# Active system visualization of solar model

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## INTRODUCTION

Anthropogenic climate change is widely recognized as a global emergency, with 196 different parties entering the Paris Agreement, a political treaty meant to limit the rise in mean global temperature below 2 degrees Celsius (Paris Agreement, 2015; Mazon et al., 2022). Summer of 2023 has been the warmest period on record since 1880, with a 1.17 degree anomaly (Fox et al., 2023). According to a Park et al. (2023), the global mean temperatures are expected to reach 2 C by the year 2040. The effects of climate change, from increased wildfires and droughts to flooding and water levels rising globally, are already evident in their impact on current ecosystems and human society (Alizadeh et al., 2021; Masson-Delmotte et al., 2022). A study by Abatzoglou and Williams (2016) has shown that global warming has contributed to approximately half of all wildfires in the western US, which can exacerbate its effects and further block tree regeneration as shown by Davis et al. (2019). Other effects, such as Arctic methane release can also increase global warming, leading to feedback loops that might not be reversible. According to the Office for National Statistics (2023), the largest contributing sector of greenhouse gas emissions is households followed by energy production. The UK government has been working on reducing carbon emissions by implementing different directives and regulations, from banning the sale of new petrol cars from 2035 to publishing the Build Back Greener, net zero strategy Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy (2021). One such directive is the Rural Energy Community

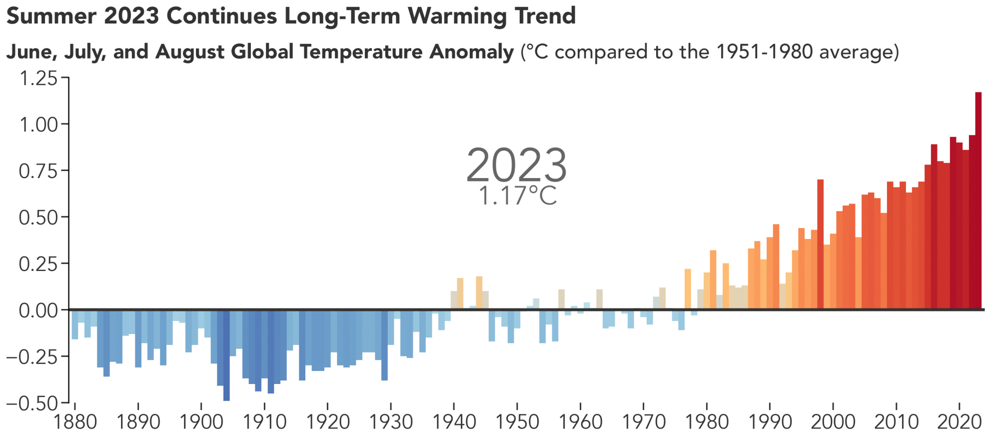



Figure 1: Meteorological summer temperature anomaly for every year on record. Data collected by NASA's Goddard Institute for Space Studies, chart created by Lauren Dauphin (Fox et al., 2023).

Fund (RECF) established in 2019 by the Department of Business, Energy and Industrial Strategy meant to support rural communities in England in transitioning towards renewable energy. The RECF scheme allocates funding in two stages: first, it offers up to 40,000 £ for a feasibility study and then, in the second phase, up to 100,000 £ for business development(Department for Business, Energy & Industrial Strategy and Department for Environment, Food & Rural Affairs, 2019). The project has now allocated all its funds, having helped over 200 communities and created five Net Zero Hubs meant to assist community energy projects (Community Energy England, 2019).

One of the beneficiaries of the RECF scheme is Brampton 2 Zero, a community interest company founded by a group of residents from Brampton with the ambitious goal of completely decarbonising the town Community Energy England (2019). During the first stage of the RECF scheme, B2Z received funding for a Low Carbon Options Appraisal conducted by Scene published on the 21st of November 2022. Their report states sufficient interest from the residential community and local businesses in a solar PV cooperative which would have the potential of generating 2.0 MW of low carbon electricity, offsetting 156 tons of CO2e each year Robinson et al. (2022). However, while the community response is positive and plenty of interest has been shown in the project, it is still important to raise awareness of the project. To aid in this endeavour, four students from Lancaster University developed and built a scale model of a prosumer community (Fitzsimons, 2023; Arbon-Donovan, 2023; Gibson, 2023; Lalli, 2023). A prosumer is a person who serves the roles of a producer and consumer in the same market. This idea is commonly used on social media websites where users produce content, it is also relevant to the field of solar power generation, when an individual can sell the excess power produced. This system has many advantages over traditional power generation, such as lower electricity costs, flexibility, and grid relief Schill et al. (2017).

