Modelling of storage-integrated solar systems for food storage (battery vs. cold/ice storage)

By

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Project Proposal

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Abstract

This project will focus on energy storage modelling, particularly batteries and cold storage for shifting solar energy for food preservation. The project's output will be an analysis of the trade-offs between electrical and cold energy storage for solar-powered cold rooms, ultimately assisting in the creation of efficient and sustainable methods of food preservation. This project is associated with the company called ColdHub.

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Chapter 1: Introduction

1.1 Background

Food is essential for human life and so is our planet. The world's mean surface temperature has increased by approximately 1 degree Celsius since the industrial revolution, and despite the seemingly small magnitude of this increase, it has caused significant consequences for both the environment and human livelihood.

According to a study, in Nigeria, about 45% of food gets spoiled due to a lack of refrigerated storage facilities, which leads to small farmers losing about 25% of their annual income, affecting nearly 93 million people. In Sub-Saharan Africa, it is estimated that the amount of food loss due to lack of proper storage facilities is nearly 123 million metric tons per year. [1]

The purpose of this project is to research the usage of solar systems with integrated storage for food preservation. The project is important as it has the potential to provide insights into the most cost-effective and efficient solutions for food preservation in off-grid or remote areas, where access to reliable electricity is limited. The results of this project could have a significant impact on the development of sustainable energy systems for food preservation and storage, particularly in developing countries. This project is associated with the company called ColdHub.

ColdHubs is a Nigerian-based social enterprise that provides solar-powered cold storage solutions for farmers, retailers, and wholesalers. The company was founded in 2015 with the goal of reducing post-harvest losses in Nigeria, which account for a significant portion of the country's agricultural produce.

As soon as fresh fruits and vegetables are harvested, they start to deteriorate due to the absence of water and nutrients, particularly affecting their texture, mass, visual appeal, taste, and nutritional content. However, cooling slows down the rate of degradation, which increases the longevity of the produce and extends their shelf life.

Overall, providing low-carbon solutions for food storage is essential for addressing climate change, improving food security, supporting sustainable agriculture, and conserving resources. By adopting sustainable and low-carbon food storage practices, we can create a more resilient and sustainable food system that benefits both people and the planet.

1.2 Problem Statement

A shortage of cold storage accounts for 45% of food spoilage in developing nations. [1]

Despite the critical role of energy storage in food preservation, current energy storage options for food preservation are often insufficient or in need of improvement. The trade-off between electrical energy storage and cold energy storage is not well understood, and there is a need for a comprehensive analysis of the performance and cost of different energy storage options for food preservation.

The problem is that current energy storage options for food preservation often fall short in terms of performance, efficiency, and cost-effectiveness. [2] The lack of understanding of the trade-off between electrical energy storage and cold energy storage makes it difficult to identify the most effective and efficient energy storage solutions for food preservation.

This project aims to address this problem by conducting a literature review, building models for batteries and cold storage, and integrating these models into a solar PV system modelling framework. The project will provide a comprehensive analysis of the trade-off between electrical energy storage and cold energy storage, and contribute to the development of more effective and sustainable energy storage solutions for food preservation.

1.3 Aims and Objectives:

The aim of this project is to model energy storage systems, specifically batteries and cold storage, for shifting solar energy for food preservation. The objectives of the project include:

1. Literature review of different types of batteries and cold storage systems to gather technical and economic data
2. Building models for batteries and cold storage systems and integrating them into a solar PV system modeling framework
3. Developing a heat (cold energy) demand model to estimate the varying energy demand
4. Building cost models of energy storage and other components for conducting further economic analysis
5. Analyzing the trade-off between electrical energy storage and cold energy storage for solar powered cold rooms.

The overall outcome of the project is to provide insights on the most cost-effective energy storage solution for preserving food using solar energy.

