UPPSALA
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Självständigt arbete i informationsteknologi
June 7, 2019

Interactive Visualization of Solar Energy Data

Isak Borg
August Dixelius
David Östlund

Civilingenjörsprogrammet i informationsteknologi

Master Programme in Computer and Information Engineering

UPPSALA
UNIVERSITET

Institutionen för informationsteknologi

Besöksadress:
ITC, Polacksbacken
Lägerhyddsvägen 2

Postadress:
Box 337
751 05 Uppsala

Hemsida:
http:/www.it.uu.se

Abstract

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Sweden has one of the lowest solar energy productions in Europe even though the weather conditions are comparable to Europe's largest solar energy producer. Although the majority of the Swedish population is in favour of spending more money on services that can limit climate change, the growth of installed solar cells is slower than that of other countries with similar climate in Europe.

To inspire people to install solar panels we created an interactive map with information regarding the solar parks in Uppland, a county in Sweden. Our goal was that this system would help spread awareness of the fact that solar parks work efficiently in Sweden. The program was then installed on a tablet which was put in a public space together with an LED installation to reach as broad of an audience as possible. To draw the passerby's attention, the LED installation was connected to the map which shows the energy production of the selected solar park in a colour scale.

Extern handledare: Fredrik Björklund, Stuns Energi AB
Handledare: Mats Daniels, Virginia Grande Castro och Björn Victor
Examinator: Björn Victor

Sammanfattning

Sverige har en av de lägsta produktionen av solenergi i Europa trots att deras väderförhållanden är jämförbara med Europas största producenter av solenergi. Även fast majoriteten av Sveriges befolkning är villiga att spendera mer pengar på tjänster som kan begränsa klimatförändringar är tillväxten av nya solpaneler långsammare än i andra Europeiska länder med liknande klimat.

För att inspirera personer att installara solpaneler har vi skapat en interaktiv karta med information gällande solparker i Uppland. Vårt mål är att programmet skulle öka medvetenheten om solparkers effektivitet i Sverige. Programmet blev sedan installerat på en surfplatta som monterades på en offentlig plats tillsammans med en LED-installation för att nå en så omfattande publik som möjligt. För att dra till sig förbipasserandes uppmärksamhet så kopplades LED-installationen till kartan som visar energiproduktionen hos den valda solparken i en färgskala.

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1 Introduction

A study done in 2018 by the Swedish Environmental Protection Agency showed that 70% of the Swedish people are in favour of spending more money on a service or product that helps combat climate change [39]. Despite this, in the year 2016 Sweden had only 67 MW of solar power privately installed compared to the European top producer [21], Germany, which had 40 GW [2] although both countries have roughly the same annual amount of sun hours [4]. The goal with our project is to encourage people to install solar cells by spreading awareness of the effectiveness of solar panels, especially in Sweden and other places with similar climates. Our system will visualize the information flow from the solar panels that Region Uppsala (a politically controlled organization) have installed throughout the Swedish county Uppland. The energy produced by the solar panels will be visualized by an LED installation based on a colour scale, where a redder and warmer colour indicates a higher production value whereas a bluer and colder colour indicates a lower value. The energy currently produced and the day with the highest energy production are among the data that we will visualize. For this purpose we have gained access to one of the public spaces belonging to Region Uppsala where we can mount our system.

When raising awareness of something, in this case solar cells, it is crucial to understand both its positive and negative sides. From an environmental perspective, a negative side is represented by the cells lifetime carbon emission, though difficult to measure, it mainly stems from the mining of raw material [6]. A positive side however is that the carbon emission from the two most common solar cells have become 55% and 69% lower the past decade [23]. These two types make up over 90% of all installed solar cells in the world [30]. Another positive aspect of solar panels is their availability to the public compared to other sources of renewable energy. Solar panels, if installed thoughtfully, can be integrated in existing constructions and buildings. This makes it a prime investment target both for people who want to make an environmental change, but also those interested in reducing their energy bills.

Today there are several different sources of renewable energy but they all come with different restrictions making many ill-suited for use in cities. Energy from wind turbines is very cost-effective, but they cause a lot of noise pollution and good sites for wind turbines are usually found in remote and rural places [12]. Hydroelectric power is limited to rivers and dams, but not every river and dam is suitable for hydroelectric power plants either. Solar power can be mounted on walls and rooftops of buildings, but can have a detrimental effect on the visual aesthetic of the building. The benefit is that they are not obstructing in any other way and the only practical limitation, is the facing of the solar panels. This makes solar power a good option for investing in green energy in urban areas. Sweden is also better suited for solar cells than many believe. A solar park in Piteå, a city in the north of Sweden, had a comparable energy production to solar parks in the south of Europe [4].

At the start of the project we had to make sure it was designed towards the correct target group. Our system is designed for the general public so our goal was not to exclude any demographic. This means that our target audience were people from the ages of five years and older, where we assume that children younger than five years old are illiterate. However, the visually impaired will not be able to interactive with our system in its current state. The system is also meant to be understood by people with and without previous technical knowledge of the data displayed. To make sure our system would be accessible for this audience we made something that is easy to interact with, but also fun and engaging enough for them to remember afterwards.

With this information we decided to create a program with an interactive map of the Swedish county Uppland and a visualization in the form of an LED-strip connected with the map. When the user clicks on different solar parks on the map, the LED-strip will change colour depending on how much energy is produced at the time by that solar park. In addition, statistics and specific information related to each park is shown as well.

2 Background

In this section we provide a background to the subject of our project and the problem that we are addressing.

2.1 Data Visualization

Data visualization in the digital age has skyrocketed, but making sense of data has a long history and has frequently been discussed by scientists and statisticians.

