ENERGEN

It's a Revolution

The team

Research, design, Power Grid, Program

BHAVANI

Team Lead, Research, design, Energy storage, Generation

POURUSH

Research, Design, Generation

MAYANK

Research, Program, writing.

VEDANT

Research, writing, Energy storage.

AGNI

**** Liana , a member of our team has been inactive since the beginning of the challenge. We reported her bud didn't get any reply.**

Problem/Background

Energy is important for the existence and development of humankind and is a key issue in international politics, the economy, military preparedness, and diplomacy. To reduce the impact of conventional energy sources on the environment, much attention should be paid to the development of new energy and renewable energy resources. The hustle doesn't end here. The electric energy system needs to be more flexible and ready to face power cuts, high demands, fluctuations due to weather, etc.

Solar energy, which is environmentally friendly, is renewable. However, its low energy density and seasonal and geographical dependence are the major challenges in identifying suitable applications using solar energy as the heat source. Consequently, exploring high-efficiency solar energy concentration technology is necessary and realistic.

Apart from this, we also noticed that there might be room for improvement in the model of the power grid. Currently, the grid is designed to supply the exact amount of energy required at each time. To make this happen, there are a lot of control systems throughout the grid that help adjust the amount supplied. With this system, the supply capacity must be large enough to meet the peak instantaneous demand over the entire year, although some supply capacity remains unused at non-peak times. Due to climate change, we can expect greater extremes of weather in years to come, which also means greater fluctuations in the demand for electric power, on top of an increase in the average demand itself (due to population growth and other factors). It, therefore, becomes even more wasteful for the power grid to not have storage, and instead be sized according to the peak demand. At last, we decided to work on Energy Storage also. Lithium-Ion batteries though good, but posses problems in terms of safety, rechargeability etc.

Hypothesis

We think that distributed energy storage in the power grid will help lower the required increase in supply capacity, as we face higher average demand as well as higher fluctuations in demand due to climate change.

The power grid system can be simplified by supplying energy from a reliable source, such as fossil fuels or nuclear power, at a constant rate throughout the year. This constant energy will be supplied at a rate below the average load, and the remaining energy will be supported from batteries. Due to the increased efficiency of Tellurium Nanoparticles, we expect the amount of energy captured from sunlight to be much more than the energy captured by regular solar panels.

When the energy supply is in excess, it can be put into storage, and when there is a deficit, energy can be used from the storage. Zinc-Carbon batteries will be able to store large amounts of energy in a small volume, making them an effective solution. This will prevent blackouts as there will always be a source of energy.

THE IDEA

Energy Generation via Tellurium Nanoparticles

This involves the reflection of sunlight using a hybrid convex lens, absorption by tellurium nanoparticles, and kinetic and mechanical energy generation using a steam turbine. The goal is to produce a higher amount of electricity that can be stored to increase flexibility.

Power Grid Optimization by Incorporating Storage

The peak supply capacity of the power grid can be brought down by building storage into the grid. This also makes the system more reliable, reducing the chances of blackouts. Using data on electricity usage in Germany, a Python program was written to calculate the required storage capacity.

Energy Storage using Zinc-ion Batteries

The storage plant with Zinc-Ion batteries is set up. With the help of electricity demand outputs from the program, energy is stored. The goal is to build a bigger, cheaper, and eco-friendly storage system that can be used with the power grid model and support the demand.

TELLURIUM NANOPARTCLES

ENERGY GENERATION

GENERATION PROCESS

01 The process starts with the installation of a hybrid convex lens, the product of a Fresnel lens and achromatic lens. It reflects the light on water pipes kept at the focus of lens.

02 The pipe will be made using Tellurium Nanoparticles, absorbing 85% of light falling on it

03 Tellurium nanoparticles transfer heat energy to water flowing in pipes. Heated water moves further and gets converted to steam.

04 The steam rotates the turbine, which converts the heat energy of the steam into kinetic and mechanical energy. The rotating turbine rotates the shaft connected to the electric generator.

05 The generator, at last, produces electric energy from kinetic and mechanical energy. Meanwhile steam gets converted to water back to flow in pipes.

