ENVIRONMENTAL SYSTEMS AND SOCITIES (ESS) EXTENDED ESSAY

Optimizing the Size of a Household Battery Storage System and Rooftop PV Solar System to Minimize Carbon Emissions and Total Electricity-Related Costs

May 2025

Word Count: 4090

Research Question: How to optimize size of a household battery storage system and rooftop PV solar system to minimize carbon emmision and total electricity-related costs?

Introduction

The need for environmental friendly methods to reduce carbon emissions and minimize electricity costs becomes increasingly urgent as the world's energy consumption keeps rising. A promising method to address these issues is household battery storage systems, that increase the reliability and effectiveness of using renewable energy. Households can save electricity costs and their carbon impact by carefully reducing the size of these systems and creating efficient charging and discharging habits. This Extended Essay investigates the balance between economic efficiency and environmental advantages in household energy systems by examining how to achieve such optimization using simulations.

Background Information

Household Battery Storage System

One technological advancement that enables people to store electrical energy for later use is the household battery storage system. It generally consists of lithium-ion rechargeable batteries that are charged with electricity generated from solar panels or other renewable energy sources, or from the electrical grid when energy costs are lower (National Grid). When electricity costs are higher, there is a strong demand for electricity, and there are power outages, the stored energy can be used. Through efficient energy storage and consumption management, these systems optimize the use of renewable energy sources and minimize dependency on fossil fuel-based grid power with lowering carbon emissions, increasing energy independence, and lowering electricity bills.

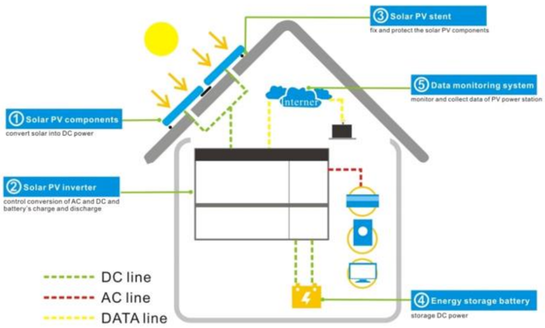


Figure1. The example model of houshold battery storage system (National Grid).

Functions

Battery storage sytsems have developed as critical components of modern energy facilities. They have the ability to store energy that is produced during periods of high renewable output and it is released it when consumptions exceeds supply (MFS South Australia). These sytsems improve the stability of the renewable energy and they also reduce reliance on fossil fuel based power generation. Initially, they make it possible to store extra energy produced by renewable resources, such solar panels, when output is at its peak (U.S. Department of Energy). In order to ensure a steady and continuous energy supply, this stored energy may be utilized later when renewable generation is low, such as at night or on cloudy days. By allowing homeowners to store energy from the grid during periods of lower power prices and use it during periods of higher electricity rates, these systems also contribute to reduced electricity costs (Environmental Energies)

Types

There are multiple types of household battery storage systems, each with special qualities that are appropriate for a range of needs and applications. The most widely used are lithium-ion batteries, which are utilized for home use due to their high energy density, efficiency, and longevity. However, they are more expensive than other batteries, such as lead-acid batteries, which are less efficient and have a shorter lifespan but are cheaper (National Grid).

A battery storage system capacity, in kilowatt-hours (kWh), determines the amount of energy stored and used. While more expensive to install initially, large batteries could end up saving money in the long term by maximizing solar usage and reducing grid usage.For homes with high energy needs or large solar installations, bigger systems are needed, and small systems can cater to the less demanding needs. Here, balancing is the key; an oversized battery is wasteful, while an under-sized one will not yield the best savings.Optimization of the size of the right battery is needed for cost, energy efficiency, and carbon saving. A well-sized system sizing maximizes renewable energy use, lowers electricity bills, and saves on carbon-dioxide-based power (Environmental Energies).

Carbon Dioxide Emmision

Non-renewable resources such as coal, oil, and gas require hundreds of millions of years to create. When fossil fuels are used to create energy, they release dangerous greenhouse gases like carbon dioxide into the atmosphere (U.S. Environmental Protection Agency).

The main greenhouse gas released by human activity is carbon dioxide (CO_2), which is mostly produced when fossil fuels like coal, natural gas, and oils are burned. A significant contributor to the continuous increase in carbon dioxide levels is the widespread use of these fossil fuels to produce electricity, which is an essential energy source for households, businesses, and industries. The quantity of CO_2 produced by each type of fossil fuel used to generate electricity varies, which raises the atmospheric carbon levels even more.(Greenly Earth).

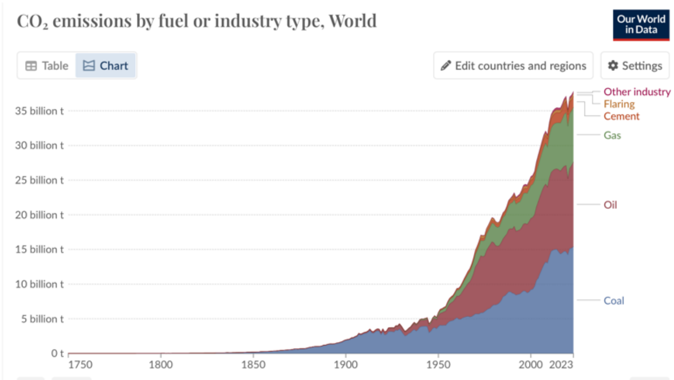


Figure2. The table of the global carbon emmissions (Our World in Data).