2.1.1 History of Data Visualization

In Michael Friendly's paper from 2009 [14], he gives a thorough description of the history of data visualization. The earliest accounts of visualization were geometric maps which depicted stars and other celestial bodies in order to aid navigation, and the oldest map of this kind was made in 6200 BC. In the early 19th century many of the modern ways of statistical graphing were invented such as the bar and pie graph, histograms and

Figure 1 Visualization of future water levels with LED lights
Figure retrieved from http://www.niittyvirta.com/lines-57-59-n-7-16w/

contour plots [31]. The more modern sense of data visualization which uses computers when making the calculations and the designing graphs gained traction in the 1950s.

2.1.2 Data Visualization in the 21st Century

Many of the older ways of depicting data, by using different kinds of graphs and tables, are still prevalent in the 21st century. But the main difference today is the huge amounts of data available which is usually digitally stored. In datasets with several billion of bytes it can be difficult to grasp the magnitude of the data by just looking at a graph. Therefore there has been numerous attempts of visualizing the data in alternative ways for example as in Figure 1 using LED-lights to visualize future water levels. Another example is in Figure 2 with a map of the world where the light intensity indicates the popularity of Facebook usage [3, 27].

Figure 2 Visualization of worldwide Facebook usage, where light intensity indicates Facebook usage
Figure retrieved from https://www.cappellmeister.com/2011/11/09/social-web-the-next-steps/facebook-verbindungen/

2.2 Stakeholders

Region Uppsala is a politically controlled organization responsible for healthcare, public transportation, culture and regional development in Uppsala county. They are one of Upplands largest energy consumers, and we worked with them through STUNS Energi. STUNS Energi is an independent contractor with a focus on connecting companies, including Region Uppsala, to the local university. Through this connection they work on providing new ways to meet the supply and demand regarding renewable energy and environmental solutions [38].

2.3 Energy in Uppsala

In 2014 the county council of Uppsala made the following goals, among others, for 2018: Region Uppsala's energy consumption in buildings (heat, cooling, steam and energy) have to be reduced by at least ten percent per square meter compared to 2014, and two percent of the consumed energy has to be self produced renewable energy [25]. This led to the start of a large scale energy investment including the installation of solar cells on most of their buildings. Region Uppsala used this opportunity not only to lower their energy costs but also to experiment with different kinds of solar panels and installing them in different angles and locations. Their project has in total lowered their energy costs with about 25%. After looking at the data from their solar cells they could conclude that their solar cells worked efficiently in Sweden. Many people might be surprised by this, claiming that there are not enough sunshine duration for the panels to work effectively enough [26]. However it has been shown that solar panels work much more efficiently in temperatures closer to 0°C compared to warmer temperatures [19, 28].

2.4 Project Formulation

Because the solar panels are more often than not installed on roofs they are not visible from the streets. Region Uppsala therefore wants a way to spread awareness of their existence and, after monitoring how well they work, display how efficiently they produce energy. We have done this in two parts where both systems use information gathered from the solar panels. We created an interactive map that visualizes the information from the solar panels in a more comprehensible way. For example showing how far an electric bus can drive on the produced energy. This map will be installed in a public space together with the second part of our project, an LED-strip that changes colour depending on the energy production of the solar parks. We did this to bring attention to that solar cells can be efficient in the Swedish climate.

3 Purpose, Aims and Motivation

Purpose. The purpose of this project is to raise awareness of the energy production of solar cells in Uppsala. To achieve this we will create a program that depicts the different solar parks while displaying information about them and their power production. An LED-strip will be connected to the program which will change its colours according to the measured values we receive. This will ideally lead to more people being aware of Region Uppsala's solar cell and their efficiency. There is also a focus on proving to companies and the public that Sweden actually is a good place to install solar panels. This is due to the panels working more efficiently in sunny conditions with temperatures closer to 0°C [19, 28]. Our system is a start to solve this issue and is meant to serve as a proof of concept for future endeavours. Future work will include updating the visualization to something more sophisticated and interesting.

Goal. The goal was to create a digital map over Uppland with Region Uppsala's solar parks as interactive elements on the map. These elements contain relevant information related to that specific solar park translated into something more comprehensible, such as the day with the highest produced energy and the weather conditions at the time. The digital map is to be installed on tablet that is mounted in a public space.

Accompanying the interactive map is a physical representation of the solar cells energy production in form of an LED-strip that changes colour depending on the produced energy of the selected solar park, where a higher production is represented by a redder colour and a lower production is represented by a bluer colour. This serves as an eye-catcher and to engage the user to a higher degree than what a single screen do. Our implementation is merely meant as a proof of concept to be expanded upon in the future. With our implementation we show a way in which the data can be interpreted and represented.

Motivation. There is an increasing need for renewable energy production in Sweden due to the dismantling of nuclear power plants planned for 2019 and 2020 [41]. There is also a lack of awareness from businesses and the public regarding their ability to produce substantial amounts of clean energy [26]. This is important to address for the wellbeing of our environment as well as to reduce stress on existing resources and infrastructure.

Everyone on our planet has an opportunity to do something about it. This means that the general public is our main target but we also want to reach out to the companies of Uppland. According to an article from SVT [46], the Swedish public service television company, Sweden is starting to close most of its nuclear power plants before having an adequate replacement. The article states that Sweden's growing population, which causes an steadily increasing energy demand, has put the country at a risk of running low on energy. The increase in energy consumption in Sweden has lead to Sweden having to import energy from coal power plants in Germany [32, 44]. The use of coal power leads to air pollution and worsens global warming. To combat the use of non renewable energy and to increase the energy production in Sweden, installation of solar cells would be a step in the right way. Of the countries in the European Union, Sweden has the 22nd most solar cells per capita, with 41.9 watts per capita, Denmark has 173.3 watts per capita, Belgium 373.2 and Germany 546.9 in 2018 [13]. These countries are all in close vicinity to Sweden and have come further with installing solar power. Increasing the awareness of how efficient solar cells can be in Sweden will be a step in the right direction to interest people and companies to invest in solar energy.