The role of the prosumer model is to "produce a proof-of-principle visual model with battery charging and use of solar/stored energy for some function, which can later be scaled up to a full-size system." Fitzsimons (2023). Additionally, the model is intended as an interactive teaching tool for younger audiences at fairs, schools and various presentations. While the project was mostly finalized in time and hasn't extended past its budget, a secondary part of the model, that of creating a small web app or web page to display the flow of energy, wasn't finished Lalli (2023). An issue with the model is transport. While it has the model itself has rechargeable batteries and solar panels to supply power, the Raspberry Pi used in measuring and displaying data has to be connected to mains power and needs an external internet source. This creates an issue with the portability of the system. This project aims to fix these portability issues and to further improve the web page visualisation.

# THE PROSUMER MODEL

The model was built as part of a collaborative project by a group of third-year students at Lancaster University. The project lasted for 9 weeks and had a total budget of 300 £, of which 239.65 was spentArbon-Donovan (2023). The full list of parts, with quantities and prices can be seen in table 1. While some of the items were more expensive than expected the team did a good job of estimating the cost and managing their budget, even allocating error margins. Additionally, the team rigorously tested the solar panels and monitoring circuits.

The finalized model is formed of "Prosumer" units meant to mimic a real house in a minimalist approach. Each unit can demonstrate power production, consumption and storage within a normal prosumer house. Additionally, the unit can import or export energy to an external circuit so that the model can illustrate the capability to sell or buy energy from a Power Plant that a prosumer has. To facilitate interactivity, each house unit has two switches available to change between import or export of energy and to turn power usage on or off. The detailed configuration of a house circuit can be seen in figure 3b while the physical image of the unit is available in figure 2b.

The power plant in this system functions similarly to the prosumer units, however, it has a larger solar panel (max output 20W) and a larger battery (7000 mAh) (Yuasa, 2023a). There are no relays and switches available as the already existing ones connect the units to the power plant. The charge controller allows the system to supply each unit with 12 volts either from the large solar panel or the battery or to charge the battery. An INA219 measuring module is available, however, it hasn't been added to any of the units, and it is likely to be intended for the power plant, however, this was not specified in any of the reports.

| Item(s) | Quantity | Cost (£) |
|---|---|---|
| Yuasa NP1.2-12 12V 1.2Ah F4.8 small battery | 3 | 25.35 |
| Yuasa NP7-12, 7Ah / 12V VDS large battery | 1 | 21.70 |
| House Charge controller | 3 | 29.88 |
| Charge controller and large Solar Panel | 1 | 37.00 |
| Small Solar Panels (unused) | 3 | 9.00 |
| Solar Panels | 3 | 30.00 |
| INA219 Sensor module | 4 | 23.96 |
| Relay module set | 1 | 15.38 |
| Wires & Connectors set | 1 | 3.00 |
| Breadboard set | 1 | 17.38 |
| PC case fan | 2 | 14.00 |
| LED | 5 | 1.00 |
| Birdhouse set | 1 | 12.00 |

Table 1: A list of all bought items and their cost for the solar model before this project started. Decorating supplies, buzzers, and voltage regulators were already available. Note that the source of the Raspberry Pi is not mentioned in the original reports.