The global carbon emissions graph indicates an increasing trend, with a significant rise beginning in the middle of the 20th century as a result of growing fossil fuel usage and industrialization.

Global Warming

Life on Earth is maintained by the ongoing carbon cycle in the air, sea, and land. Breathing organisms release carbon dioxide (CO_2), which is reabsorbed by natural processes like photosynthesis and ocean absorption. However, this equilibrium is disrupted when excess greenhouse gases are produced by human activities like burning fossil fuels (United Nations).

Global warming is caused by the greenhouse effect, primarily by CO_2, but also by other gases that retain heat in the atmosphere, increasing global temperatures and altering climate patterns.Rising global temperatures affect climate patterns generally by causing extreme weather, sea level rise, and ice cap melting (U.S. Environmental Protection Agency).

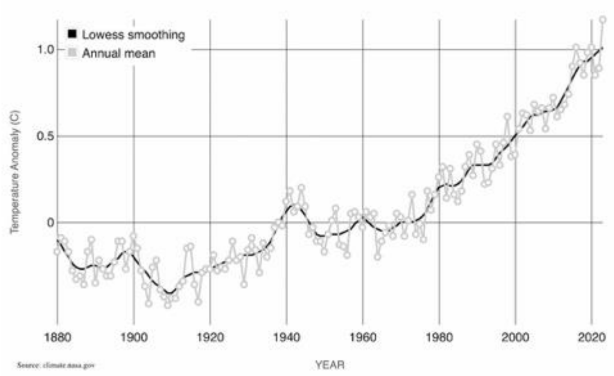


Figure3. Average worldwide temperatures (NASA Climate).

Average worldwide temperatures have been clearly rising since the middle of the 20th century, according to the global warming graph. Global temperatures have been rising at an accelerated rate since the late 1800s, with the last few decades seeing very steep increases. This illustrates how human activity, particularly the combustion of fossil fuels, has continued to have an impact on the climate, increasing the amount of greenhouse gases.

Renewable Energy and Battery Storage Systems for Carbon Emission Reduction

There are various types of renewable energy. Renewable energy decreases the effects of global warming since it reduces CO_2 production by replacing fossil fuels with cleaner energy sources (United Nations). The most commonly used renewable energy is solar power, which converts sunlight into electricity using photovoltaic panels or solar thermal systems. Other renewable sources include wind energy, which captures the kinetic energy of moving air, and geothermal energy, which harnesses heat from beneath the Earth’s surface. Hydropower, ocean energy, and bioenergy also contribute to sustainable energy production (U.S. Department of Energy).

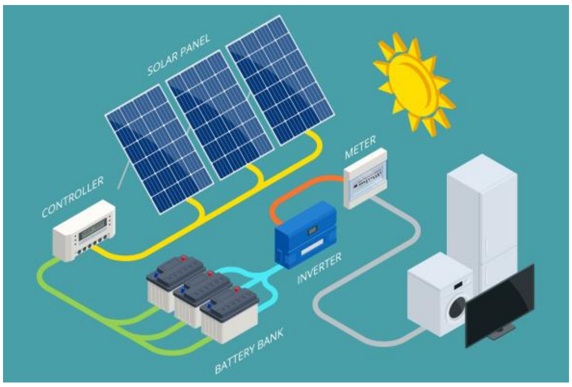


Figure4. The example modelling of the household battery storage system (Sunlight Solar).

Battery storage systems are significant for accelerating the transition from fossil fuels to renewable energyBy reducing reliance on grid electricity, which is often generated from fossil fuels, battery storage systems contribute to lower electricity costs and reduced carbon emissions (Environmental Energies).

The process starts when photovoltaic cells in solar panels convert sunlight into electrical energy, generating DC electricity, which is then transformed into AC electricity via an inverter for home use. Surplus energy flows into the battery storage system, where it is stored as chemical energy. System algorithms and computerized control systemsmanage energy production, determining when to store or release energy based on demand and pricing. Charge controllers regulate stored energy to prevent overcharging and ensure efficiency (Energy Education). By efficiently storing solar energy, these systems reduce reliance on grid electricity, which is often generated from natural gas and other fossil fuels. This lowers CO_2 emissions, mitigates climate change, and supports a sustainable energy transition. Reducing reliance on natural gas slows climate change and promotes cleaner energy consumption(National Grid).

Hypothesis

The amount of electricity that can be stored and used during periods without sunlight rises with the size of the battery storage system. However, larger systems require more powerful batteries and infrastructure, leading to higher initial costs. Smaller systems may not store enough energy for extended periods without sunlight. Therefore, a medium-sized battery storage system offers the best balance, storing enough energy for household needs while maintaining a more affordable cost, satisfying energy storage requirements without the high expenses of larger systems.