By promoting the use of solar cells we are by extension promoting the production of solar cells, which requires metals and minerals. The mining of these have a negative impact on the surrounding environment by ruining habitats and poisoning some of the animals [9, 18]. Many mines in developing countries have poor working conditions such as not following security protocols and poor equipment [42]. A positive development however is the recycling of solar panels which is a growing industry, especially in Europe where manufacturers have to pay a recycling fee [45]. This lowers the demand of mining the essential minerals and metals, due to them being repurposable from recycling instead. The production of solar cells also result in greenhouse gas emissions that needs to be taken into account. The solar cells, and the production of them, are becoming more efficient resulting in better solar cells. As a result, since 2011 there has been a break-even between the cumulative detriments and benefits of solar power in terms of total greenhouse gas emissions [23].

Our system will ideally promote the installation of more solar cells, or at least pave the way for other projects of this kind. That would lead to an increase in energy sustainability by getting more solar cells installed. Several of the global goals the UN agreed on in 2015 can be linked to our project, where the main one is the goal of affordable and clean energy (goal number 7). Our system could also help to make cities more sustainable (goal number 9) by improving or decreasing the load on the infrastructure and reducing the need for energy sources that contribute to pollution and noise. And, lastly, by encouraging the use of solar cells the project will help combating climate change and its impacts (goal number 13).

There are not many ethical qualms when it comes to our system specifically, but one is that it is not accessible for everyone. People with visual impairment will have issues interacting with our system. A possible solution to this would be to integrate text to speech and voice control to our system [37].

4 Related Work

During the project we analyzed other systems concerned with displaying and visualizing energy data. This allowed us to draw inspiration from several different solutions. In this section we will analyze and compare each solution and goal to our system.

4.1 Sun Labs

Sun Labs is a company that was formed after making a project similar to ours, where they created a cross-platform application that visualizes data from solar panels [15]. Their goal was to share knowledge about renewable energy sources, specifically solar panels and how these can be used in the most efficient way. They worked with the

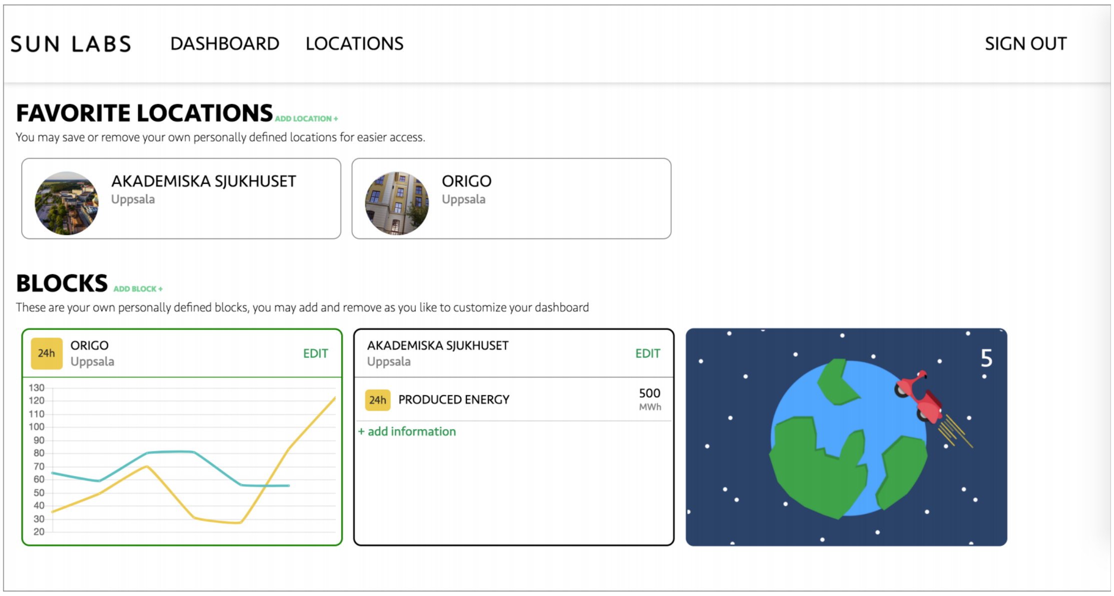

Figure 3 A screenshot of Sun labs product for displaying energy production.
Figure retrieved from "Making Solar Energy Data Accessible for Everyone" by L. Frosteryd, V.Ingman, and K. Ramström

same stakeholders as we did, STUNS Energi and Region Uppsala but the application was meant to be released to the public while our system was to be installed in a public space. The main difference between our projects is the way we represent the data, Sun Labs mainly used time graphs as shown in Figure 3 while we interpret the data in a way that corresponds to each solar park. For instance if the solar park is located at the bus depot, the data will be translated into how many kilometres an electric bus could travel with the energy production of the current day.

4.2 Data Visualization Study

A study was made concerning how to efficiently do data visualization where they created a process to efficiently do a design study [34]. It compared different methods and found 32 pitfalls that are likely to happen when creating designs. Among these pitfalls are such things as having insufficient knowledge of visualization literature, premature design commitment and many more.

This gave us pointers and showed us what we should look out for whilst doing the design of the system. It also provided us with a "check-list" to keep us on track and produce a good end-product.

4.3 Monitoring Energy Consumption and Visualization of Solar Cells

One study similar to our project has been made regarding a system monitoring energy consumption and visualizing the use of solar cells for households. It explores and creates a system to track energy consumption of ordinary systems in a household. It also compares these with the energy generated by installed solar cells to ascertain whether or not it is economically viable to install solar cells [24]. This was quite similar to our problem but they were more concerned with deciding whether to buy electricity, or producing and potentially selling their own. Matsui et al. gathered weather data and put it in relation to each individual house (size, area, residents etc.). In the end the group created a software that gathers values and does the comparison with a simple time graph.