1.4 Motivation

This project aims to improve the understanding of energy storage options for food preservation and to evaluate the trade-off between electrical energy storage and cold energy storage. By conducting a literature review and building models for batteries and cold storage, the project will provide a deeper understanding of the technical and economic data for different energy storage options. By integrating these models into a solar PV system modelling framework, the project will also provide a real-world evaluation of the performance and cost of different energy storage options. [3]

The project on modelling of storage-integrated solar systems for food storage is important for several reasons:

1. Food security: Food storage is a critical aspect of ensuring food security, especially in areas with limited food resources or unpredictable weather conditions. Energy storage plays a key role in preserving food and reducing food waste, and this project will help to improve the understanding of energy storage options for food preservation.

2. Reducing food waste: Food waste is a major global challenge, and improving energy storage for food preservation is an important step in reducing food waste. By evaluating the trade-off between electrical energy storage and cold energy storage, this project will help to identify the most effective and efficient energy storage solutions for food preservation.
3. Solar energy efficiency: In case of Solar energy, storage is an important aspect of increasing energy efficiency and reducing greenhouse gas emissions. This project will contribute to the understanding of energy storage options for food preservation and help to identify the most energy-efficient solutions.
4. Reducing Carbon Footprint: Food storage is responsible for a significant amount of carbon emissions, particularly in the form of refrigeration and transportation. Low-carbon solutions can help reduce the carbon footprint of food storage, which is essential for addressing climate change and reducing greenhouse gas emissions.

1.5 Solution Approach

The development of energy storage systems and cold storage technologies for a variety of purposes, including food preservation, has been the focus of prior work in areas linked to this project. The following are some of the major areas of earlier work:

1. Energy Storage Systems: Earlier studies concentrated on creating several battery types, including lithium-ion, lead-acid, and nickel-cadmium batteries, for use in energy storage systems. These research looked into the cost, lifespan, and technical performance of several battery types.

Battery Type	**Cost**	**Lifespan**	**Technical Performance**
Lead-Acid	Low	3-5 years	High power output, lower energy density, requires maintenance
Lithium-Ion	High	10-15 years	High energy density, high efficiency, high power output, low maintenance
Sodium-Ion	Lower	~5 years	Similar energy density and efficiency to lithium-ion, still in early stages of development
Flow Batteries	Higher	10-20 years	High energy density, lower power output compared to lithium-ion, easily scalable
Zinc-Bromine	Lower	10-20 years	High power output, lower energy density compared to lithium-ion, still in early stages of development

2. Cold Storage Technologies: There has been significant research into the development of cold storage technologies for food preservation, including the use of refrigeration and air conditioning systems, phase change materials (PCMs), and sensible heat storage. These studies have investigated the thermal performance, energy efficiency, and cost of different types of cold storage systems.

Cold Storage System	Thermal Performance	Energy Efficiency	Cost
Vapor-compression refrigeration systems	Good	High	Relatively expensive
Absorption refrigeration systems	Average	Lower than vapor-compression systems	Can be cost-effective in certain cases
Thermoelectric cooling systems	Low	Low	Can be relatively inexpensive
Phase change material (PCM) systems	Low	Low	Can be cost-effective for certain applications
Evaporative cooling systems	Limited	Limited	Can be relatively inexpensive

3. Solar PV Systems: The studies in this section have concentrated on the technical performance, cost, and efficiency of various solar PV system types and their constituent parts. [4]

These previous studies provide valuable information and insights into the technical and economic viability of energy storage and cold storage systems for food preservation. They provide a foundation for further research and development in this area. [5]

The Solution is given below:

ColdHub provides a solution to post-harvest losses of perishable foods by offering a solar-powered walk-in cold room that is modular and can be installed in food production and consumption centers such as markets and farms. Farmers can place their produce in clean plastic crates which are then stored in the cold room, where the 120mm insulating cold room panels help to retain the cold. This extends the shelf life of fruits, vegetables, and other perishable food from 2 days to about 21 days. The energy from solar panels on the roof-top of the cold room is stored in high capacity batteries which feed an inverter that in turn powers the refrigerating unit. ColdHubs offers farmers a flexible pay-as-you-store subscription model, where they pay a daily flat fee for each crate of food they store. The output of My project will help cold hub in the expansion of its business. [6]

The future goals of ColdHubs include expanding their operations to reach more small-scale farmers and other food producers in Nigeria and other countries in West Africa. Cost Models developed in this project will help them to reduce the cost of the product. This will enable more farmers to access affordable and reliable cold storage facilities and reduce their post-harvest losses.