Variables

Variable Type	Variable	Description
Independent Variable	Size of the battery storage(kWh)	The household battery storage system size under test in the simulation. Different sizes will be tested to determine their effect on carbon emissions and electricity cost.
Dependent Variable	Carbon emissions (kg CO_2)	The level of CO_2 emissions reduced due to optimized battery storage and reduced consumption of grid electricity from fossil fuels.
Dependent Variable	Total Cost ($)	The reduction in total electricity-related costs, both domestic electricity bills and system investment, with regard to battery storage capacity and optimized charging/discharging cycles.
Controlled Variable	Solar panel capacity (kW)	The power output of the solar panel system must be fixed to enable fair comparisons for different battery sizes.
Controlled Variable	Household energy consumption (kWh/day)	The total energy requirement of the house must remain fixed as part of the simulation to examine the effect of battery storage on grid dependency.
Controlled Variable	Charging and discharging efficiency (%)	Battery efficiency affects the volume of stored and used energy; keeping this fixed ensures fair comparisons.
Controlled Variable	Weather conditions	Solar energy production is dependent on the sun, and thus a uniformamount of solar radiation in the simulation ensures uniformity.

Explanation of Smart Home Optimiziation Simulation

For this research, I used the Smart Home Optimization simulation, a computer program that may be utilized to analyze household electricity consumption, solar power generation, battery storage, and cost savings. This software was obtained from an electrical engineering business called EPRA Energy.

The simulation enables users to choose the best energy management approach by entering various solar panel capacities, battery storage capacities, and domestic electrical usage.The simulation works by employing key input parameters, including:

- **Solar Panel Capacity (kW):** Determines the quantity of electricity produced from solar energy.
- **Battery Storage Capacity (kWh):** Controls the quantity of excess solar energy that can be stored and used when needed.
- **Electricity Price (c/kWh):** Hourly fluctuating rate that affects energy cost calculation.
- **Household Load (kW):** Represents the energy demand of the houseat different hours of a day.

After variables are set, the simulation determines the best energy use plan to reduce carbon emissions and save on energy costs. It providesgraphical representations of changes in the cost of electricity, solar generation of electricity and use of storage batteries.

Results are as follows:

1- Total electricity bill ($/day): the daily cost based on optimized energy use.
2- Carbon emissions (kg CO_2/day): effect of electricity consumption on the environment.
3- Battery and PV costs ($): effect of electricity consumption on the environment.

I was able to identify the most economical and ecologically beneficial configuration by repeatedly varying the solar panel and storage battery size systematically. Then simulation outcomes were analyzed to decide the effect of each parameter on carbon emissions and the cost of electricity.

Data Analysis

First Simulation: Without Solar Panel and Storage System

The first simulation represents a household without a battery storage system or solar panel, relying entirely on grid electricity. The data provided includes hourly electricity prices, fixed household load, daily electricity costs, and carbon emissions.

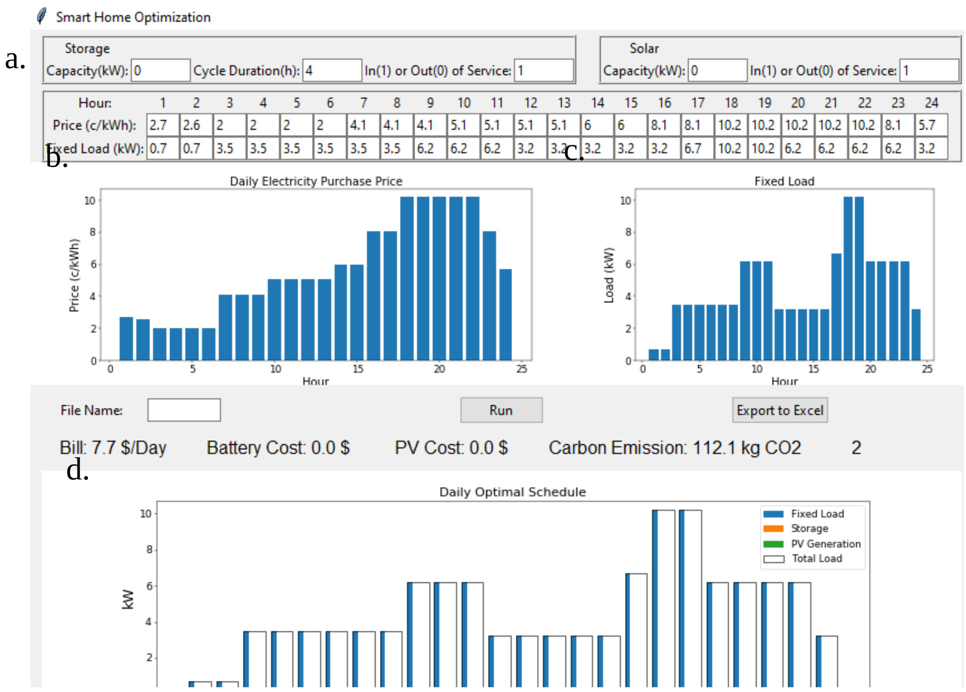


Figure5. The screenshot of the mainpage of the simulation. (a) Shows the input parameters panel, (b) shows the daily electricity price variations, (c) shows the household's electricity consumption pattern, (d) shows the optimized energy usage throughout the day.