In our project we do not differentiate between individual houses, and we are not concerned with the price of electricity or the different usages of the generated energy. We want to gather data and compile it in a database which then allows us to compare it to previous days and the total production of each site. This data is displayed in numbers alongside a visualization in a more comprehensible way such as how many phones can be charged or how far an electric car could drive on the produced energy.

4.4 Visualizing of Household Energy Consumption

There has also been a study done in Norway by Julie Marie Røsok in which she tried to increase the awareness of peoples household energy consumption [33]. She created an app that could be connected to a smart energy meter in households. In the app, the user could see the current energy consumption and previous days energy consumption averages. Everyone with the app would be connected to a leaderboard where they could compete with other users. She also researched persuasive technologies and implemented some of the methods that was previously established to incite change in people.

This gave us a different insight in what to actually visualize. The idea to see how much money people saved is something that can be very appealing to businesses and the public. Instead of seeing what the user saved by not consuming energy, in our project they would see how much money the solar cells saved compared to purchasing energy the conventional way. But this idea was discouraged by our stakeholders as it would be difficult to calculate.

5 Method

The following section aims to describe the methods used in the project. We start by describing the tools used in the making of the map program and then the tools used in the creation and linking of the physical visualization with the map. Lastly, we describe how we receive and store all the data from the solar cells.

5.1 Tools Used for the Interactive program

The interactive program was created with the game engine Godot. We used a game engine because it provided a graphical user interface that contained buttons, menus and means of combining interactive elements [40]. We chose Godot specifically because it is free, open source and lightweight unlike some of the other popular alternatives such as Unity and Unreal Engine [22]. It also provides easy exporting to either Android or iOS. As we did not know what operating system the tablet that we were supposed to install the program on had, we had to have a lot of flexibility.

As we needed a map of Uppland, several different alternatives map API's were considered, such as Google Maps and Bing Map. We then realized that the functionality of a traditional online map was not needed, such as viewing specific addresses and receiving directions, so an image of Uppland was used instead. The image that we use is taken from (*OpenStreetMap*) [29] , an online tool that provides geographical information, and we have marked the locations of the different solar parks on it. With the help of the framework provided by Godot we added interactive elements and buttons to the map.

To help us in designing the program we used the mockup tool *moqups*. We chose this tool due to it having all the functionality we needed, such as drag and drop creation and ease of interaction with elements. This was done by first creating different designs until we had two that we liked based on aesthetics and clarity. These were then presented to STUNS Energi who chose the one they liked the most. Later in the design process we also did user tests, as can be seen in Section 7.2 to make sure that the final design met our requirements of the system. The work with the program went as expected overall because of our well structured design plans.

5.2 Tools Used for the Physical Visualization

For the visualization we used an LED-strip since it is easy to manipulate and mount: we can display the full colour spectrum and it has an adhesive side, making it easy to install where we want. Another alternative would have been to build our own addressable LED-based artwork which would allow us to control each individual light. This would in the end lead to more flexibility, but since the visualization only serves as a proof of concept, it was not worth the time and effort on our end to create something more sophisticated.

To control the LED-strip a micro-controller was used to interface with, and control, the physical visualization. Another possible solution would have been to us the single-board computer Raspberry Pi,with the difference being that Raspberry PI has the most processing power and hardware control [5]. In our project processing power was however not very important and the hardware control of the Arduino was enough for our project because of the simplicity of our physical visualization. The previous arguments together with the Arduino having a lower power consumption made it our choice. If a more advanced installment is to be created other micro-controllers might be of interest.

5.3 Information Flow and Storage

We got the energy data from energy meters utilizing MQTT, a messaging protocol further explained in Section 8.1, which is connected to Region Uppsala's solar cells. The MQTT broker was already implemented before the start of the projects and to use the data from from it a JSON parser was created in Python. The data is stored in a local database created with SQLite. SQLite was chosen because it is well suited for constrained devices and local databases [10].

6 System Structure

Our system consists of two major parts: the physical visualization and the interactive map.

STUNS Energi has previously implemented sensors connected to the solar cells that gather data from them to a centralized point. Connecting to this information point gives us new values every fifth second, allowing us to create detailed statistics regarding the production. This data is stored in our database which is connected to the rest of the system. We created the program gathering the data from the solar cells and database from scratch to serve the specific needs of our project. A visual representation of the system structure can be seen in Figure 4 where the boxed in parts makes up the system that we have created. The solar panels, energy meters and MQTT protocol were already implemented at the start of the project.

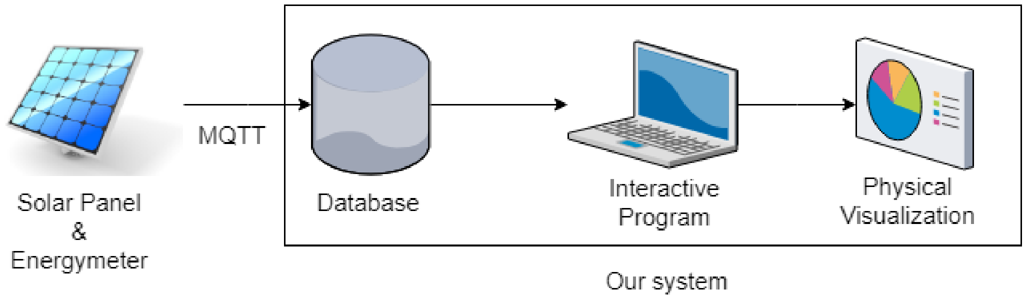

Figure 4 A visualization of our system structure.
Figure created at https://www.draw.io

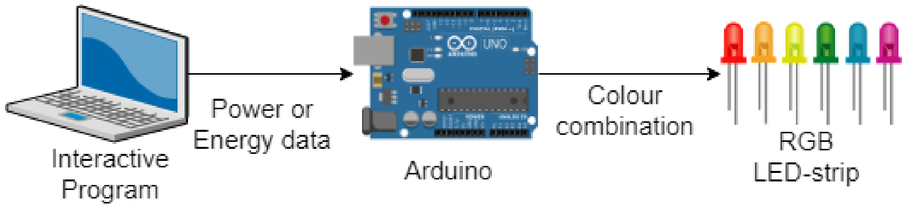

Figure 5 A visualization of the system structure from the program to the LED-strip.
Figure created at https://www.draw.io

6.1 Structure of the Map

The interactive map depicts the different solar parks which belongs to Region Uppsala. The user can click on individual parks and if they do, they will be able to see specific data such as the current production and the top production belonging to that solar park.

