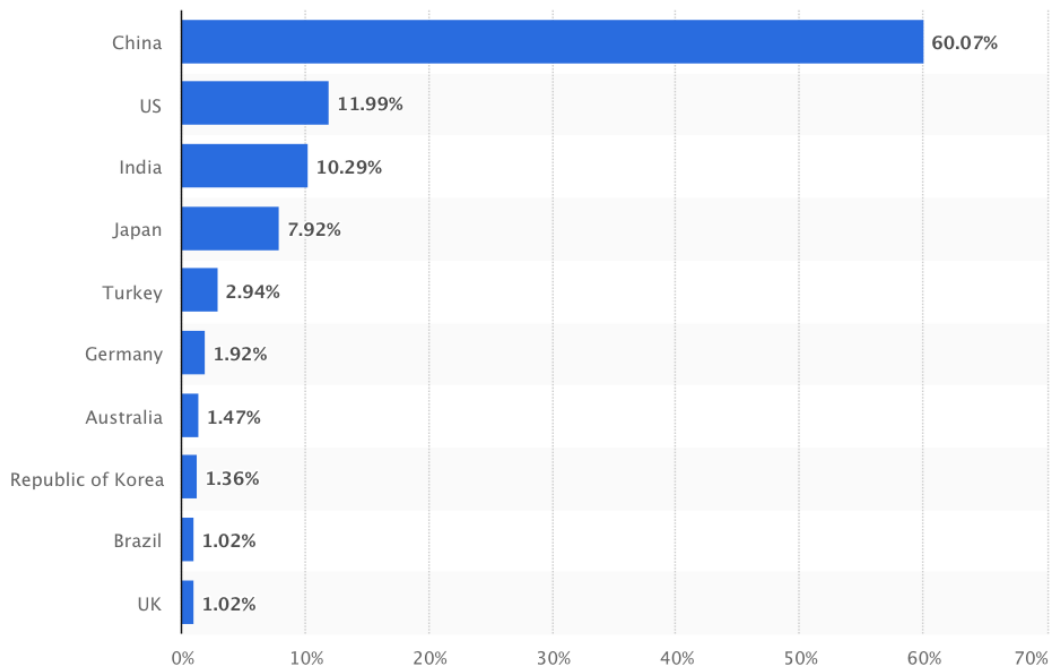
```
    str = document.getElementById('input_feedback').value;
    document.getElementById('input_feedback').value = "";
  }
};
xmlhttp.open("GET", "feedback.php?t=" + str, true);
xmlhttp.send();
}
/*----- Social Networks -----*/
document.getElementById("twitter_link").href = "http://twitter.com/intent/tweet?status=Find out how
much solar energy you can produce on: https://solearn2019.000webhostapp.com/";
</script>
</body>
</html>
```

APPENDIX H. Worldwide renewable energy production in 2017

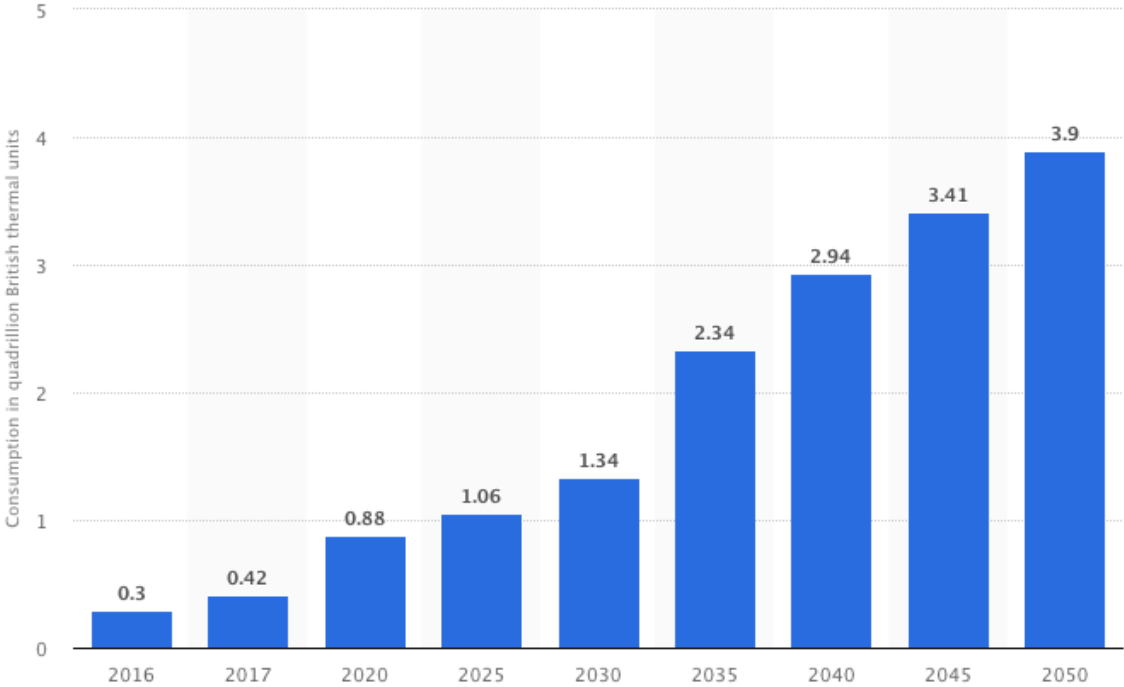


Source: INSEE

APPENDIX I. Percentage of newly installed capacity in different countries.