1.6 Expected Outcome

The key deliverables and expected outcomes of this project are:

1. Literature Review: A comprehensive literature review of different types of batteries and cold storage, including technical and economic data, will be conducted to identify the best storage options for food preservation.

2. Energy Storage Model: A battery and cold storage model will be built and integrated into a solar PV system modelling framework.

3. Heat Demand Model: A heat demand model will be developed to estimate the varying energy demand for food preservation.
4. Cost Model: Cost models of energy storage and other components will be developed to conduct further economic analysis.
5. Integration and Analysis: The battery and cold storage models, heat demand model, and cost models will be integrated and analyzed to determine the trade-off between electrical energy storage and cold energy storage for solar-powered cold rooms.
6. Technical Report: A technical report documenting the methodology, results, code, and conclusions of the project will be produced.
7. Presentation: A presentation summarizing the key findings and recommendations of the project will be delivered.

The expected outcomes of this project include a better understanding of the trade-off between electrical energy storage and cold energy storage for food preservation, as well as recommendations for the best storage options in terms of technical and economic feasibility

Chapter 2: Methodology

2.1 Proposed Methodology

For this project, a combination of regression and optimization techniques from machine learning could be used. The following is a high-level overview of the process:

1. Literature Review: As mentioned in the project description, start with a literature review to gather technical and economic data of batteries (different chemistries) and cold storage (sensible and phase change materials).
2. Data Collection: Collect data on the cost and performance of different batteries and cold storage systems. This data will be used to build the cost models and energy storage models.
3. Energy Storage Modeling: Use regression techniques to build models for both batteries and cold storage systems. The models should take into account factors such as capacity, efficiency, and cost.
4. Solar PV System Modeling: Integrate the battery and cold storage models into a solar PV system modeling framework. This model should be able to simulate the energy demand and energy storage capacity of the system.
5. Heat Demand Modeling: Build a heat demand model to estimate the varying energy demand for cold energy storage.
6. Economic Analysis: Use the cost models and energy storage models to conduct an economic analysis of the trade-off between electrical energy storage and cold energy storage for solar powered cold rooms.
7. Optimization: Finally, use optimization techniques to find the optimal solution for the trade-off between electrical energy storage and cold energy storage. This can be done by minimizing the total cost of the system while meeting the energy demand requirements.

In conclusion, the machine learning models used in this project will mainly focus on regression and optimization techniques. The specific models and techniques will depend on the nature of the data and the requirements of the problem, but the above steps provide a general outline of the process.

To develop the battery and cold storage models, heat demand model, and cost model using machine learning include following steps:

1. Data Collection: Collect data related to battery and cold storage technologies, energy demand patterns, and costs of components. This data could be obtained from various sources such as academic research papers, industry reports, and publicly available databases.

2. Data Pre-processing: Clean and pre-process the data to make it suitable for modeling. This could involve converting the data into a format that can be fed into the machine learning algorithms, handling missing or incorrect data, and normalizing the data.

3. Feature Engineering: Identify the most relevant features that can impact the performance of the models and extract these features from the pre-processed data.

4. Model Development: Train machine learning and deep learning algorithms such as neural networks, decision trees, and random forests using the processed and engineered data. Fine-tune the models to achieve the desired accuracy.

5. Model Evaluation: Evaluate the performance of the developed models using appropriate evaluation metrics such as accuracy, recall, precision, and F1-score. Repeat the modeling process as necessary to achieve the desired performance.