The map is connected to the LED-strip which allows the user to control what is visualized. Bringing up different solar parks and different information makes the LED-strip visualize the energy production.

6.2 Structure of the Physical Visualization

The gathered data from the solar cells reaches the Arduino via our interactive map program which sends the processed information to the Arduino via USB, as can be seen in Figure 5. Those received values are used to control the LED-strip, allowing us to show different colours corresponding to the values. The interactive map will be used as a controller for the LED-strip. Clicking on different solar parks and displaying different types of statistics will send corresponding colour signals to the Arduino, which will change the LED-strip's colour to visualize the data.

7 Requirements and Evaluation Methods

Our system has two main requirements that need to be fulfilled, robustness and usability. In this section we describe the requirements and how they will be tested.

7.1 Robustness

In computer science, robustness is the ability of a system to handle problems that arise during its execution. One such problem that could exist for our system is the loss of Internet connection. To test this we interrupted the Internet connection of our system for ten seconds and made sure it was able to reconnect afterwards and continued working without any malfunctions. Our system also needs to be able to handle faulty inputs in case there are problems with the MQTT broker connected to the power panels. The faulty inputs we protect the system from are negative energy productions and if letters are received where only numbers should be accepted.

7.2 Usability

It is very important that our system is intuitive and easy to understand. This means that the user should be able fully understand how the system works without any prior instructions. The accomplishment of this requirement was tested with the help of user interviews during the design stage. We tried to make the test group as diverse as possible, with people of the ages 5 and older as the system is to be available to the public. The test group consisted of five people aged, 22, 23, 18, 51 and 62. They had varying levels of technical knowledge, with the younger testers having more experience. During the testing the user were allowed to explore the program freely while we took notes of behaviours akin to when the user got stuck or tried to do something that did not work. We also took note of features that the user did not access. After the testing we asked the user a few questions.

- What was your general impression of the program?
- How did it feel to navigate the program?
- Were there any parts that felt annoying or interruptive?
- Why was not the noted feature accessed?

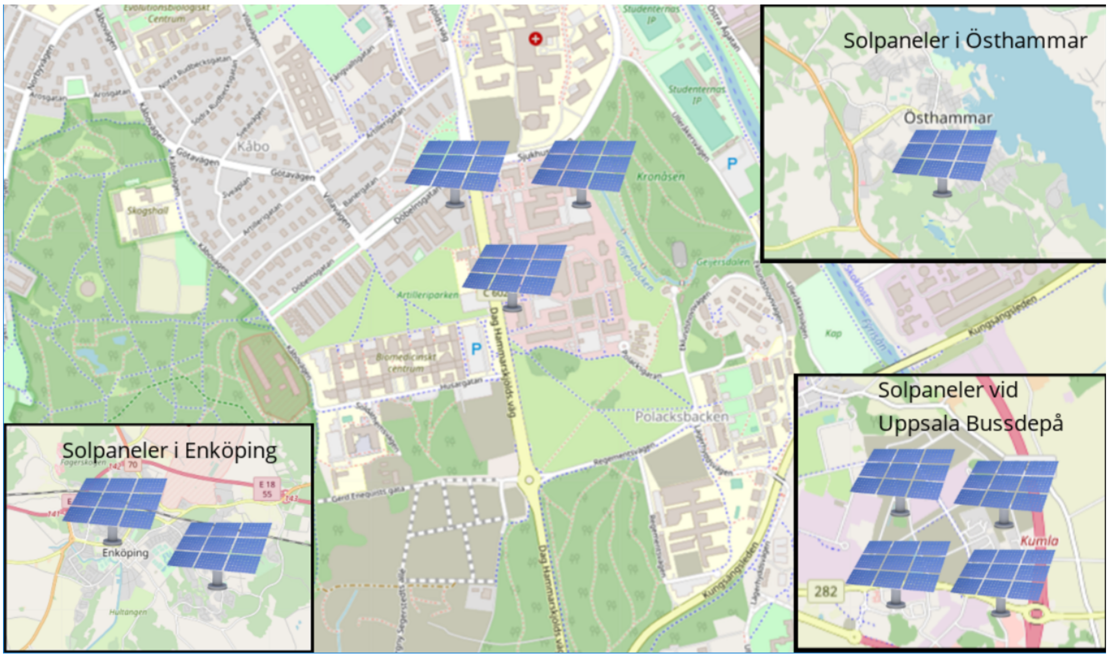

Figure 6 The initial screen of the interactive map. The center and bottom right sections depict solar parks in Uppsala, the top right section depicts a solar park in Östhammar and lastly, the bottom left section depicts solar parks in Enköping. These locations are cities situated in the Swedish county of Uppland.

8 Implementation of the Interactive Map

In this section the implementation of the interactive map will be described. Figure 6 shows the initial screen of the map and represents the part of Uppland where Region Uppsala's solar parks are located. In the center we have a zoomed in view of Uppsala showing the area where most solar panels are positioned. The bottom right part shows the bus garage of Uppsala where they have the second largest solar panel installation. The top right and lower left parts show two smaller towns of Uppland, Östhammar and Enköping, where Region Uppsala also have installed solar panels.