## 2.1. THE PROSUMER UNIT

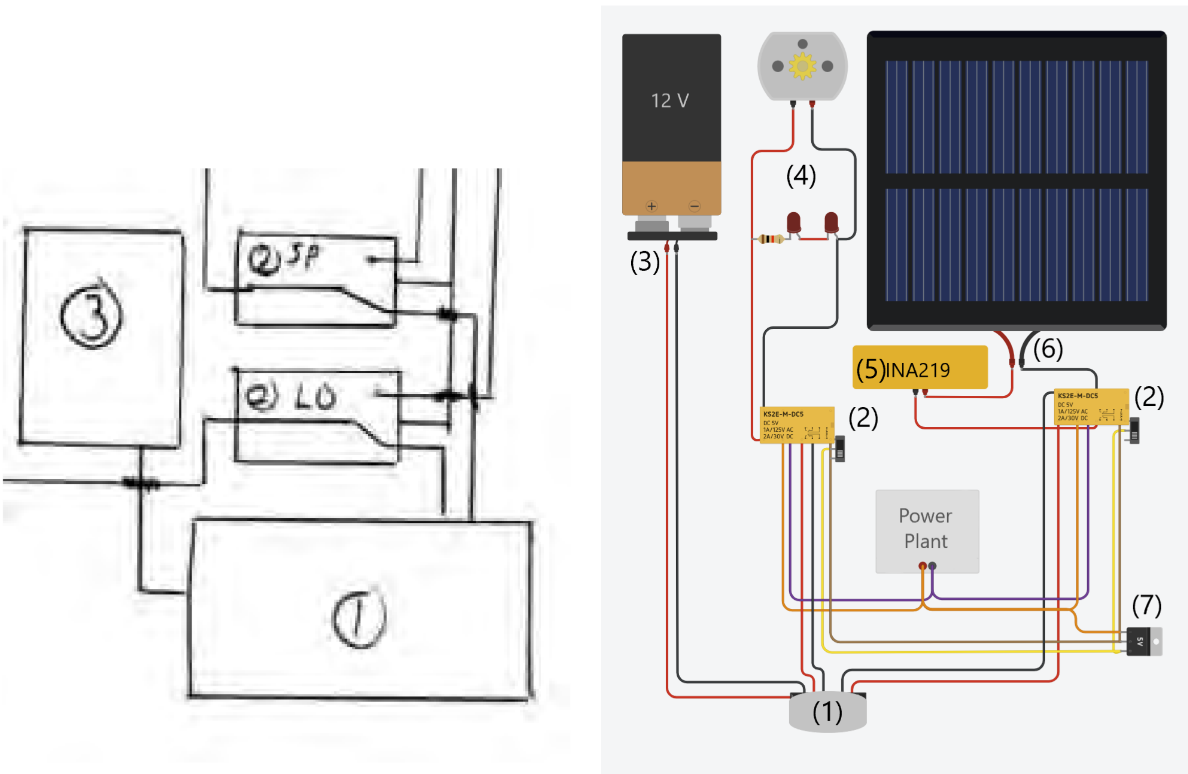
Initial plans for the model assumed each house would use a different method to display energy use, some would be colourful, making use of LED, and others would have fans or water heaters. In the end, the team combined the different house types in one, incorporating both fans and LED in

(a) Front of the model as it is displayed, photo from original reports (b) Inside view

Figure 2: The first image is taken from the original reports, while the second image was taken when debugging an issue with the wire connections. From top to bottom: the small solar panels are set on the roof of each house on the right side, and the load circuit is inside the house with fans glued to the exterior of the green and blue house. In front, the charge controllers are visible under each house, with switches for the different modes on the right side of them. Image b shows the model partially open and the large battery can be seen in the centre with the large solar panel behind the model and the Raspberry Pi in front. Because the solar panels are hard-wired to the box, the lid can never be fully opened.

each house as seen in figure 3b. The consumer circuit can be powered by activating a relay of type JQC-3FF-S-Z on both the high and low sides of the circuit. This is represented by a different type of relay but with identical functionality in figure 3b. The power drawn from the consumer circuit is somewhat hard to estimate, but it falls between 0.5-2 Watts. The original reports are sparse on technical detail and as such it becomes difficult to ascertain the exact nature of certain components, however, the fan appears to be a 2cm 5 V ventilator for Raspberry Pi, with a power draw between 0.8-1.2 Watts and the LED's used are regular spare pieces, paired with a 1 kOhm resistor. At this power use, the 1200 mAh battery can theoretically supply a circuit for 7 to 14 hours or even longer when using solar panels. In practice the time is closer to a few hours, the reason for this is unclear.

Since its invention, solar panel technology has advanced significantly, as such there are multiple options available. The team chose the cost-effective poly-crystalline silicon panel for the project. According to Center for Sustainable Systems, University of Michigan (2022) this type has lower efficiency (around 20.4%) than others, like mono-crystalline panels (around 24.4 %), they are cheaper while still fulfilling the technical requirements. This specific model is capable of supplying up to 2W at 12V electricity, as seen in table 1. The exact voltage and power generated by the Photovoltaic cells depends on the intensity of light available to the panel, as such it fluctuates unpredictably. This limits the production of useful energy in the daytime. To resolve this issue, batteries are often installed in tandem with solar panels, such that any excess energy captured when sunlight is available can be used at a later time. Each housing unit is therefore also supplied with a 12V lead-acid battery with a capacity of 1200mAh, capable of supporting 2 W of power draw for 7.2 hours (Yuasa, 2023b). Initial designs for the model considered the use of lithium-ion batteries, which were dismissed because of their higher price point. While lithium-ion batteries are more energy-dense and




(a) Original diagram of a house unit

(b) The new diagram for the house unit.

Figure 3: The original diagram of a house unit provided by the team that created the model and a more detailed recreation made for this paper using tinkercad.com, a free web app for creating technical circuits. Each of the components is labelled with a number. From 1 to 3, the labels are identical for both circuits, while any other labels are present only in the updated circuit diagram. 1 – charge controller, represented here by inputs only, 2– relay switches used to activate/deactivate the load (2a, consume) circuit and photovoltaic cell (2b, produce), 3– battery, 4– consumer unit formed from an LED and fan motor that provide visual and auditory feedback with 1 kΩ resistor, 5– the INA219 voltage measuring device, 6– supply circuit, 7– voltage regulator.

hold their charge for longer, lead-acid batteries are more suited for this model where weight is not a constraint. The specific advantage of lead-acid is the low maintenance requirements, these batteries specifically can be left unattended for months and still function correctly, additionally, the battery type is safer than lithium-ion (). The latter point is specifically important as the model was initially designed for outdoor activities and school events. Lithium-based batteries are famously dangerous given improper care, and while the model should not be left unattended, accidents can happen, as such, a safer battery is more suited for the task.