6. Model Deployment: Integrate the developed models into the solar PV system modeling framework and test it for practical implementation.

The technical crux of the project lies in the accurate and detailed modelling of the different components of the system and the integration of the models into a comprehensive system-level framework.

I am going to use python and machine learning for model development.

2.2 Available Python tools and libraries

1. NumPy: A numerical computing library for Python that provides support for arrays, matrices, and operations on them. It is often used as the foundation for more advanced numerical and scientific computing tools.

2. Pandas: A library for data analysis and manipulation in Python, providing support for handling and manipulating tabular and time series data.

3. Matplotlib: A library for creating visualizations and graphs in Python, used for data visualization and exploration.

4. PyPSA: A toolbox for simulating power systems in Python, including support for renewable energy sources and energy storage systems.

5. SciPy: A collection of scientific computing tools for Python, including optimization, linear algebra, signal processing, and more.

2.3 Machine Learning Tools and Libraries

There are several websites and platforms that you can use to build, train, test, and validate your machine-learning models for this project. Some of the most popular ones include:

1. TensorFlow: TensorFlow is a machine learning framework by Google with a set of tools and libraries for model development and deployment.
2. Keras: Keras, a high-level API for neural networks, can be implemented on top of TensorFlow, CNTK, or Theano.
3. PyTorch: PyTorch, an open-source machine learning library, provides an intuitive interface for creating and training models.
4. scikit-learn: Scikit-learn is a machine learning library for Python that features efficient tools for data analysis and mining, including algorithms for regression, classification, clustering, and dimensionality reduction.
5. Amazon SageMaker: Amazon SageMaker is a fully-managed machine learning platform that offers various tools to build, train, and deploy machine learning models on the cloud or on-premises.
6. Google Colaboratory: Google Colaboratory provides free online access to a Jupyter notebook environment with GPU access, making it useful for prototyping and training machine learning models.

Chapter 3: Project Plan

3.1 Estimation

The detailed methodology of the project with a high-level timeline could be as follows:

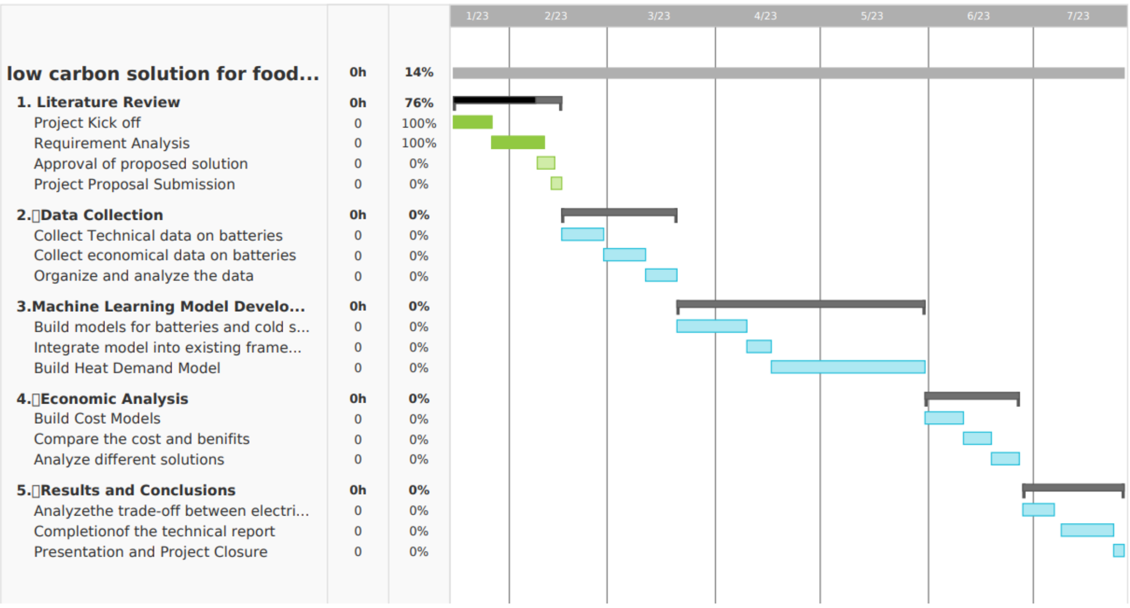
1. Literature Review (80 hours)
   - Collect information on existing research on energy storage modelling, batteries, cold storage, and solar PV systems
   - Review relevant journals, articles, and reports.
   - Synthesize information to identify gaps in current knowledge.
2. Data Collection (80 hours)
   - Gather technical and economic data on different types of batteries and cold storage solutions.
   - Collect data from manufacturers, industry reports, and government databases.
   - Organize and analyze data to understand the performance and cost characteristics of different solutions.
3. Machine -Learning Model Development (200 hours)
   - Build models for batteries and cold storage solutions (80 hours)