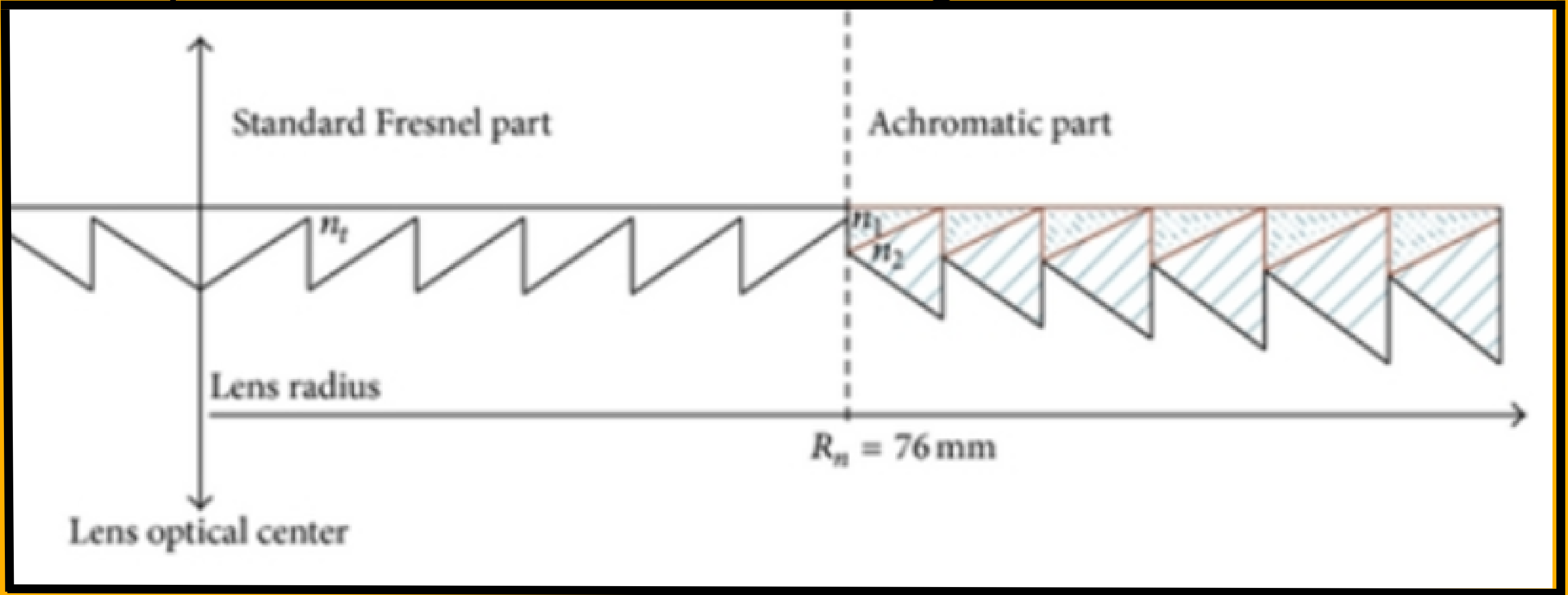
REFLECTION VIA CONVEX LENS

The convex lens is a hybrid of the Fresnel lens and an achromatic lens. It is in many ways advantageous to the regularly used parabolic trough system. The resistance of the wind load is much better in the hybrid lens because it is convex-shaped and the system looks like a cylinder. In addition, it can be set close to the land, or the upper part of it can even be set underground. The convex surface faces up towards the sky and the receiver. There is no secondary reflector, so the wind resistance is reduced. It resists the accumulation of rain and dust, which gives it good performance when it is set in a place for a long time, giving it resistance to rainstorms and snowstorms. Therefore, it remains efficient for long periods of time. This reduces the fluctuation in reflection, leading to more flexible and reliable electricity generation.

The required tracking precision is kept around 1.5 degrees. It is seven times smaller than a parabolic trough. Thus, the tracking mechanism can use a stepping motor to take the place of the hydraulic mechanism, which is much cheaper. Meanwhile, electricity consumption is decreased. Moreover, the driving torque will be much smaller when the system rolls along with its centre of gravity. The material of a lens is made of organic transparent plastic, which is easily shaped and even produced by an assembly line. The costs of manufacture, assembly and maintenance are greatly decreased.

Hybrid Fresnel Convex Lens

The hybrid Fresnel convex lens design is obtained by combining a central part based on a standard Fresnel profile together with an achromatic design for the outer area up to a radius limit of 101 mm. This innovative design involves a standard part representing 56.7% of the whole surface and an achromatic one that represents 43.3% of the total aperture. This type of lens combines the advantages of a standard Fresnel lens with the most useful features of the achromatic lens. Throughout this procedure, several solutions have been compared in terms of efficiency, flux distribution, concentration factor, and dependence on wavelength or incidence angle. Thus, it has achieved a new lens design with high numerical aperture, capable of a higher degree of efficiency than the standard Fresnel lens, and increased stability against the angle of incidence and spectral components of incident flux. This improved design can be very effective in maximizing the capture area of the focusing lens without sacrificing the efficiency. Therefore, it ensures that a higher level of concentration is maintained for a longer interval of time, as the response of the lens is also more stable against changes in the incidence of the beam. Specifically, through this novel hybrid lens design, a concentration level of 18% higher than the standard Fresnel lens has been obtained.