APPENDIX J. Projection of the electric power sector's solar photovoltaic consumption in the U.S. from 2016 to 2050 (in quadrillion British thermal units)*



APPENDIX K. Report prepared after the photovoltaic laboratory exercise

Investigation of the PV module tilt angle on the final relative conversion efficiency

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Maxence Gaude
Jorge Navarro Deltell
Szymon Kuźmiński
Damian Olczak



1. Exercise description

The main description of PV cell parameters is normally presented by the current versus voltage graph called I-V characteristic of the cell. On the same graph we can also plot the power of the cell, obtained from the multiplication of current and voltage values, which can be later used to calculate maximum power point (MPP) of the given cell.

Apart from the cell specification, to obtain best possible performance of the PV installation, the proper lightning conditions are also required. One of those conditions is to position the surface area of PV cell perpendicularly towards the rays of sunlight. However such positioning is not always possible due to various reasons. The questions rises by itself – how does the change in the positioning of PV cell or change of position of the sunlight, depending on the season of the year or the hour, would affect the performance of PV system.

During the experiment we investigated the phenomenon of energy loss caused by the non-optimal tilt angle of the photovoltaic installation. To check the energy losses we used, previously stated, I-V cell characteristic and power formula and its graph.

The experimental setup consist of the lamp of constant light intensity which was subjected to round frame with ability to slide on it. The lamp was directed to the centre of the frame and in this centre the PV cells were placed together with control panel and electric meters.

Firstly we conducted the measurement of the characteristic for angle of 90° (Zenith) meaning that lamp was directed in perfect perpendicular position to the surface of cell. By manipulation of the knobs we were changing the resistance of the PV cell circuit and could collect data from the electric meters (at least 10 results). The characteristic was needed in full scale so the resistance was changed from $R=0$ to $R=\infty$. After all measurements for particular angle we was switching the position of light on the frame by 15° and repeating the procedure. Frame span allowed us to collect such data for 6 different angles.

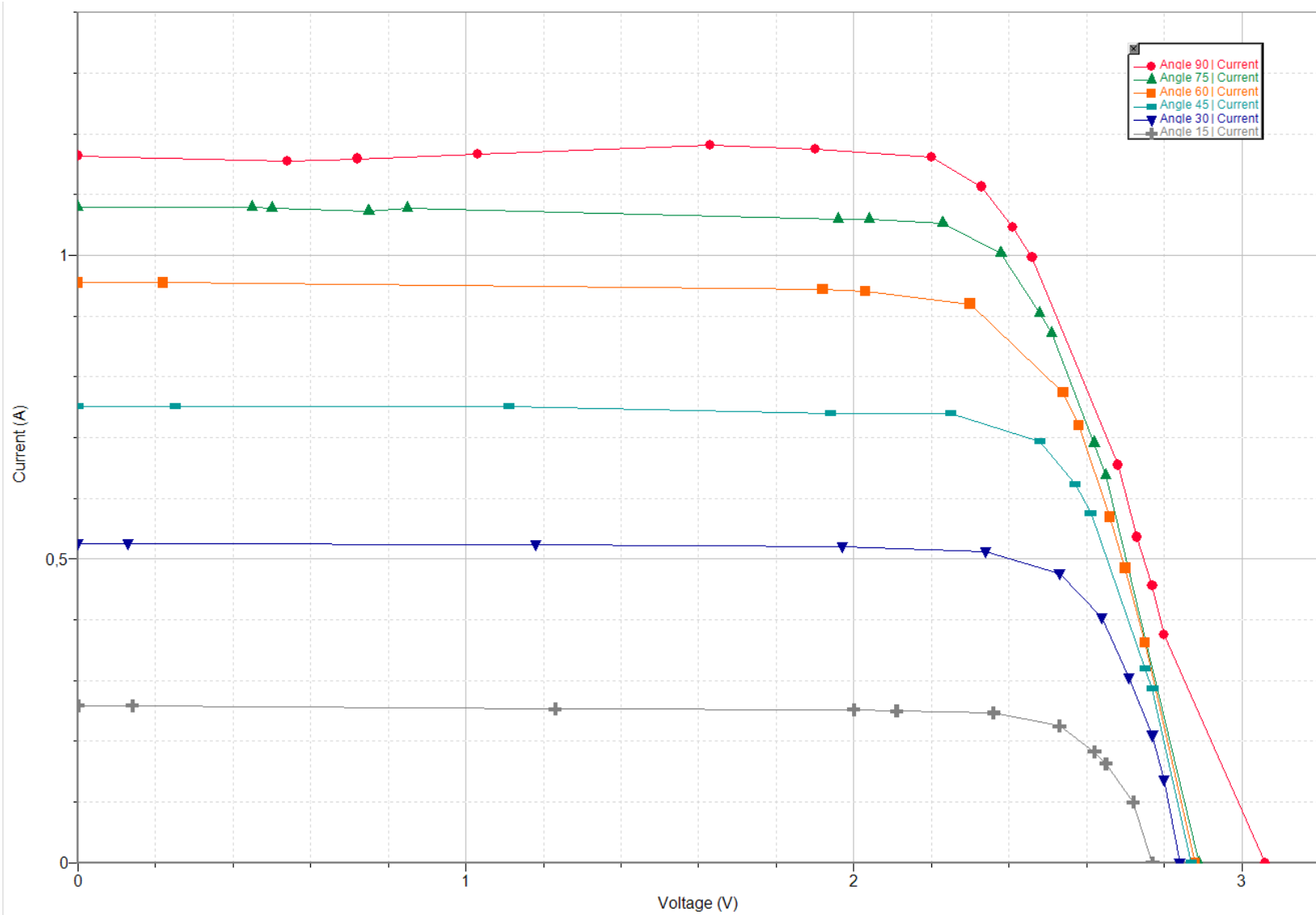
Data was processed only by calculation of the power to each of the measurements and by preparation of sufficient graphs to represent the characteristics and maximum power point change in different tilt angles.