Labelling and Explanation of the Simulation:

I will define key elements of the Smart Home Optimization simulation so that the reader has an understanding of how the simulation operates. Following is an explanation of the key elements in the simulation and what is their significance.

1. **Input Parameters**

Storage Capacity (kWh): This determines the quantity of energy that can be stored in the battery for later use. The larger the capacity,the greater amount of energy can be stored but at a higher price.

Cycle Duration (h): This refers to the charging and discharging cycle of the battery in hours.

Solar Capacity (kW): This refers to the installed capacity of solar panels, which determines the level of solar energy generated.

In(1) or Out(0) of Service: Specifies whether the solar system or battery storage is engaged in the simulation.

2. **Table of Hourly Data**

Hour (1–24): Refers to the day hours, which are divided into 24 hours.

Price (c/kWh): Indicating the cost of electricity per kilowatt-hour during different times. The cost depends on peak hours and off-peak hours.

Fixed Load (kW): Represents the household's electricity consumption at different hours.

3. **Graphical Representations**

Daily Electricity Purchase Price (b): Shows hourly variations in electricity prices and helps in deciding peak hours when electricity is most expensive.

Fixed Load (c): Represents hourly energy demand of the home and distinguishes when maximum and minimum usage occurs.

Daily Optimal Schedule (d):

• **Blue Bars (Fixed Load):** Total energy demand of the house at each hour.

• **Green Bars (PV Generation):** Amount of electricity produced by solar panels.

• **Orange Bars (Storage Usage):** Stored and used energy from the battery.

• **White Outline (Total Load):** Total energy use, including the grid power, solar energy, and stored energy in the batteries.

<u>Simulation Analysis</u>

First Simulation: No Solar Panel, No Battery Storage

1.Total Cost and Consumption Trend of the Simulation One:

The simulation output in Figure 5 shows that the price of electricity fluctuates throughout the day. Figure 5(b) indicates that prices are lowest during off-peak hours 1:00 AM - 6:00 AM, while the highest prices occur during peak hours 3:00 PM - 9:00 PM. This suggests that grid demand increases in the evening when households are most active.

The fixed load data in Figure 5(c) shows that household electricity consumption is low at midnight and early morning but rises throughout the day. A steep peak between 6:00 PM and

9:00 PM is observed, likely due to cooking, lighting, and nighttime appliance usage. This peak coincides with the highest electricity prices, as seen in Figure 5(b), leading to increased overall costs. The daily optimal schedule in Figure 5(d) helps visualize how energy is distributed throughout the day to manage these costs effectively.

2.Financial and Environmental Impact:

Since the household does not have a battery or solar panel, it must purchase all its electricity directly from the grid, regardless of price fluctuations, as shown in Figure 5(a). As a result, the cost of electricity each day is $7.7, as indicated in Figure 5(d), which is quite high since the majority of the power is consumed during peak usage. The carbon emission is 112.1 kg CO_2, as seen in Figure 5(a), indicating that the electricity source is heavily dependent on fossil fuels. This baseline scenario shows the inefficiency and cost of relying solely on grid electricity. Without energy storage, the house is unable to shift electricity consumption to cheaper times, as seen in Figure 5(d). Additionally, without renewable energy, there is no reduction in carbon emissions.

Second Simulation: Solar Panel Added, No Battery Storage

In this simulation, a 5 kW solar panel system was installed with battery storage still at 0 kWh. This configuration aims to investigate how introducing solar energy alone will impact electricity costs and carbon emissions without energy storage. By comparing the result against the first simulation, the effectiveness of solar production in reducing dependence on grid electricity is evaluated.

1.Selection of Solar Capacity:

Before selecting 5 kW as the controlled variable, multiple simulations were conducted by increasing the panel capacity from 1 kW to 6 kW and analyzing the economic and environmental impact at each step. The results showed the following trends: as the solar panel capacity increased from 1 kW to 5 kW, there was a steady decrease in electricity bills and total cost due to reduced reliance on the grid. However, for 6 kW and more, the total cost started increasing because surplus energy was being generated that was not being used efficiently.