Light Energy Absorption

A broadband absorber (pipes) made of tellurium nanoparticles with a wide size distribution can absorb more than 85% solar radiation in the entire spectrum. The radiation from sunlight can increase the temperature of water from 29 °C to 85 °C within 100 seconds. By dispersing tellurium nanoparticles into the water, the water evaporation rate is improved by three times under solar radiation of 78.9 MW/cm2. The unique permittivity of tellurium nanoparticles results in this high performance. This photothermal conversion surpasses that of plasmonic or all-dielectric nanoparticles reported before. Perfect absorption (more than 85%) can be achieved in the entire spectrum of solar radiation (300 to 2000 nm). Especially in the ultraviolet (UV) region (300 to 400 nm), the absorptivity reaches a value of more than 95%. The total absorption covers the entire spectrum of solar radiation due to the enhancement by plasmonic-like and Mie-type resonances. It is the first reported material that simultaneously has plasmonic-like and all-dielectric properties in the solar radiation region. Also, these particles are cost-efficient, eco-friendly, risk-freeThe real part of permittivity experiences a transition from negative to positive in the ultraviolet-visible–near-infrared region, which endows tellurium nanoparticles with the plasmonic-like and all-dielectric duality. The total absorption covers the entire spectrum of solar radiation due to the enhancement by both plasmonic-like and Mie-type resonances. It is the first reported material that simultaneously has plasmonic-like and all-dielectric properties in the solar radiation region. These findings suggest that the tellurium nanoparticles are a highly promising photothermal conversion material for solar-enabled water evaporation.

The Results

01 The concept is eco-friendly and is completely recyclable. Even one unit is sufficient for a household of four. It can reduce the carbon footprint of a household by almost 80 percent a year.

02 It utilizes almost all the energy that it receives from the sun with the use of plates made primarily of tellurium nanoparticles enhanced by a configuration of the light maneuvering lenses. It can provide a great power output even when planted individually. Therefore, it does not necessarily require huge land plots to be planted.

03 The entire system is 90% efficient which is relatively 68 % more efficient than the 22% efficient parabolic solar panel system. This results in higher electricity generation. We can store extra energy to compensate during power cut-offs. The storage system will mainly result in making the electricity usage flexible.

POWER GRID OPTIMIZATION

THE PYTHON PROGRAM

POWER GRID SYSTEM

Current Grid System	New Grid System
Designed to supply the exact amount of energy required at each time, which requires complicated control systems.	Energy will be supplied from a reliable source at a constant rate (average load) for a fixed interval of time, reducing the need for complicated control systems.
Supply capacity must be large enough to meet the peak instantaneous demand over the entire year, although some of the supply capacity remains unused at non-peak times.	Distributed energy storage in the power grid will help lower the required increase in supply capacity as excess energy can be put into storage, and when there is a deficit, energy can be used from the storage.
With greater extremes of weather, there will be greater fluctuations in the demand, on top of an increase in the average demand itself, so it becomes even more wasteful for the power grid to not have storage.	Zinc-Carbon batteries will be able to store large amounts of energy in a small volume, making them an effective solution. This will prevent blackouts as there will always be a source of energy.

The Python Program

To calculate the amount of storage that would be required for our power grid system, and to better understand the load data through graphs, we wrote a Python program, which is available on GitHub: **https://github.com/bhavaniv1101/power_grid/blob/master/main.py**

The program calculates the required storage capacity when averaging the load over different time periods. It does this by starting with an initial storage capacity of 0.1 GWh. It is assumed that the supply is constant at the average over a specific time period (e.g. When averaging over 24 hours, it is assumed that the supply for each day is at the average demand of that day). At each 15-minute interval, the excess (difference between the demand and average) is added to the storage. If the supply is more than the demand, the excess is positive, and if the supply is less than the demand, the excess is negative. When the storage has reached the maximum capacity, the supply is ramped down to exactly match the demand. If, at any point, the amount of energy in storage is less than the deficit, it means that the storage capacity is not large enough, so it is increased by a factor of 1.1. This process is repeated until it reaches a storage capacity which is large enough to supply the required energy whenever there is a deficit. Since the storage is increased by a factor of 1.1, the final storage capacity is within 10% of the exact value.