2. Experimental results

	Angle 90			Angle 75			Angle 60				
	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)		
1	0	1,164	0,000	0	1,079	0,000	0	0,955	0,000		
2	0,54	1,155	0,624	0,45	1,079	0,486	0,22	0,955	0,210		
3	0,72	1,159	0,834	0,5	1,077	0,538	1,92	0,944	1,812		
4	1,03	1,166	1,201	0,75	1,073	0,805	2,03	0,941	1,910		
5	1,63	1,181	1,925	0,85	1,078	0,916	2,3	0,92	2,116		
6	1,9	1,175	2,232	1,96	1,06	2,078	2,54	0,774	1,966		
7	2,2	1,162	2,556	2,04	1,06	2,162	2,58	0,72	1,858		
8	2,33	1,113	2,593	2,23	1,053	2,348	2,66	0,569	1,514		
9	2,41	1,046	2,521	2,38	1,004	2,390	2,7	0,485	1,310		
10	2,46	0,997	2,453	2,48	0,904	2,242	2,75	0,362	0,995		
11	2,68	0,655	1,755	2,51	0,872	2,189	2,88	0	0,000		
12	2,73	0,536	1,463	2,62	0,691	1,810					
13	2,77	0,456	1,263	2,65	0,638	1,691					
14	2,8	0,375	1,050	2,89	0	0,000					
15	3,06	0	0,000								
16											
	Angle 45			Angle 30			Angle 15			Angle vs Max Power	
	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)	Angle (°)	MPP (W)
1	0	0,752	0,000	0	0,526	0,000	0	0,259	0,000	90	2,59329
2	0,25	0,752	0,188	0,13	0,526	0,068	0,14	0,259	0,036	75	2,38952
3	1,11	0,752	0,835	1,18	0,524	0,618	1,23	0,253	0,311	60	2,116
4	1,94	0,74	1,436	1,97	0,52	1,024	2	0,252	0,504	45	1,72112
5	2,25	0,74	1,665	2,34	0,512	1,198	2,11	0,25	0,527	30	1,20428
6	2,48	0,694	1,721	2,53	0,476	1,204	2,36	0,247	0,583	15	0,58292
7	2,57	0,624	1,604	2,64	0,404	1,067	2,53	0,225	0,569		
8	2,61	0,576	1,503	2,71	0,305	0,827	2,62	0,183	0,479		
9	2,75	0,32	0,880	2,77	0,21	0,582	2,65	0,163	0,432		
10	2,77	0,287	0,795	2,8	0,137	0,384	2,72	0,1	0,272		
11	2,87	0	0,000	2,84	0	0,000	2,77	0	0,000		
12											