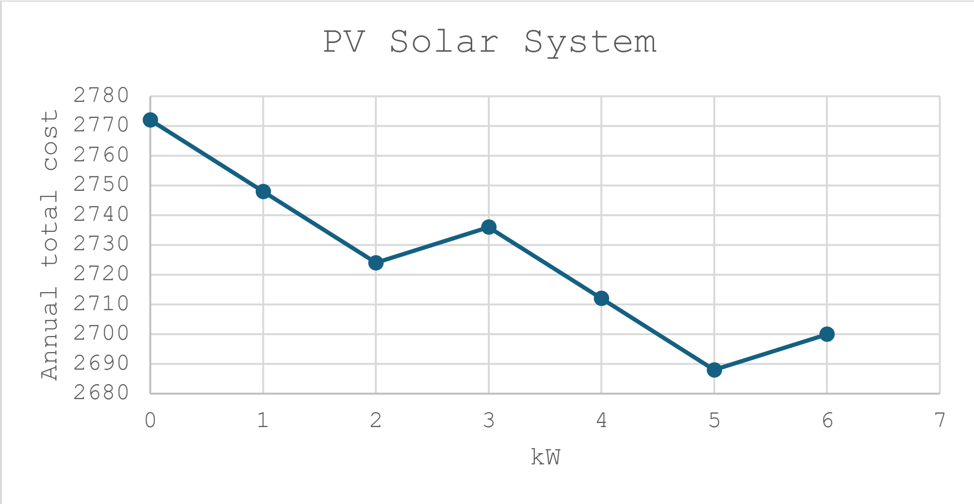


Table1. Effect of different solar panel capacities on total cost, based on simulation results.

The graph shows the impact of increasing capacity of solar panels from 1 kW to 6 kW on total cost and electricity bill. The total cost decreases when capacity is increased as there will be reduced dependence upon the grid. But, after 5 kW, cost is rising because panels are oversized and excess energy cannot be effectively used so this increase overall expenses. Based on these observations, 5 kW was selected as the optimal solar panel capacity, as it provided the greatest cost reduction without leading to unnecessary expenses from excess solar generation. This ensured an efficient balance between electricity savings and system investment.

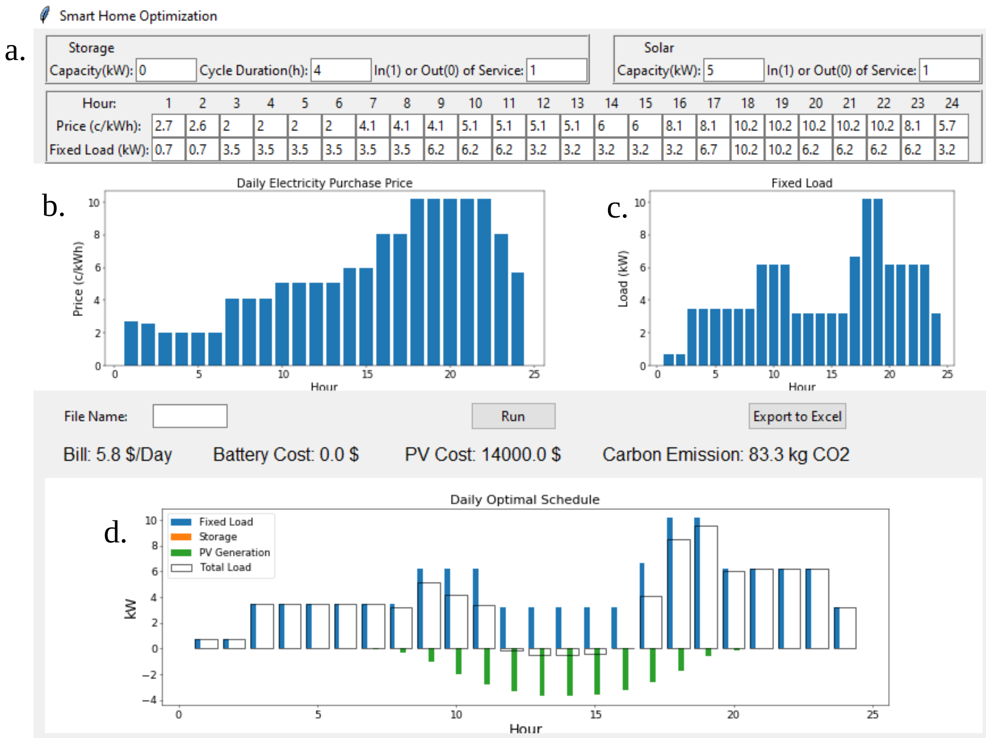


Figure6.The screenshot of the simulation wih solar panel addition

2.Analysis of Electricity Pricing and Consumption Patterns:

The household demand and electricity price trend followed the original simulation, where peak prices occurred between 3:00 PM and 9:00 PM and fixed load peaking occurred between 6:00 PM and 9:00 PM, as shown in Figure 6. Adding solar power introduced a lot of changes, including Figure 6(d) showing that solar power, when used during the day, significantly reduced the consumption of grid electricity and met a significant portion of the house load. Figure 6(b) and Figure 6(d) indicate that during the evening peak demand period, when it was most costly to use electricity, the household still had to rely on grid electricity due to the lack of stored solar energy.