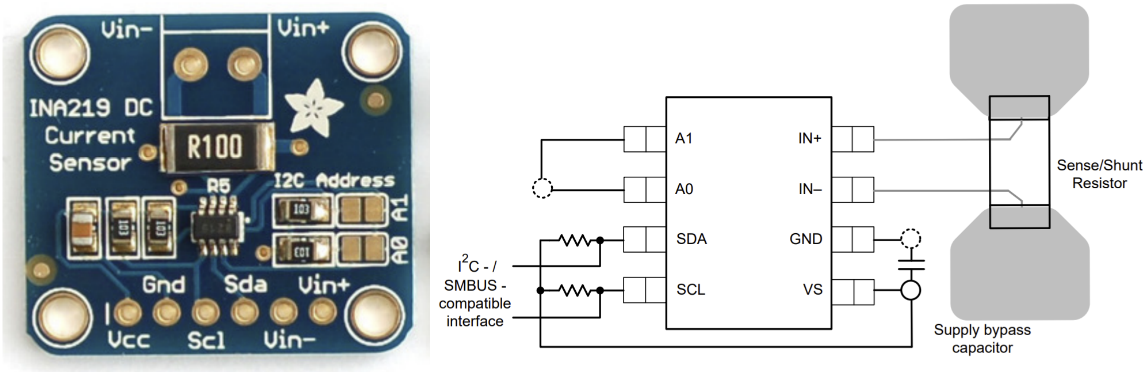
The battery charging and discharging process is regulated with an external unit designed for lead-acid (OPEN, GEL and AGM) batteries (topcloud, 2013). The model has a built-in LCD seen in figure 2b and uses PWM to charge batteries in a 4-stage process. The apparatus draws less than 10 mA of current, however, it requires that the battery is charged to at least 10 Volts to function. This proved in practice to be quite limiting as the model cannot be easily charged from a plug and the batteries discharge quite fast between uses. The batteries are each connected to their own charge controller directly, while the load circuit and the solar panels are connected indirectly, with a relay to the external power plant system. A simple 5V regulator is used to limit the current from the power plant to the relay modules (two modules, each containing 2 relays on each house, or 4 relays per house and 12 in total) (Lalli, 2023).

## 2.2. RASPBERRY PI AND MONITORING SYSTEM

A Raspberry Pi is a functional computer meant for a wide variety of uses, from educational to industrial projects. The solar model uses a Raspberry Pi 3B+ with 1 GB of RAM to record voltages from each solar panel at a frequency of 3.33 Hz and record the average results every 3 seconds. While the computer seems overpowered for this task it's important to remember that it runs a database and web app to display this information in real time. The computer runs a version of Raspberry Pi OS (previously known as Raspbian), based on Debian. This is one of the many operating systems (OS) in the Linux ecosystem Rapsberry Pi Foundation et al. (2021a). Each Pi is built with a set of GPIO (general-purpose input/output) pins that allow it to interface with various electronics and can be programmed individually. While the Pi requires an external source at 5V, most of the GPIO pins run on 3.3v logic, with two supply pins at 5V. Because of this, the Pi is completely isolated from the system, requiring its own power source Rapsberry Pi Foundation et al. (2021b). Each module connected to it is also supplied by the Raspberry itself so that the model can be a completely closed system. Obviously, in a real-life prosumer community, the monitoring systems would be part of the loop, however, power generation and consumption are meant to be scaled down. This cannot be done with the monitoring system, and the Raspberry Pi would drastically affect the results if it were part of the model.

As mentioned previously, the electrical output of the solar panel varies greatly with light intensity and the model should be able to display this effect on a monitor so that the energy flow can be observed directly. To achieve this the team incorporated an INA219 module within each house unit. This module is ideal for this purpose as it can provide highly accurate readings with 1% precision. It comes equipped with a 0.1 Ohm resistor, as seen in figure 4a, measuring high-side currents up to 26 V. While simpler, low-side measuring cannot be used in this model where the ground voltage level is unstable. By using high-side current sensing the INA219 module can bypass this issue (lady ada, Adafruit, 2023).