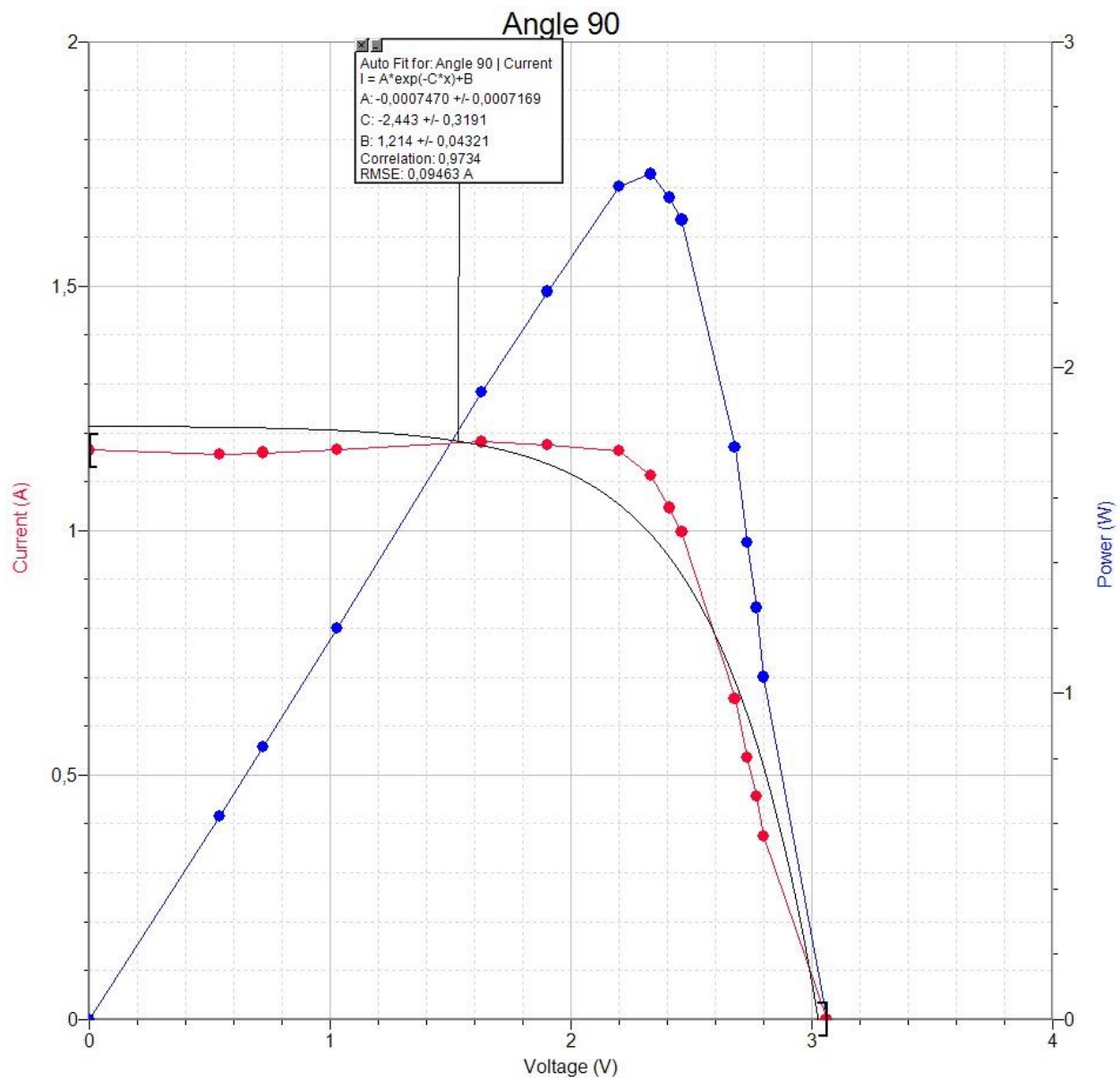
Data obtained from measurements and calculations.





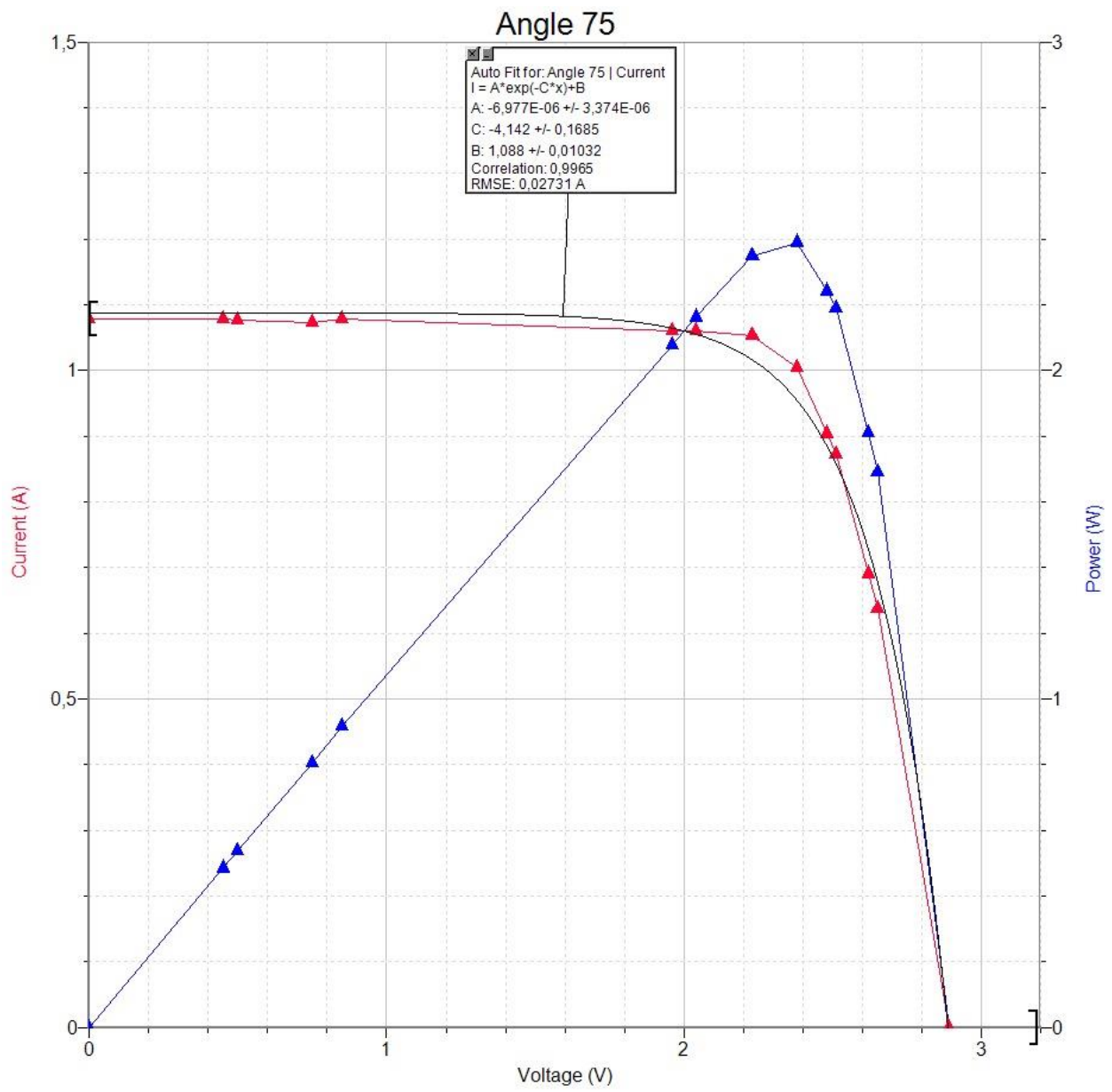
All I-V characteristics for different angles.