Program Functions

We wrote 6 functions to process the data. Here is a brief description of each.

01

country_demand - Takes a country code and returns a numpy array of the demand every 15 minutes for that country. It also prints the average, minimum, and maximum demand, as well as the time of the first and last 15-minute interval and the number of 15-minute intervals.

02

country_supply_clean - Takes a country code and returns a numpy array of the energy supplied from solar and wind every 15 minutes for that country. It also prints the average, minimum, and maximum supply from these sources, as well as the time of the first and last 15-minute interval and the number of 15-minute intervals.

03

average_demand_over_interval - Takes a numpy array of the demand over successive 15-minute intervals, and the number of 15 minute intervals over which the demand is to be averaged. It returns a numpy array of the average over blocks of the specified number of 15-minute intervals.

04

required_storage - Takes a numpy array of the demand and a numpy array of the supply over successive 15-minute intervals. It calculates and returns the required storage (within 10% of the exact amount required) using the method described earlier.

plot_country_demand - Takes a country code, the number of hours over which to average (can take multiple values and plot them on the same graph), the day from which to start plotting, and the number of days for which the average should be plotted. It then plots a graph with the specified averages and the load without averaging. It also plots the energy supplied by the clean sources (wind and solar) on a separate axis.

05

06

plot_country_clean_supply - Takes the same parameters as the previous function and plots the clean energy supplied in the country, averaged over various time intervals.

The program also has a function to take arguments from the command line

Main Function

The main function brings all the functions together into a simple function to plot graphs and calculate the storage capacity. It also displays some statistics of the data to help us analyze it.

1. It creates a numpy array for the demand using the country_demand function and displays the peak supply capacity without averaging by finding the maximum value in the array.

2. It finds the average demand over each time interval and prints the required peak capacity and storage for each time period.

3. It also finds the storage required when there is a base supply of 30 GW from fossil fuels and the rest is supplied by solar and wind, and the storage required when the energy from clean sources is ten times the current amount.

4. It calls the functions to plot graphs for the average demand over various time intervals, as well as graphs for the average supply from solar and wind sources over various time intervals.

CODE: https://tinyurl.com/ypksdjpy

Output: Graph Interpretation

We plotted graphs for the load and clean energy supply (wind and solar), and their averages over various time periods. This showed us some patterns in energy consumption and helped us better understand the data.

GRAPH 1

We plotted a graph of the daily and weekly average load over a year, along with the average load over the entire year. The first thing we noticed was seasonal variation ; the load is highest at the beginning and end of the year (during winter), and it is lower in the middle of the year. We also noticed that the daily average is much lower on weekends compared to weekdays, and realized that this must be because a majority of the energy is consumed by industries and offices, which do not operate on weekends.