The module can communicate using the SMBus or I2C protocols, the latter of which allows up to 127 different devices to be controlled by a single processor, in this case, a Raspberry Pi model 3B+. The communication protocol must be initiated by a primary device (often referred to as master), and the devices that are controlled by the primary are secondary devices (or, using the old terminology, slave). This module can only operate as a secondary device. When using the I2C protocol, seven bits




(a) Photograph of the board as is

(b) The recommended layout of the INA219 module

Figure 4: Images sourced from lady ada, Adafruit (2023) and Texas instruments (2015). The Vin+/Vin- (top a) parts are connected to the solar panels to measure the voltage, while the other ports are isolated from it. GND and VCC provide power to the module and SCL/SDA are used for data transfer and as such work on 3.3 V logic. The A1 and A0 pins are used to hard set the address

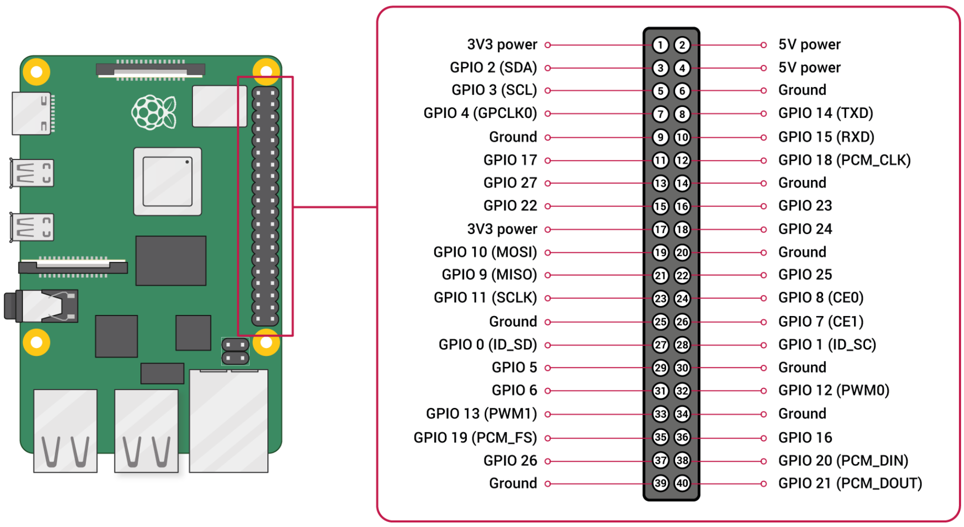



Figure 5: The pinout of a Raspberry Pi with its diagram from Rapsberry Pi Foundation et al. (2021b). All INA219 modules are connected in series to the following pins: 3 (SDA), 5 (SCL), 9(GND), 17(VCC, 3V3).

encode the address of a secondary device and the eighth bit indicates the direction of information flow, forming a byte of data. The first bytes specify the address of the secondary device that is called, allowing for multiple devices to be connected in parallel. The exact flow of information between primary and secondary devices lies outside the scope of this paper, however, it is covered in great detail in the data sheet (Texas instruments, 2015).

## 2.3. THE CELLULAR MODEM MODULE

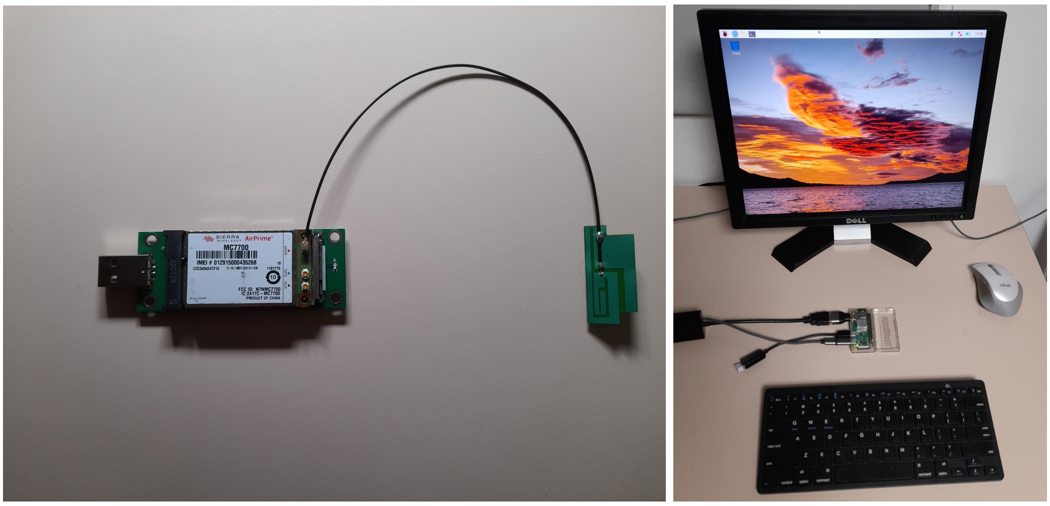
The original plans for the Solar Model relied on its portability. One issue with this is that the monitoring system requires an internet connection. The Raspberry Pi can use both WiFi and Ethernet (cable) connection (Rapsberry Pi Foundation et al., 2013), the latter is not usable for a moving project. Using a WiFi connection with a phone acting as a router (mobile hotspot) would be the easiest solution however, it cannot allow for server hosting and it was dismissed at the start as a phone was not expected to be always available. This option remained as a backup solution to the internet connection issue. The other solution was to incorporate the Raspberry Pi itself with a wireless internet connection using a SIM card. The budget for this extension was set at 20 £. To functionally connect a SIM card to a Raspberry Pi three different parts are needed: a cellular modem, an adaptor from mini PCIe to USB and an antenna.