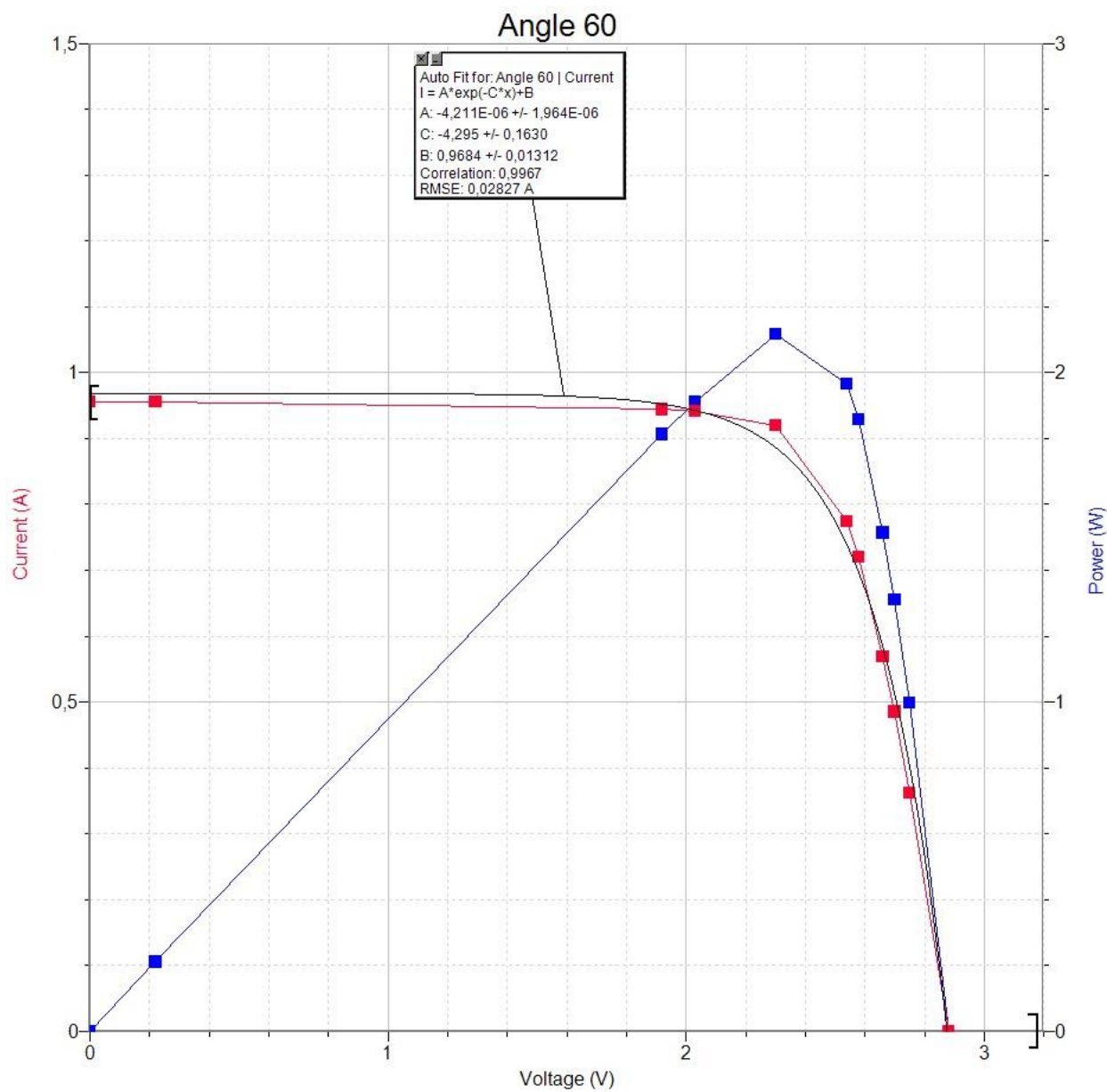
I-V characteristic and power graph for position of 90° (Zenith).