- Integrate the battery and cold storage models into a solar PV system modelling framework (40 hours)
- Develop a heat demand model to estimate the varying energy demand for food preservation (80 hours)

4. Economic Analysis (100 hours)
    - Build cost models for the energy storage and other components (80 hours)
    - Conduct a comprehensive economic analysis to compare the costs and benefits of different solutions (20 hours)
5. Results and Conclusions (140 hours)
    - Analyze the trade-off between electrical energy storage and cold energy storage for solar-powered cold rooms (60 hours)
    - Completion of the technical report (60 hours)
    - Present the results and conclusions of the analysis, including a discussion of the advantages and disadvantages of different solutions (20 hours)

It is important to note that this timeline and the number of hours required for each task is a rough estimate and can vary based on the specific requirements and constraints of the project. The actual timeline and resources required will be refined as the project progresses and I gain a deeper understanding of the problem.

3.2 Gantt Chart



Chapter 4: Risk and Ethics

4.1 Risk Evaluation Matrix

Risk description	Probability	Impact	Contingency plan
R1: Data Availability from ColdHub	Low	High	• Rigorous literature survey will be done to collect the data. • This risk can be mitigated by using artificial data available on the internet, but it is important to make sure that the data is relevant and represents the real-world scenario.
R2: Model Performance Risk	Low	Medium	• This risk can be mitigated by conducting regular testing and validation of the models and making improvements as necessary.
R3: Economic Analysis	Low	Low	• This risk can be mitigated by performing analysis and comparing results with different models and taking feedback from supervisor/coldHub.
R4: Time Constraints	Low	High	• This risk can be mitigated by having a detailed project plan, breaking down the project into smaller tasks, and regularly monitoring progress.

It is important to continuously monitor and assess these risks throughout the project and have contingency plans in place to minimize their impact.

The risks involved in completing the project could include below points:

1. Data Availability: The availability of data for batteries and cold storage systems may be limited, which could affect the accuracy of the models developed. Availability of the data from coldhub could be difficult.
2. Model Accuracy: The accuracy of the models developed for batteries, cold storage systems, and the solar PV system may be affected by uncertainties in the data and assumptions made in the model development.
3. Economic Analysis: The economic analysis conducted as part of the project may be subject to uncertainties and limitations, such as the accuracy of cost data and the availability of financial information.
4. Time Constraints: The tight deadline for completing the project by July may increase the risk of not being able to complete the project within the allotted time frame.

4.2 Ethics and GDPR Considerations

In this project, I am not going to collect any personal data of users however following considerations will be taken into account:

Data Privacy: I Ensure that all personal and sensitive data is collected, stored, and processed in accordance with GDPR regulations.

Data Security: Appropriate technical and organizational measures will be taken to protect personal data from unauthorized access, alteration, or destruction.

Data Retention: Personal data will not be kept for longer than necessary and is deleted or anonymized when no longer required.

Data Transparency: I will Be transparent about the data that is collected and how it is used to complete the project.

Data Accuracy: I Ensure that the data collected is accurate and up to date.

Chapter 5: References

5.1 References

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