| Item(s) | Quantity | Cost (£) |
|---|---|---|
| Antenna | 1 | n/a |
| Cellular Modem | 1 | 6.99 |
| mini PCIe | 1 | 9.88 |
| SIM card | 1 | 13.00 |
| Total | 4 | 29.87 |

Table 2: A list of each item used to provide the model with internet connectivity and their price. Note that the sim card includes 10 £ of credit which is part of the running costs of the model.

With the restrictive budget, the only option for a cellular modem was a second-hand or refurbished part. After multiple options were considered, the most suited modem found was the Sierra Wireless MC7700 (2013) with LTE Cat-3, which is capable of 50 Mbps upload and 100 Mbps download speeds at 20 MHz bandwidth. The modem can only operate on Band 1, 4 and 17, of which Band 1 is the only one currently covered by most carriers in the UK (4g.co.uk). This would somewhat limit the bandwidth, but it would still be more than needed for exporting the data. The adaptor used was a simple mini PCIe adaptor, the only one available within budget and somewhat verified. Other options were HAT-style connectors for Raspberry Pi that used the GPIO pins to transmit data. These were simply unavailable in the given time frame. The UFL connector Antenna was repurposed from a different project with a length of 238mm and covering Band 1. A breakdown of spending is available in table 2.

The assembled device can be seen in figure 6a. First, it was connected to a dev setup: a Raspberry Pi Zero with a monitor and screen since the Solar Model was not available for the first few weeks of the project. The computer used in development is functionally similar enough to the one used in the project but with worse performance. To use the device the NetworkManager and ModemManager are required to be installed on the device as well as the libqmi-utils and udhcpc libraries. When installing the NetworkManager the Raspberry Pi will lose all previous internet connections and they need to be reconnected manually or to reactivate 'dhcpcd' from the 'raspi-config/network-config' menu. Once all libraries are installed the device can be connected and the network manager enabled. To check that the modem is working and the drivers are installed, run the commands "lsusb" and "lsusb -t" (Laurens Slats, 2022).



(a) Cellular Modem with adaptor and antenna (b) The development setup used

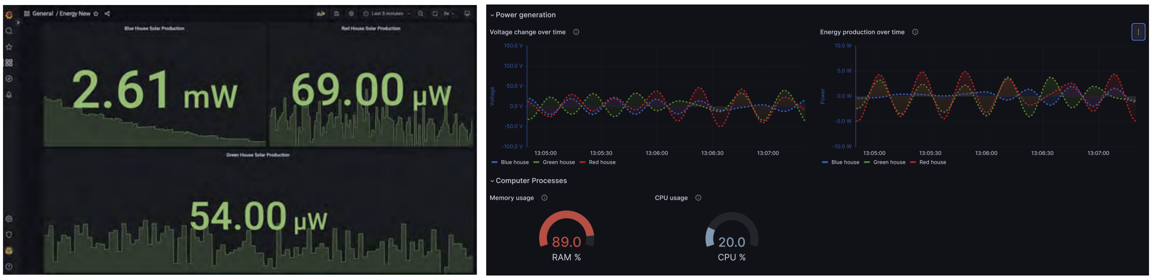
Figure 6: On the left, the module that connects the SIM card to the Raspberry Pi (the SIM card is situated underneath). On the right, the setup is used to mimic the project for development.

Finding a suitable data provider was a somewhat more involved process. Early communications with different companies were either ignored or followed by unreasonable offers. In the end, the SIM card supplier chosen was Things Mobile, an international company specializing in IoT connections. Unfortunately, the SIM card arrived a week later than expected and required further setup to activate. Things Mobile also require an online subscription to access the full functionality of this device. Since setting up a SIM card requires the actual card, no time was left to troubleshoot the issue. The SIM has between 100 - 400 Mb of data depending on whether or not the card is connected to an account. The rest of the device appears to be functional and should work once the SIM is set.