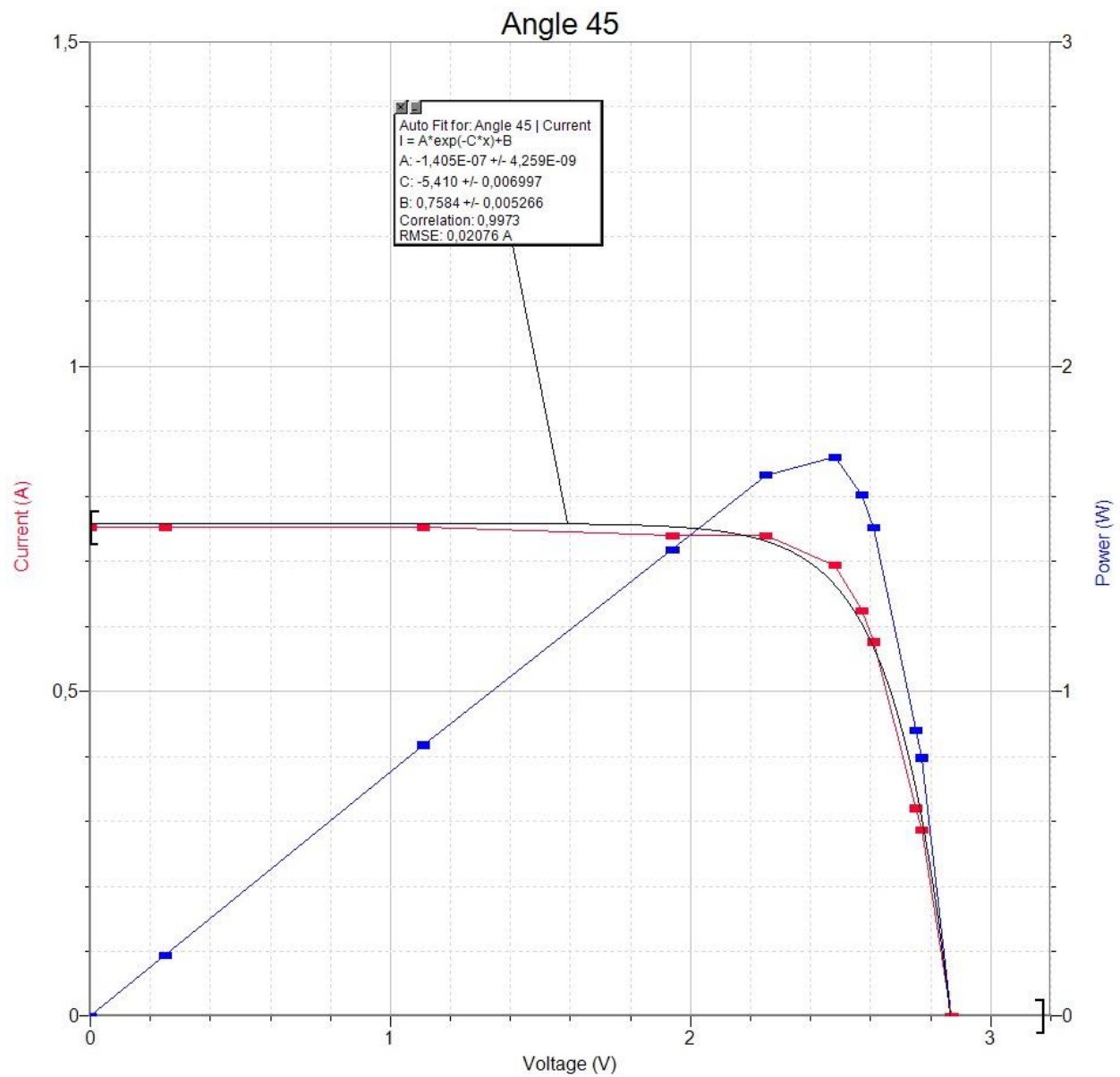
I-V characteristic and power graph for position of 75°.





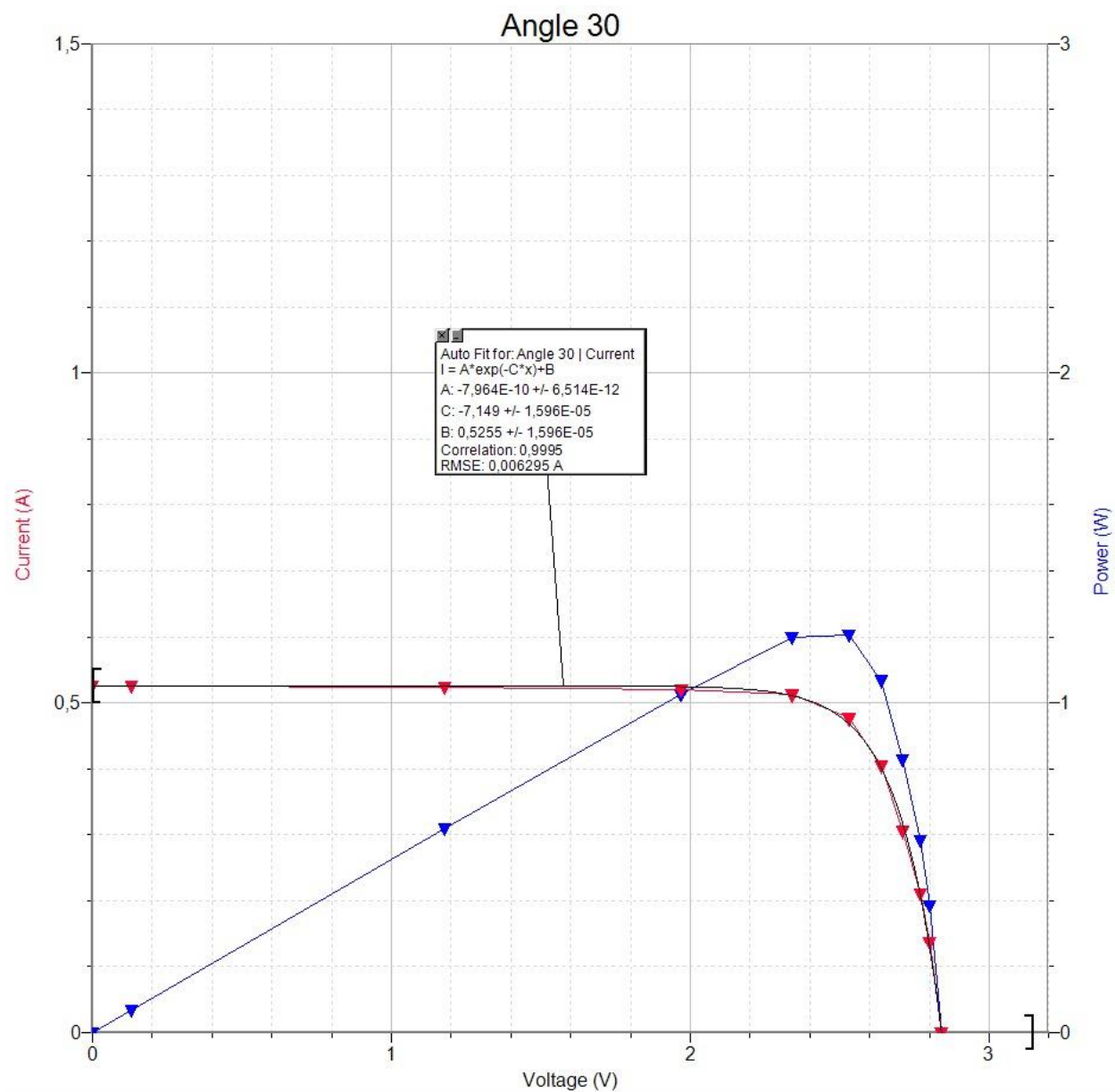
I-V characteristic and power graph for position of 60°