3.Financial and Environmental Impact:

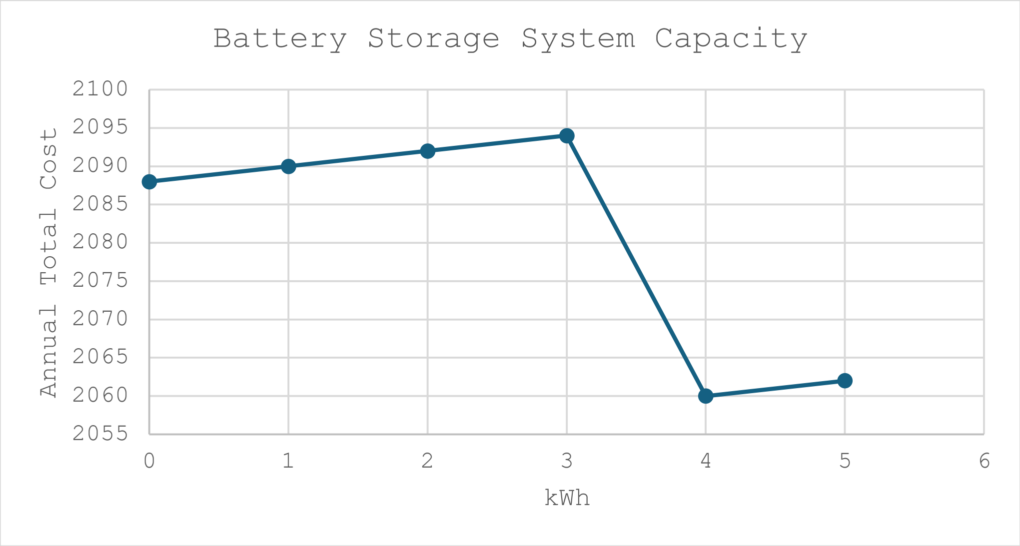
The daily electricity bill lowered from $7.7 to $5.8, demonstrating increased cost-effectiveness through savings on grid electricity consumption, as shown in Figure 6(d). Carbon emissions declined from 112.1 kg CO_2 to 83.3 kg CO_2, as indicated in Figure 6(a), highlighting the environmental benefits of using solar power instead of electricity from fossil fuels. The PV system cost of $14,000, as seen in Figure 6(a), represents a significant initial investment, which must be considered when evaluating the long-term economic advantages of the system. In contrast to battery storage, Figure 6(d) shows that solar energy alone does not provide complete energy independence, as grid electricity is still required during periods without sunlight.

Third Simulation: Solar Panel with Battery Storage Added

In this simulation, a battery storage system was introduced after fixing the solar panel capacity at 5 kW. The primary objective was to assess how battery storage impacts electricity costs, carbon emissions, and overall energy efficiency by storing excess solar energy and utilizing it strategically during peak demand hours. By comparing this simulation to the previous two (one without renewable energy and one with only solar panels), we can determine whether adding a battery enhances financial and environmental benefits.

1.Selection of Battery Capacity:

To optimize battery storage, multiple simulations were conducted with battery capacities ranging from 1 kWh to 5 kWh. From 1 kWh to 4 kWh the electricity bill and total cost steadily decreased as the battery capacity increased. This occurred because more excess solar energy could be stored and later used during peak pricing hours, reducing reliance on expensive grid electricity. At 5 kWh and beyond, the total cost began to increase. This was due to the higher initial battery cost outweighing the additional savings from further reducing grid electricity consumption.



Graph2. Effect of different battery storage capacities on total cost, based on simulation results

The graph shows how increasing the size of battery storage from 1 kWh to 5 kWh affects overall cost and bills. Initially, increased battery size leads to decreasing costs as more sunlight energy is stored and used during peak hours. Past 4 kWh, however, the overall cost starts to rise because the larger initial investment on the battery outweighs the increased savings. 4 kWh was identified as the optimal capacity because it provided the greatest reduction in electricity costs while maintaining an economically reasonable battery investment.By selecting 4 kWh, the system effectively stored excess solar energy during daylight hours and discharged it during peak evening hours when electricity prices were highest.