## DATA VISUALISATION

One of the goals of this project is to develop a web page accessible from a mobile phone to display a visual of battery charge and energy flow within the model. This was meant to be done as a part of the industrial project, however, only a simple version was created (Lalli, 2023). The updated web page was built in tandem with the cellular modem. The first step was creating a setup compatible with the model. This was somewhat difficult as no information was given about the Raspberry Pi, the location of the INA219 modules or other important parts in the reports (Lalli, 2023; Fitzsimons, 2023; Gibson, 2023; Arbon-Donovan, 2023). The setup used to develop the software can be seen in figure 6b, this was essential for development as the Solar Model wasn't available during most of the project period.

All the information collected by the Raspberry is saved in a database. For this specific use, a time series database is ideal, as such, the project continued to use InfluxDB which is highly efficient open source. During the first step of the development process, all data was stored using InfluxDB Cloud, a service provided by InfluxData. The advantage of this is a reduction in data usage, as Raspberry only has to send data to a server, from where the data can be accessed with the right credentials. This service is free to use with limited storage and functionality. Once the project's Raspberry Pi 3B+ was available for onboard development, a second database, hosted locally, was created. The reason for this delay is given by the minimum requirements to run a local database exceeding the




(a) The old Grafana Dashboard

(b) The updated version, with color-coded houses.

Figure 7: The new Grafana dashboard uses simulated numbers but can display all three houses independently. Note that the dashboards have gone through a few iterations and are likely to change again.

capability of a Raspberry Pi Zero (InfluxDB API).

The code used to record the numbers is based on the previously used code, with a streamlined architecture and an additional set of functions that access the InfluxDB API. The code can use both database configurations, it then automatically measures network traffic (to monitor data usage), model data, CPU and RAM usage (for troubleshooting, however, it can be dismissed) and automatically saves the data with either database. It raises no errors except for critical problems to streamline user experience. Everything else is logged locally for troubleshooting, and erased once the next session starts or it reaches a critical size (Chira, 2023). One issue that the previous team encountered was using the SSH protocol to connect and work on the Raspberry Pi remotely over eduroam provided internet. Eduroam stops all SSH connections and blocks all port forwarding (websites cannot be hosted through university-provided internet without special permission). A part of this project was solved by using Tailscale Tailscale, a free online VPN that can allow SSH connections even when not sharing the same network.

The data visualisation is done using Grafana, an open-source analytics and monitoring tool. It works seamlessly with both InfluxDB local and cloud, it's relatively fast to set up and can be run locally or on the cloud. The original Grafana page for the model can be seen in figure 7a, with the updated version in figure 7b. Each dashboard can be tailored to a specific need with a high amount of versatility and can even process data to some extent, saving bandwidth. Grafana Cloud provides a free server host and additional features, however to display the dashboard publicly it requires a paid subscription of 30 £ per month, which is beyond the budget for this project. However, the same dashboard can be easily recreated and hosted on a Raspberry Pi. The downside of the locally hosted website is yet again, the internet connection. To be able to host a website, the device providing the internet connection to Pi should be configured to allow outside traffic. This can't be trivially done when using a phone for connection and with the modem not functioning it limits the Grafana dashboard to a local host only, requiring a screen for the Raspberry Pi. Alternatively, a laptop or portable computer with a screen can be used to create a Grafana Cloud account and display the data without requiring mains power.

Currently, there are three steps in displaying the information. The first step, collecting and processing the data is done locally, using minimal processing power and no network. Then the data is saved, either on the Raspberry Pi (local InfluxDB database) or on a server (using InfluxDB Cloud). If the data is saved on the cloud then it is sent over the network, using data, but if it is saved locally then Grafana must also be hosted on the Raspberry Pi. Hosting the Grafana server locally won't use any data if it is shown directly on a screen but that would require mains power. Opening the local server up to visitors (the people attending the presentation of the model) would use much more data than a normal IoT device is intended and would probably tax the device when multiple people log in at the same time. The best option would be to use the Raspberry to send data directly to Influx Cloud, from where the data can be manipulated in multiple ways, either sent to Grafana Cloud