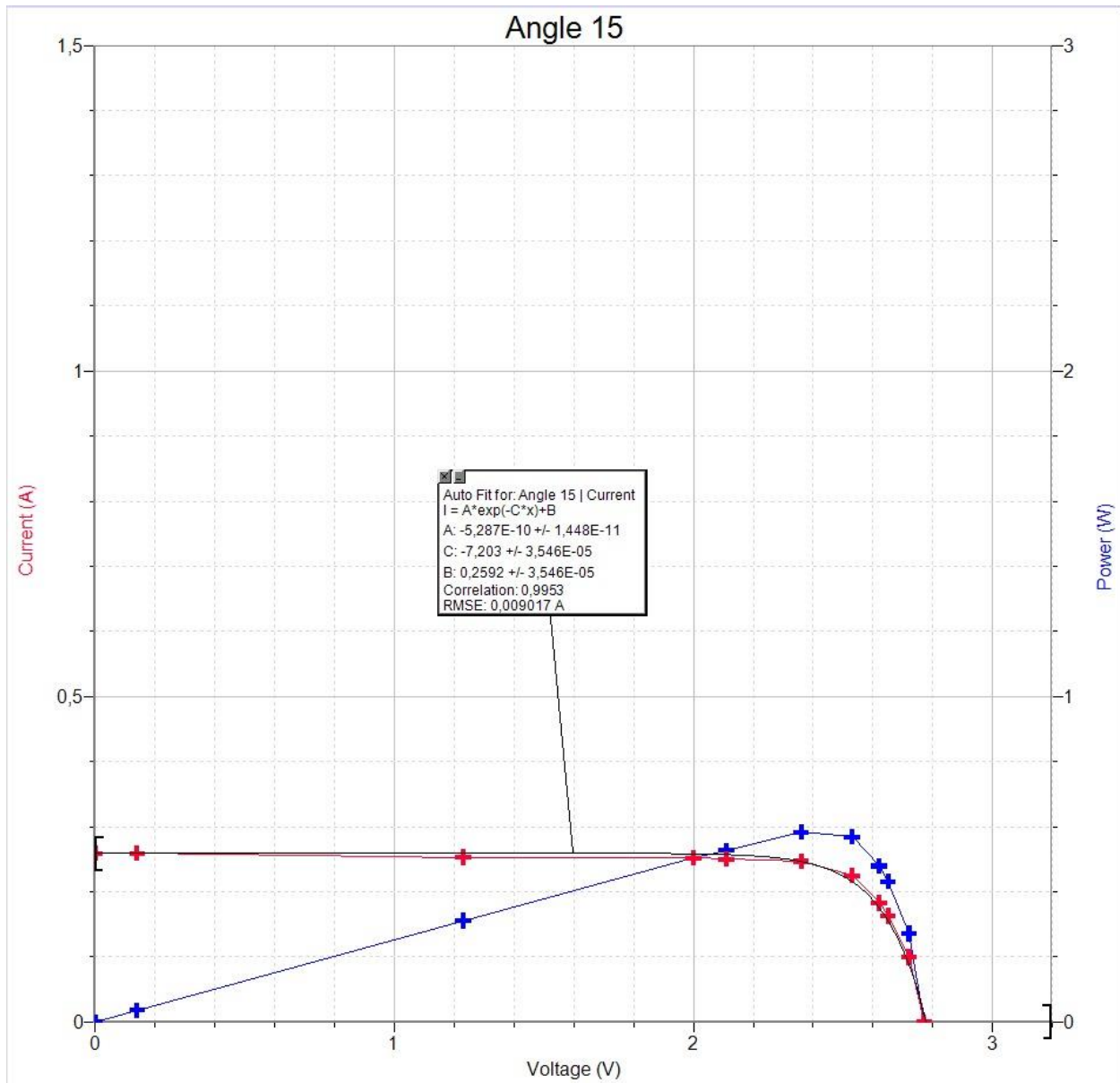
I-V characteristic and power graph for position of 45 °.