GRAPH 2

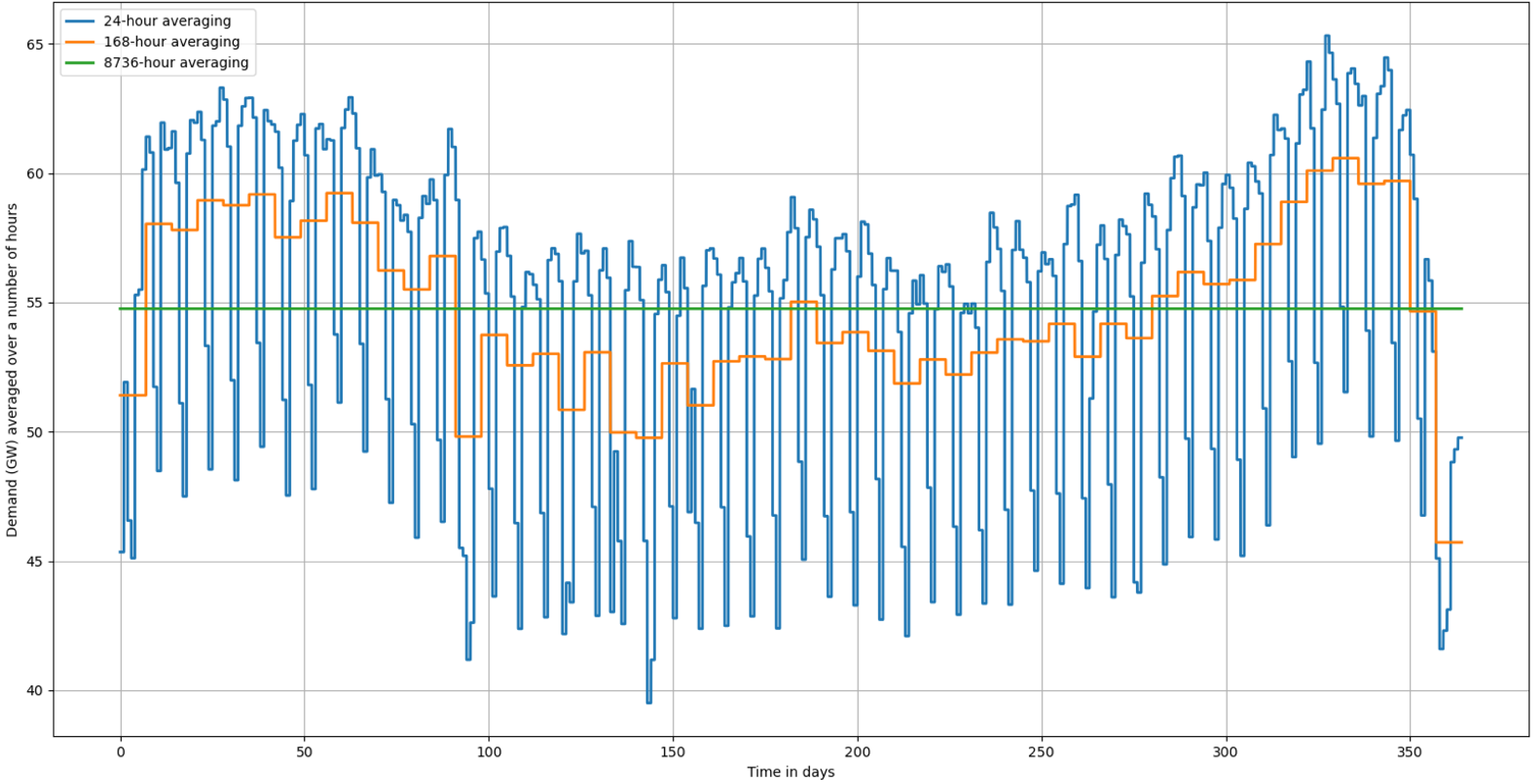
The second graph displays the load without averaging, the hourly average, daily average, and weekly average over a period of 4 weeks. This graph shows us that the hourly average traces the exact load, so there is very little variation within an hour. It also makes the difference in load on weekdays and weekends more prominent.

GRAPH 3

This graph displays the energy supplied by solar and wind without averaging, the hourly average, daily average, and weekly average over a year. It show us that there is a lot of variability in the amount of energy produced, making it an unreliable source. It is clear that there are a lot of periods when the supply is low, or nil, making the storage requirement even higher.