Figure 7 shows the pop-up that is presented after pressing any of the solar panels on the initial screen. At the top we have the name of the selected solar park and on the right a picture of the solar panels. When pressed the three buttons on the left, “Just nu” (right now), “Totalt idag” (total today), “Toppdag” (top day), change the text that is displayed. Pressing “Just nu” shows how much power is produced at that moment and the current weather conditions. Pressing “Totalt idag” shows how much has been produced so far this day. Pressing “Toppdag” shows the day that the solar park produced

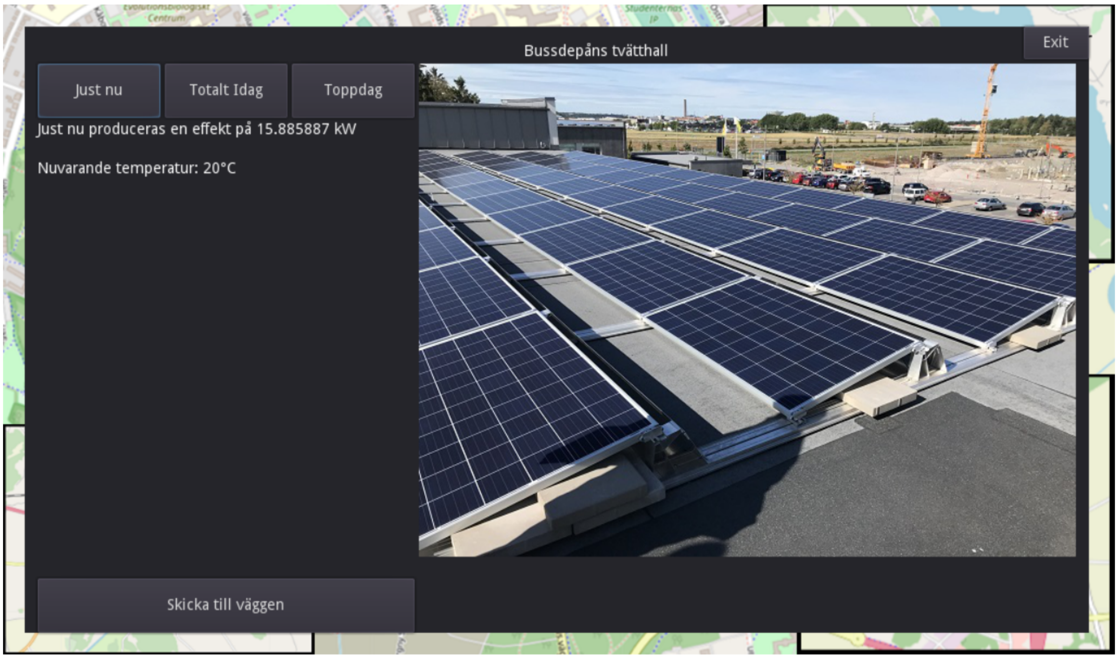

Figure 7 The popup showed after pressing any of the solar panels in the initial screen.

the most power so far, how much power it produced and the weather conditions at the time. It also translates the energy from kWh, its base unit, to something connected to that specific solar park. For the solar park on the bus garage this could for example be the amount of kilometre the produced power can take an electrically driven bus. Finally at the bottom of the pop-up is a button called "Skicka till väggen" (Send to the wall) which when pressed sends the power production of the currently selected solar park to the LED-strip.

8.1 Linking the Database to Solar Cell Data

The solar cells are connected to a energy meter, and the energy meter transmits the data via an MQTT broker. MQTT stands for message queuing telemetry transport and is a message protocol designed for constrained devices (small devices with limited processing, memory and power resources) [20]. A common example are devices used in the "Internet of Things". The MQTT broker uses a subscribe/publish messaging system via the TCP protocol, meaning that a device publishes messages that can be subscribed to. By using log-in credentials from STUNS Energi we could subscribe to all endpoints of their information broker, giving us periodic values from each solar park every five seconds. The subscription is done through a python software which handles the data

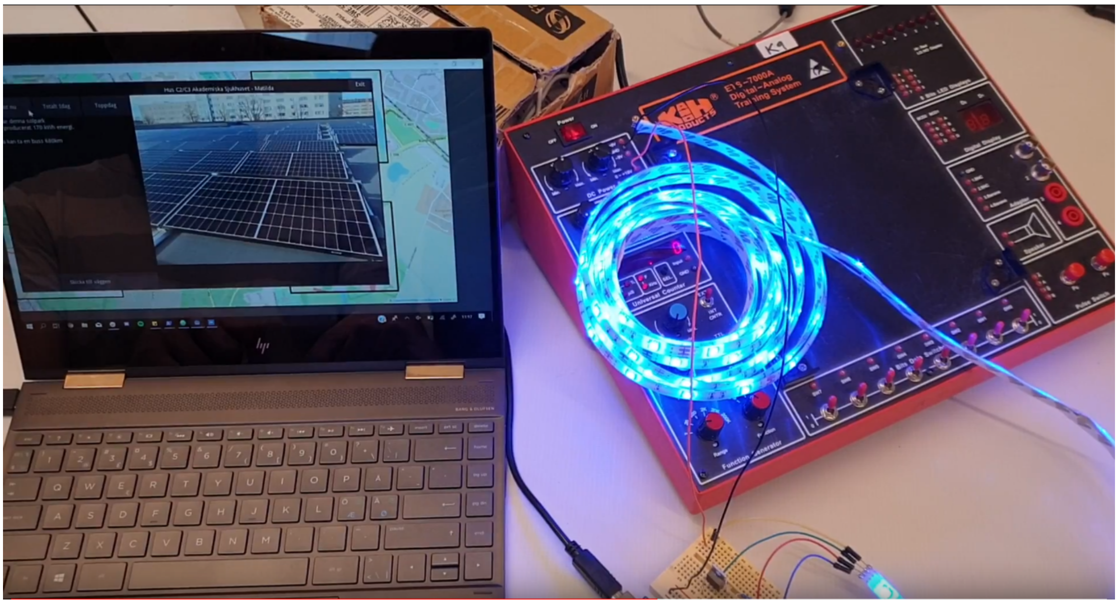

Figure 8 A demo setup of our system, showing the interactive map connected to the LED-strip.