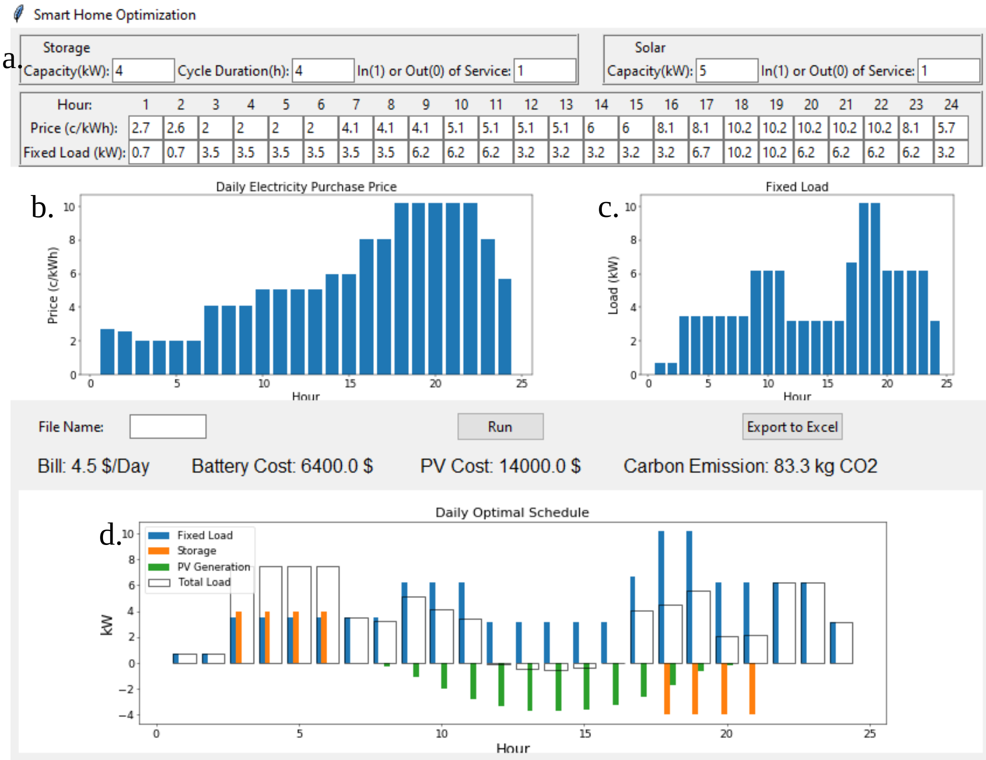


Figure7. The screenshot of the simulation with solar panel and battery storage system

2.Impact on Electricity Cost and Consumption Patterns:

Compared to the second solar-only simulation, the introduction of battery storage significantly changed the household electricity consumption profile. Figure 7(d) shows that solar panels generated surplus electricity during the daytime beyond the household's immediate demand. Instead of letting this spare energy go, the battery stored it to utilize later. During the evening peak pricing period 3:00 PM- 9:00 PM, as seen in Figure 7(b) and Figure 7(d), this stored energy was utilized, reducing the house's demand to buy electricity from the grid within the peak period. The load distribution curve in Figure 7(d) now reflects a shift in energy usage, where the evening load consumes less grid power and instead utilizes stored solar power to meet demand.

3.Financial and Environmental Impact:

The daily electricity bill decreased from \$5.8 to \$4.5, as shown in Figure 7(d), representing a significant improvement in cost efficiency compared to the solar-only system. This highlights the advantage of storing solar energy for peak demand periods rather than purchasing electricity from the grid. Figure 7(a) indicates that carbon emissions remained at 83.3 kg CO_2, the same as in the previous simulation. This shows that while battery storage improves financial efficiency, it does not directly reduce emissions further once solar energy is maximized. The battery cost was $6,400, as seen in Figure 7(a), adding a substantial initial investment that must be considered when evaluating long-term financial benefits. Unlike the solar-only system, this setup increases energy independence, as the household relies less on grid electricity and can make better use of self-generated solar power, as indicated in Figure 7(d). This simulation demonstrates that adding a 4 kWh battery to a 5 kW solar system further reduces electricity costs by strategically using stored energy during peak demand hours.

Analysis of the Simulations

Comparing all three simulations:

1. **No solar, no battery:** Highest bill ($7.7/day) and highest carbon emissions (112.1 kg CO_2).
2. **Solar (5 kW) only:** Lower bill ($5.8/day), lower emissions (83.3 kg CO_2), but excess solar energy is wasted.
3. **Solar (5 kW) + Battery (4 kWh):** Lowest bill ($4.5/day), same emissions (83.3 kg CO_2), and better energy efficiency.

The analysis of different energy storage scenarios demonstrates that optimizing solar panel capacity and battery storage size is crucial for minimizing electricity costs and carbon emissions in a household energy system. The findings highlight key trends. Without solar panels or batteries, the household relies entirely on grid electricity, resulting in the highest electricity bill ($7.7/day) and highest carbon emissions (112.1 kg CO_2/day) due to fossil fuel-based power generation. Adding a 5 kW solar panel system reduces electricity costs ($5.8/day) and carbon emissions (83.3 kg CO_2/day) by replacing a portion of grid electricity with renewable solar energy, though some excess energy is wasted.

Incorporating a 4 kWh battery alongside the 5 kW solar panel system further optimizes cost savings ($4.5/day) by storing surplus solar energy and using it during peak hours. However, carbon emissions remain at 83.3 kg CO_2/daysince all excess solar energy is already being utilized in the system.

Discussion and Evaluation

This study was able to examine best the storage capacity of batteries and charge/discharge cycles to maintain electricity costs low and minimize carbon emissions. The hypothesis is supported that solar panel installation and battery storage have lowered electricity cost but maintained the amount of carbon emissions low. From the simulation outputs, solar power alone lowers fossil fuel consumption but the inclusion of battery storage maximizes the usage of energy by eliminating the cost of electricity at peak hours.

Effectiveness of the Methodology

The use of the Smart Home Optimization simulation was determined to be an effective method in the study of the impact of different battery capacities on household energy consumption. The controlled conditions allowed for accurate comparison between different solar panel and storage battery systems. The simulation of cost savings and carbon savings were successfully achieved in the model, thereby making the model a valuable reference tool for energy efficiency research.