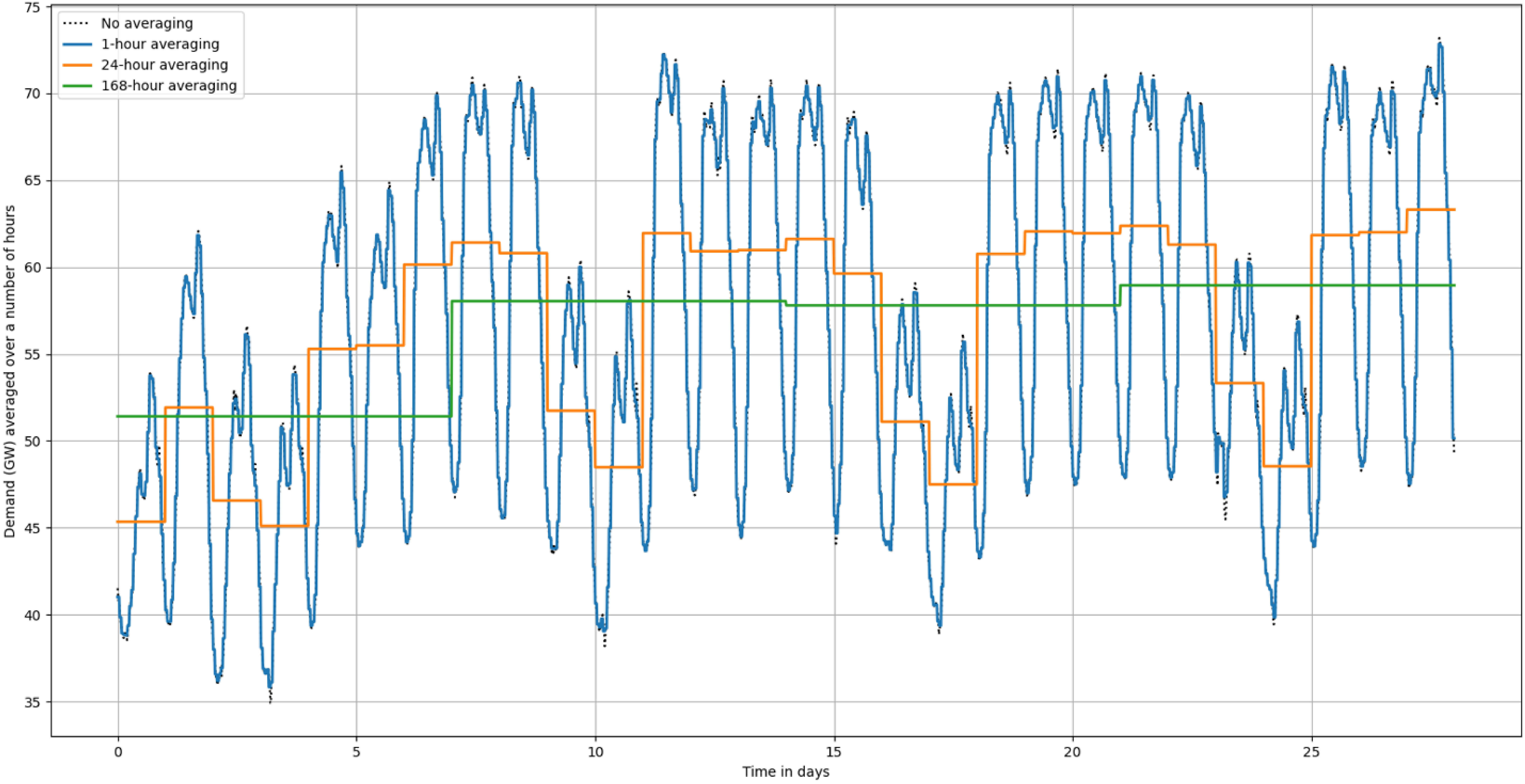
3 Graphs →

GRAPH 1

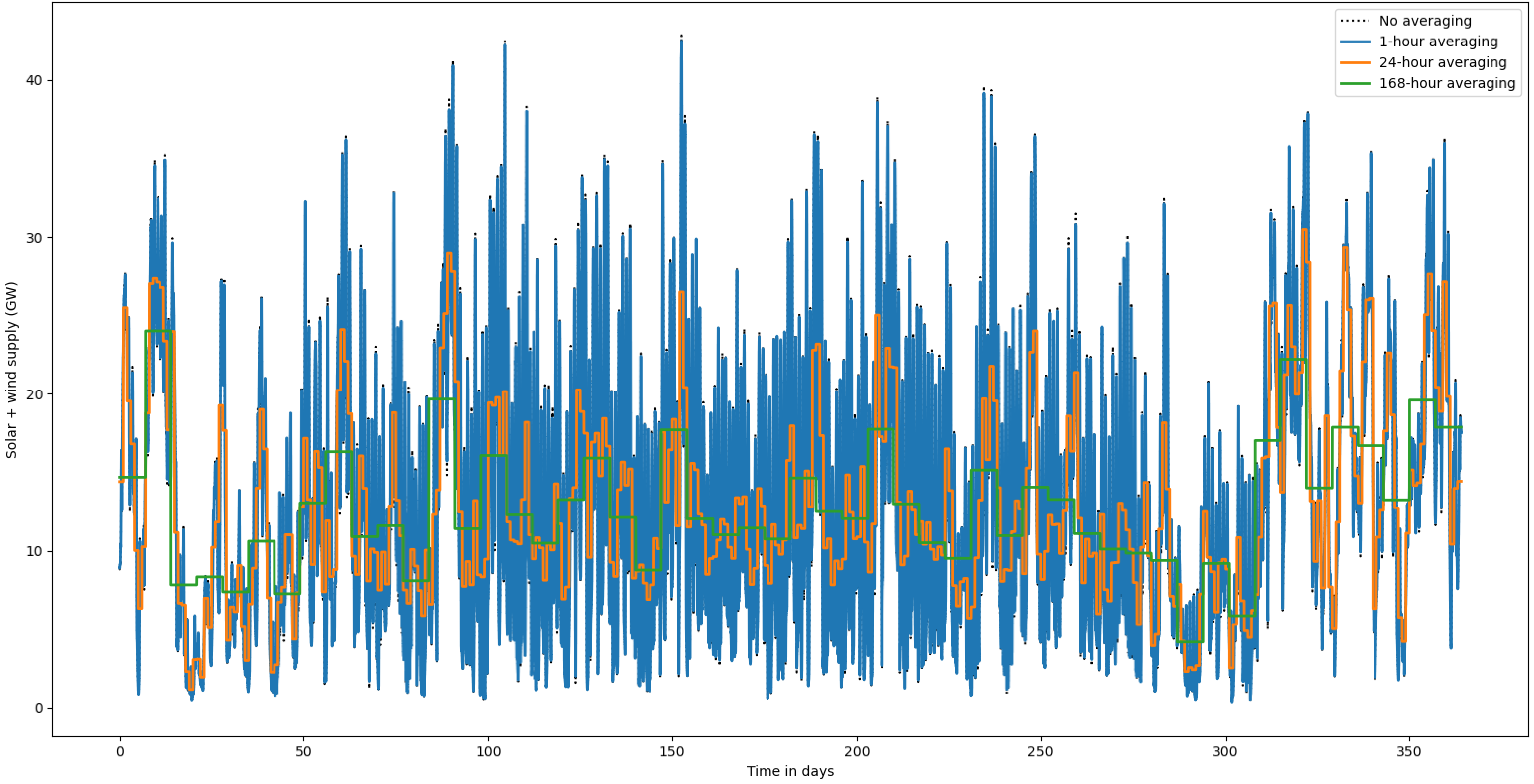


24-hour averaging
168-hour averaging
8736-hour averaging
65
60
55
50
45
40
Demand (GW) averaged over a number of hours
0
50
100
150
200
250
300
350
Time in days

GRAPH 2


No averaging
1-hour averaging
24-hour averaging
168-hour averaging
Demand (GW) averaged over a number of hours
Time in days
75
70
65
60
55
50
45
40
35
0
5
10
15
20
25

GRAPH 3



No averaging
1-hour averaging
24-hour averaging
168-hour averaging
Solar + wind supply (GW)
Time in days
0
10
20
30
40
0
50
100
150
200
250
300
350

Program Results

We obtained the following results for storage requirement in Germany

Average demand = 54.8 GW
Maximum demand = 76.0 GW
Minimum demand = 30.2 GW
Required peak supply capacity without averaging = 76.0 GW

With averaging over 1 hour:
Required peak supply capacity = 75.8 GW
5.0 GWh storage is not enough
5.5 GWh storage is enough!

With averaging over an hour, the peak supply capacity reduces by only a marginal amount, but the storage capacity is quite large. As the interval for averaging gets longer, the storage capacity keeps getting larger.

With averaging over 24 hours:

Required peak supply capacity = 65.3 GW

127.2 GWh storage not enough

139.9 GWh storage is enough!

With averaging over a day, the peak supply capacity is around 86% of the capacity required when there is no averaging. However, the required storage capacity is extremely high.

These results show us that significant advancements in storage would be required to make the incorporation of storage into the grid feasible and viable. The storage methods we have today are expensive and not efficient enough to use at such a large scale. This led us to think about ways to make storage cheaper and more efficient so that it can be used in the grid to make solar energy more reliable, and reduce our dependence on fossil fuels. After some research, we decided to use Zinc-ion batteries.

ZINC-ION BATTERIES

ENERGY STORAGE

The storage plant

Energen's Energy storage plant is a large scale operation using BATTERY ENERGY STORAGE SYSTEM(BESS). For BESS, ZINC-ION BATTERIES will be used. The main work of the plant is to store the extra energy generated and use it to meet the electricity demands at times when generation goes off. It will also be required when the demands exceeds the generation to meet the flexibiltity. Zinc-Ion batteries store electricity through electro-chemical processes—converting electricity into chemical energy and back to electricity when needed. The plant will be managed by a computerized control system. This will help in proper usage of energy coordinating with python program written to manage the power grid model. An individual unit discharges energy within 1 hour of demand.