in three steps. Firstly, it parses the data and extracts the relevant information. Secondly, it checks whether the timestamp on the received data is from the same day as the timestamp stored in the "current" table to determine if it is from a new day. Thirdly it stores the retrieved data to the correct position in the database, if the comparison of the timestamps did not match, i.e. it is from a new day, the "production" value is reset.

9 Implementation of the LED-strip

This section describes the implementation of the physical visualization of our project, the LED-strip. The LED-strip is connected to an Arduino which receives data from the interactive map. The data is then translated into a colour which is sent to the LED-strip lighting it up in the selected colour, as can be seen in Figure 8. A high production value is represented by a redder, warmer, colour while a lower production value is represented by a bluer, colder, colour. This follows the segment of the kelvin colour scale shown in Figure 9.

The implementation and connection of the LED will now be described in more detail. Figure 10 shows the schematic for the setup of the LED and each specific part is explained further in the following list.

Figure 9 The part of the Kelvin colour scale used by the LED-strip to represent different production values. A red colour indicates a higher production value while a blue colour indicates a lower.

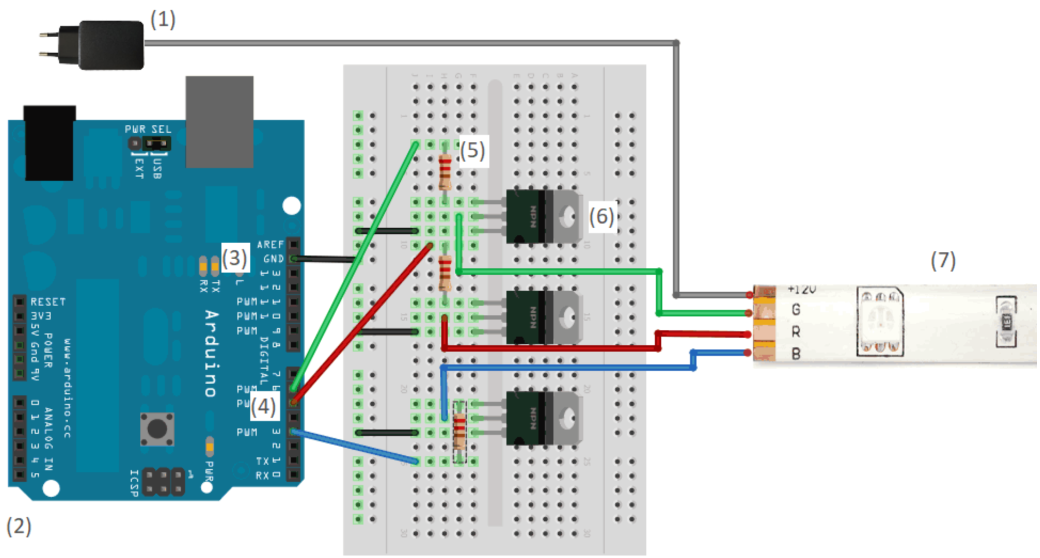

Figure 10 Setup of the LED-strip. (1) Power supply, (2) Arduino Uno, (3) Ground pin, (4) PWM pins, (5) Resistors, (6) MOSFETs, (7) RGB LED-strip.

1: Power supply Supplies 9V to power the LED-strip.

2: Arduino Uno The microcontroller, and as such, the brain of our physical visualization. We have uploaded software to the Arduino that allows it to listen for specific signals sent from the interactive map via the existing USB-port on the Arduino. With the help of these signals the Arduino knows how it is supposed to manipulate the physical visualization.

3: Ground-pin Makes sure that the LED-strip is properly grounded, which is required to create a closed loop for the circuit. Shares common ground with the power supply.

4: PWM-pin (pulse-width modulation) A digital pin that controls the dimming of LEDs by controlling when the power is on or off [7]. By connecting through these pins we gain the ability to minutely control the values for red, green and blue individually.

5: 220 ohm resistor These resistors are used to limit the current going to the LED to a safe value, that does not make LED burn.

6: MOSFET(metal oxide semiconductor field effect transistor) A transistor that is used for amplifying and switching electronic signals in the device [11]. Together with the resistors, the MOSFETs are in place to keep the Arduino from high currents.

7: RGB LED-strip The way that we have setup the LED-strip we have the ability to control each RGB-value independently.

10 Implementation of the Database

The database was constructed using SQLite. SQLite is an open source and file based relational database management system, known for its portability and reliability [10]. The database was separated into four different tables as seen in Figure 11. The first table contains the solar parks current production, the second one the accumulated daily production, the third one keeps track of the auto-increment property and the fourth one contains all the solar parks top days.

The tables “current”, “daily” and “topDays” contain one entry for each solar park. The following list describes the contents of the database:

- **id:** An integer used to identify the solar park. In all tables, the id is connected to the same name making the id and the name interchangeable.
- **timestamp:** An integer following the Unix epoch timestamp convention. This

Name	Type
Tables (4)	
current	
id	INTEGER
old_timestamp	INTEGER
new_timestamp	INTEGER
name	TEXT
power	INTEGER
daily	
id	INTEGER
timestamp	INTEGER
name	TEXT
production	INTEGER
sqlite_sequence	
name	TEXT
seq	TEXT
topDays	
id	INTEGER
timestamp	INTEGER
name	INTEGER
produced	INTEGER

Figure 11 The structure of our database.

means that the number shows how many seconds that has passed since January 1, 1970. In the "current" table, when receiving a new value from the solar panels, both the old and new value's timestamps are saved.