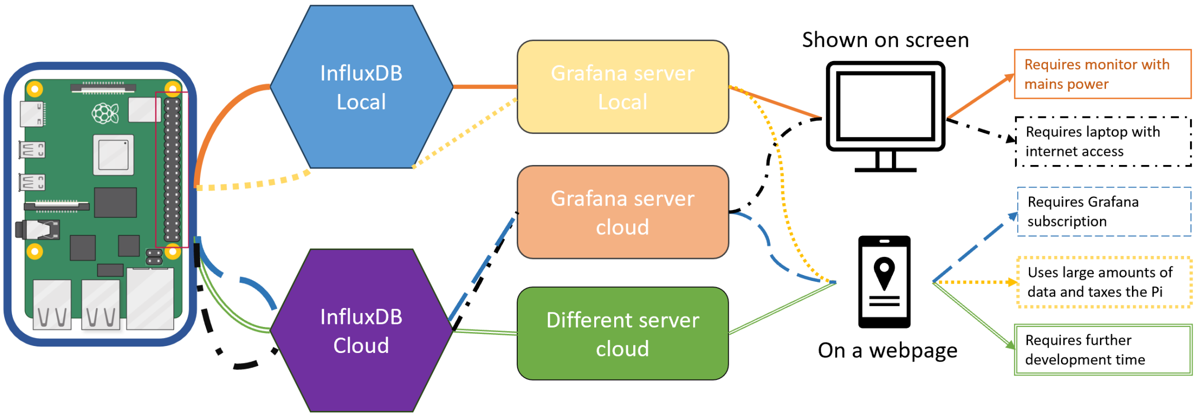



Figure 8: A chart of all possible paths to create the web page, made in PowerPoint, Raspberry image from the Rapsberry Pi Foundation et al. (2021b)
, and icons from the PowerPoint suite. Each line represents a possible path the data can take. They all start from the Raspberry Pi which collects all the data. The paths are then split into two groups: local database and cloud database. From there on the options are split into three for the server, and two more for the visualisation method. Total number of mathematical paths are 12, of which only 5 are viable/practical. The final remark states the main issue with the path taken: for example, the fully local path (red solid line) doesn't use an internet connection but it requires mains power, limiting mobility severely. The most ideal path for the project is the green double line, moving away from Grafana Cloud completely (could still use Grafana local Server on a different machine).

(expensive) or a version of Grafana hosted on a dedicated machine, or rather, any other server, as the InfluxDB API can integrate with Python or JavaScript easily. A schematic of possible project paths is available in figure 8 .

## 3.1. FURTHER WORK

While the project has achieved many of its goals, there is definitive room for improvement. One constant issue that the model had was with the wiring of all the systems. The use of breadboards in the finished project meant that very often during transportation the wires to the load circuit would come loose, as well as some internal wires. Additionally, the unlabelled, all-blue wires made it more difficult to troubleshoot any problems or make sense of the issue. This meant that during the already limited time with the model, most of that time was used fixing the wiring. As such a small set of circuits, the same as the load circuit, were soldered on a PCB to replace the breadboard circuit. A few hours spent rewiring, colour coding and strengthening the model would be extremely beneficial or even avoid a short-circuit and fire hazard.

Another issue appears when the batteries discharge. While nobody can stop batteries from losing voltage over time, there is no method to quickly and effectively charge them, requiring the use of solar panels. The addition of a mains charger that powers up the system from the mains through the same channels used by the large solar panel would solve this issue with little modifications required. However, if the batteries fall below 10 Volts, this would not work as the charge controller stops working. The solution to this isn't clear beyond investing in a dedicated charger or reworking the model. Data supply is another issue as well since voltage measurements are only taken from the small solar panels, and while the charge controllers can measure the battery voltage, they cannot be read through the Raspberry Pi.

To finish the website, an appropriate cloud host needs to be found, incurring a monthly cost for upkeep besides that of the SIM data needed. The SIM card needs to be properly installed and maintained. Another option is to run a second Raspberry Pi with internet access to host the web page while the old computer sends data from the model. If the SIM card module fails, a mobile hotspot might be a similarly priced alternative.

# CONCLUSION

A prosumer is an entity that acts both as a consumer and producer within a given system. In the realm of energy production, most people are consumers, relying on large-scale factories, and may have no input on how that energy is produced. In the cases that the energy produced relies on fossil fuels or coal, the consumer is limited in their options to fight for the environment. Adding solar panels is a step in the right direction, but, as discussed by Robinson et al. (2022) the peak of energy demand is during the early or late hours while the peak energy production is midday. As a simple consumer this results in a waste of energy, but in a prosumer network this energy can be sold back and used. In the case that the nearby Power Plant runs on fossil fuels, the produced energy can even help reduce the production of CO2e. In the case of Brampton, with only a part of the companies choosing to use solar panels and only 10% of residents, up to 156 tons of CO2e can be offset (Robinson et al., 2022).

A prosumer network is also more reliable. With the current global conflicts and the rise in energy costs that follow, it's clear that prosumer communities are better. The idea is a bit older but with the use of modern computers, this can be further optimised and improved (Schill et al., 2017). Additionally, energy production is the second largest polluting sector in the UK, only overtaken by housing (Office for National Statistics, 2023). While the goal of Net Zero seems impossible, small changes that scale up can have an overwhelming impact, and every bit is needed.

# ACKNOWLEDGEMENTS

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