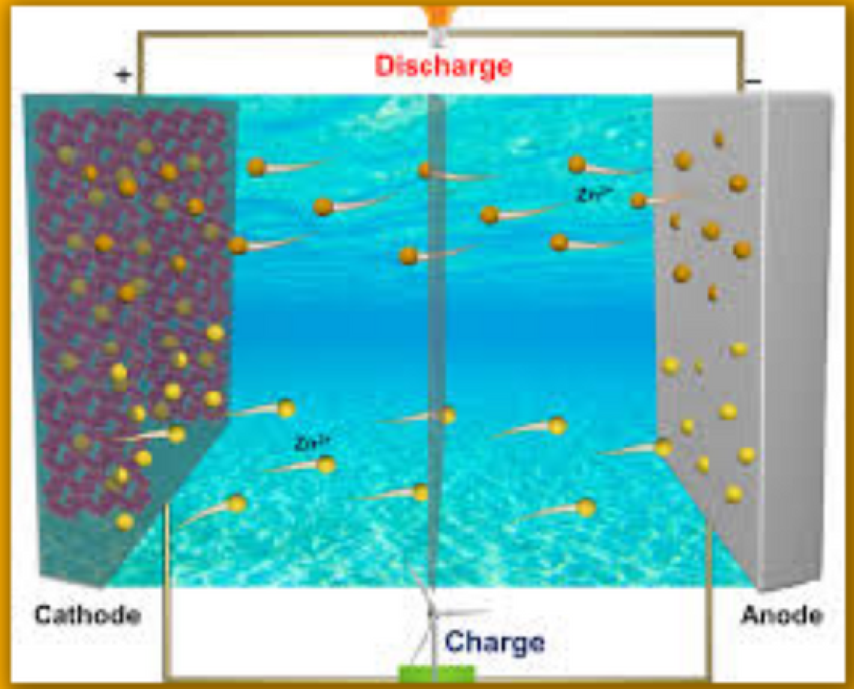
Construction

A 1 GW storage plant will be set up. Each energy storage unit will contain several components: one or more battery modules, onboard sensors, control components, and an inverter. It will be an Ac coupled unit, therefore inverter will be integrated in the system. Integrated inverters makes the installation process easy and offers more flexibility in usage than DC coupled unit. Various accumulator systems will be used depending on the power-to-energy ratio, the calculated lifetime and the costs

Why Zinc-Ion ?

Zinc Ion Batteries are effective in storing large amounts of energy in a small volume, making them an effective solution for our energy storage method. Although Lithium Ion batteries are a good solution for storage of renewable energy, there is a lack of raw materials available to keep up with the rising demand. Zinc Ion Batteries are effective in storing large amounts of energy especially for portable electronic technology. We will use aqueous electrolytes, which give them an advantage over multivalent ion batteries (e.g., Mg2+, Ca2+, Al3+) that require more complex electrolytes." Zinc batteries also remove the safety issues associated with Lithium Ion Batteries. Its water based chemical makeup makes this a safer and cheaper alternative. They are also more environmentally friendly, making them a key potential use case in our experiment. Moreover, Zinc Ion Batteries are more scalable than other types of energy storage methods, making it useful in the feasibility of our design.

Storage Plant



Zinc-Ion battery

Zinc-Ion vs Lithium-Ion

Zinc-ion's key differentiators from lithium-ion are safety and supply chain security. Zinc-ion's intrinsic safety, due to its use of water as the electrolyte, means it will be able to gain traction in markets where lithium-ion adoption has been limited due to safety concerns.

Similar to lithium-ion Zinc-ion battery functions using intercalation. Zinc ions react at both electrodes and travel between them through a water-based electrolyte. During discharge, zinc metal at the anode is dissolved into the electrolyte as zinc ions. At the same time, zinc ions are absorbed into the cathode from the electrolyte. This process is reversed during the charge. The use of intercalation means that the electrolyte's only function is as a conduit for ions, enabling a small amount to be used. The active materials used in zinc-ion batteries are very energy-dense, allowing for sufficiently high energy to be stored even in thin electrodes. In fact, zinc-ion batteries can improve on lithium-ion manufacturing processes. Lithium's violent reactivity with water requires many of its production steps to take place in a highly controlled atmosphere which makes the process more costly, and more complicated. As a water-based battery, zinc-ion does not have this constraint.

Zinc-ion batteries do not require formation cycling at the end of life. This means they can more quickly move from the manufacturing line to the customers. This ability to use lithium-ion manufacturing means that the production of zinc-ion batteries can be rapidly and inexpensively scaled-up.

Thank You !!

We would like to express our immense gratitude to the New York Academy of Sciences for the Junior Academy Initiative. Throughout the challenge period, we have learned about a lot of new and interesting topics. The Junior Academy has given us a platform to be able to interact with some of the smartest young minds and apply our knowledge to solve real world problems.

We would also like to thank our mentor, **Abdul Moeez** for his support and contribution to the success of our project. The mentor's important insights and effort made the process very smooth and enjoyable for me. We are grateful to have got such an excellent opportunity to make the world a better place due to the efforts of the Junior Academy and the mentor and the entire team.

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