Environmental Considerations

While battery storage is an important aspect of reducing reliance on fossil fuels, it must be pointed out that not all battery technologies are environmentally friendly. Lithium-ion batteries, the most common batteries, entail the extraction of rare earth elements, which results in environmental degradation and pollution. Furthermore, battery disposal and recycling remain areas of concern for long-term sustainability. Follow-up research could examine the consequences of using different chemistries in batteries, such as solid-state or flow batteries, which offer cleaner alternatives with less environmental impact.

Applicability Across Different Homes and Regions

One limitation of this study is that the findings may not be broadly applicable to all homes and areas. Battery storage effectiveness is a function of climate, solar adiation levels, electricity pricing structures, and household electricity load profiles. In areas with low solar radiation or inexpensive grid electricity, battery storage cost-effectiveness may be significantly less. Future studies can explore regional case studies to determine how different energy policies, government incentives, and climatic conditions affect the feasibility of battery storage systems in residential households.

Study as a Model with Assumptions

This research is based on a theoretical model and, therefore, assumptions were assumed for solar efficiency, battery operation, and future trends in grid pricing. Real-world conditions of battery degradation with time, cyclicality of solar output, and unforeseen patterns in energy consumption can influence the economic and environmental effects of such a system. Future research would have to adjust for long-term battery performance history and real-life energy consumption trends to improve forecasting accuracy. The study can further be broadened by exploring the different models and sizes of the batteries in search of combinations offering the maximum extent of cost decrease with green surroundings.

Conclusion

This study confirms that optimizing battery storage capacity and charging/discharging patterns is an effective solution for reducing electricity costs while maintaining lower carbon emissions. The results support the hypothesis by showing that the use of a 4 kWh battery to a 5 kW solar panel installation reduces electricity costs significantly while ensuring that solar energy is used to the maximum during peak hours.

The Smart Home Optimization simulation was an effective tool for analyzing energy consumption trends and economic feasibility. However, as a model-based solution, it relies on assumptions that may not account for real-world variability in solar power generation, household demand, and electricity prices.One of the key limitations of battery storage is its impact on the environment because current lithium-ion batteries contribute to pollution through mining and disposal. Additionally, this study's findings may not be directly applicable to all homes and regions, as factors like climate, energy policies, and electricity costs vary globally.

Despite these limitations, household battery storage remains a promising solution to increase energy independence, reduce reliance on fossil fuels, and optimize the use of solar energy. Future research should focus on the evaluation of different battery technologies, cost-benefit analysis in real life, and regional variations in battery feasibility to further develop the understanding of sustainable household energy storage systems.

Bibliography

1- Environmental Energies. “What Are the Benefits of Battery Storage for Renewable Energy?” *Environmental Energies*, www.environmentalenergies.co.uk/battery-storage/. Accessed 26 Feb. 2025.

2- Energy Education. “Battery Storage.” *University of Calgary Energy Education*, energyeducation.ca/encyclopedia/Battery_storage. Accessed 26 Feb. 2025.

3- Greenly Earth. “CO_2 Emissions and Their Impact on Global Warming.” *Greenly Earth Blog*, www.greenly.earth/co2-emissions-impact. Accessed 26 Feb. 2025.

4- MFS South Australia. “Understanding Household Battery Storage.” *MFS South Australia*, www.mfssa.com.au/household-battery-storage-guide. Accessed 26 Feb. 2025.

5- National Geographic. “The Carbon Cycle and Climate Change.” *National Geographic*, www.nationalgeographic.org/carbon-cycle. Accessed 26 Feb. 2025.

6- National Grid. “Battery Storage and the Future of Energy.” *National Grid*, www.nationalgrid.com/battery-storage. Accessed 26 Feb. 2025.

7- United Nations. “How Renewable Energy Helps Reduce Carbon Emissions.” *United Nations Climate Action*, www.un.org/climate-action/renewable-energy. Accessed 26 Feb. 2025.

8- U.S. Department of Energy. “How Solar Energy Works.” *Office of Energy Efficiency & Renewable Energy*, www.energy.gov/solar-energy. Accessed 26 Feb. 2025.

9- U.S. Environmental Protection Agency (EPA). “Greenhouse Gas Emissions and Climate Change.” *EPA Official Site*, www.epa.gov/ghgemissions. Accessed 26 Feb. 2025.

10- NASA Climate.“Global Temperature Change.” *NASA Global Climate Change*, climate.nasa.gov/vital-signs/global-temperature/?intent=121. Accessed 26 Feb. 2025.

11- Sunlight Solar. “How Do Solar Batteries Work?” *Sunlight Solar Energy*, sunlightsolar.com/how-do-solar-batteries-work/. Accessed 26 Feb. 2025.

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Topic: Permission for using Smart Home Optimization Simulator for academic purposes

To whom it may concern;

We would like to indicate that [redacted] who is a student at [redacted], has utilized the Smart Home Optimization Simulator of EPRA Energy under our permission for her academic studies at the school.

Sincerely,

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