- **name:** A text that describes the solar park. The name is connected to the same id in all tables .
- **seq:** An integer that shows what id an element will get if entered into a table with the auto-increment property enabled.
- **power:** An integer that represents the current power production in kW. The value is replaced every time a new one comes in.
- **production:** An integer that represents the power production in kWh accumulated during the current day. Every time a new value is entered in "current" it is converted form kW to kWh and added to this value. The production is reset each day at 00:00.
- **produced:** An integer that represent the total power production in kWh of the day with the solar parks highest production so far.

11 Evaluation Results

In this section we will evaluate the results of the evaluation methods described in Section 7. In short our system fulfills the requirements set upon it.

11.1 Evaluation Result of Robustness Tests

Our robustness tests were successful, with all of the requirements mentioned in Section 7.1 passing the tests. The program can successfully reconnect automatically after losing connection to the Internet. It can also handle faulty inputs from the MQTT broker if such should occur, though this is unlikely.

11.2 Evaluation results of Usability Tests

Our user test shows that user of varying age and technological background found the program easy to understand, and navigate. Unfortunately it was hard to find a test group that encompassed the demographic, mentioned in Section 7.2, that we desired. This was mostly due to how broad the desired demographic was, which only excluded people under 5 and the visually impaired. However, we still feel that the user test gave us good feedback, which mostly concerned the design of the program. Improvements that were mentioned were that we should make it clearer what the figures on the map view represented. The users did not always understand that they depicted solar parks that were located on that exact position in the real world. It was also mentioned that we could make it possible to see the energy production of all parks simultaneously.

12 Results and discussion

We have created an interactive program that accesses data concerning energy production of the solar parks belonging to Region Uppsala. The program visualizes the solar parks as solar panels on a map of Uppland which when clicked on opens a window showing information relevant to that specific solar park. The program is also connected to an LED-strip which receives information from the program regarding the energy production of the selected solar park. Depending on what data is received the LED-strip lights up in different colours representing different levels of production. The finished system worked well and the layout was easy to understand but the visual design still needs to be worked on. All of this was in line with the goals mentioned in Section 3.

The reason for the success of the program was due to a well thought out design and careful planning of what functionalities it should have. As mentioned in Section 5.1 we iterated over several different designs until we had two that we liked from an aesthetic viewpoint. Having to wait for confirmation from the shareholders meant that we could not go ahead with the final design and creation of the interactive program as soon as we would have wanted. Because of this the layout of the program was not as fully developed as we initially would have hoped. If we were to redo this project, getting a design confirmed by the stakeholders as early as possible would be a significantly higher priority.

An alternative way to solve our problem would have been to make an animated slideshow describing the data instead of the interactive program, or a screen with data that is frequently updating akin to an airport information screen. This has already been done in other projects and we wanted a system that differs from these implementations and one that also engages the audience to a higher degree. If a user engages and explores a subject they are likely to retain the information to higher degree than if they just read text concerning said subject [1].

13 Conclusions

We created a system that with an interactive design shows how much energy is produced and what weather conditions leads to the higher production. As mentioned in Section 3, the goal of our project was to raise peoples interest in investing in solar cells. In Sweden 80% of the population want the country to invest in more solar power, making it the most appraised source of energy production in Sweden 2016 [16]. In the European Union's ranking of 2018 for solar cell capacity per inhabitant (watts per inhabitants) Sweden were in 22nd place [13]. In comparison, Germany had a capacity that was 13 times larger which put them at first place, and Denmark at tenth place which had a capacity 4 times larger than Sweden. These are both countries with comparable number of sun hours but with a much bigger solar energy investment [36, 43, 8]. This shows that even though the Swedish population believes that solar power is a good source of energy, there is great potential to expand the solar energy infrastructure in Sweden. We believe that our project is a step in the right direction to unlock some of this potential.

The program was also connected to an LED-strip where its colour represent the current energy production of the solar park chosen by the user on the program. This was done as a proof of concept, hopefully paving way for a more advanced form of physical visualization.

The importance of this project lies mostly in how and in what new ways you can visualize data in a comprehensible manner to the public. More and more people gain access to the Internet each day [17], and the amount of data uploaded or downloaded daily is also increasing [35]. This means that it is becoming difficult to get a good grasp of the available information. It is here that our project is of utmost importance, making the data accessible and understandable helps with conveying knowledge to everyone. Regrettably, the system we have developed will only be accessible at the public space supplied to us by Region Uppsala and as such the number of people we can reach is greatly reduced.

14 Future work

As the LED-strip was intended as a proof of concept, there is a potential to make more advanced physical visualizations of the data. Possibilities include making a larger and more sophisticated LED-screen which gives the capability of changing both the colour and shape of the displayed object. There are also more abstract approaches which give users a feel of the amount of generated energy such as a Lichtenberg figure, shown in Figure 12, or a water fountain with altering water levels and flow.

Regarding the interactive program, making it a web application would have greatly increased its accessibility and capacity to spread information. Furthermore, expanding the map to span the whole world would be the ultimate goal. This could be done by slowly expanding outwards with the first goal to have it show all solar parks in Uppland, not just the ones owned by Region Uppsala. Another future project is to add other sources of renewable energy such as wind turbines and hydroelectric power to the interactive program. Adding these other sources of energy production and their production would give a more accessible overview of the overall energy production in a city, nation, or even the entire world.

Figure 12 Lichtenberg figure
Figure named "Electrical Discharge Lichtenberg Figure" uploaded by Ted Kinsmann

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