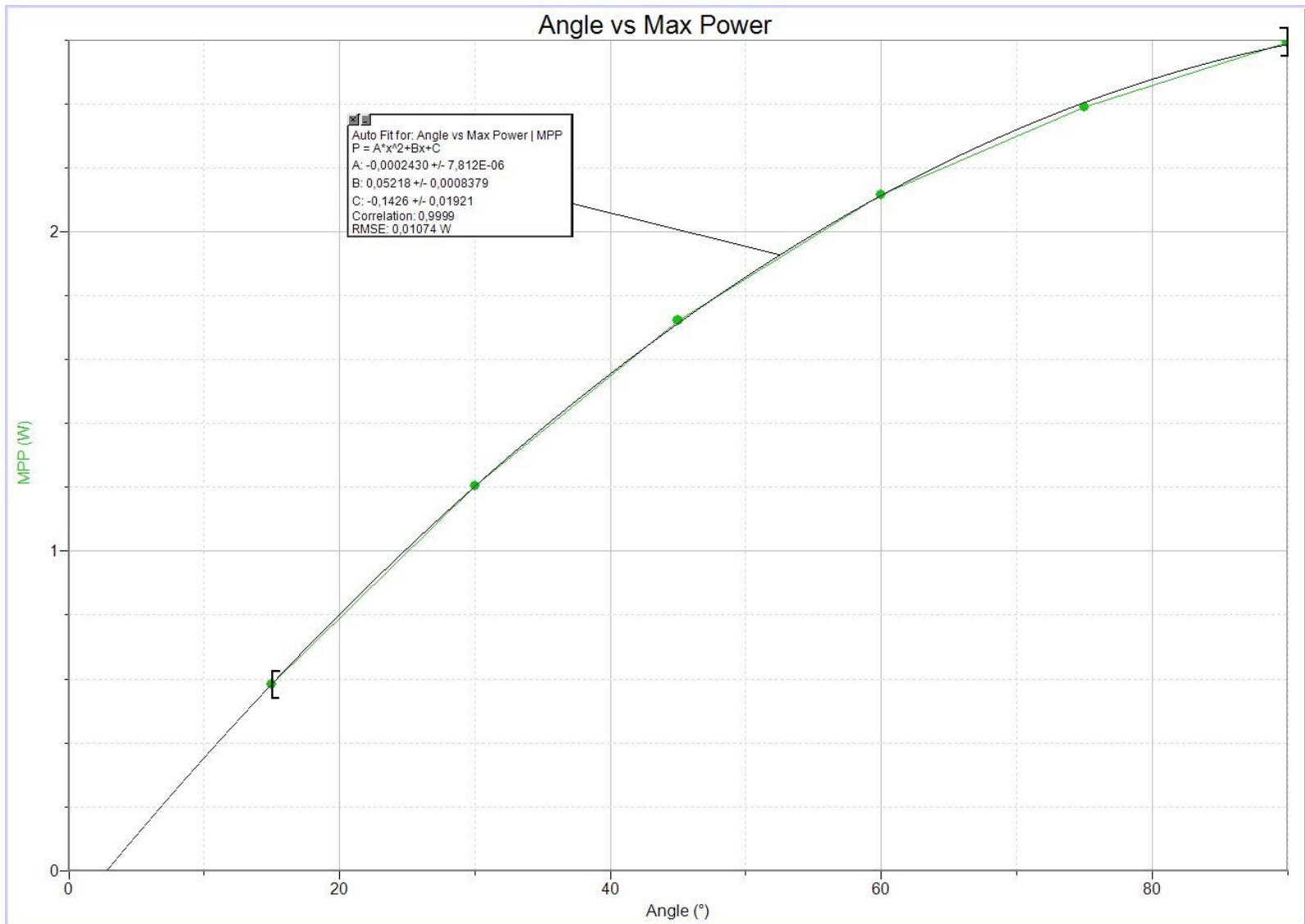
I-V characteristic and power graph for position of 30 °.





I-V characteristic and power graph for position of 15 °.





Dependence between the angle of position and maximum power point



3. Conclusions

The PV cells have the highest power output at the 90 degrees angle. Lower angles produce the following approximate percentages of power output in comparison, assuming best possible conditions as emulated in the lab:

- 75 degrees angle – 91%
- 60 degrees angle – 81%
- 45 degrees angle – 66%
- 30 degrees angle – 46%
- 15 degrees angle – 22%

As such, we conclude that dropping below 60 degrees angle should be avoided, as there's a noticeable drop in power output below that angle. Tracking systems should take this data into consideration, so they can be set up in a way that their power output is maximized while their power usage for tracking the sun is minimalized. This of course depends on the geographical position of the PV cell and the current season in its location.



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