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FINAL REPORT

Development of Smart Greenhouse (SGH) for Temperate and Alpine Regions to Enhance Agriculture Farming for Future Food Sustainability

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1. Summary

Agriculture is one of the most crucial activities that sustains human life. With an increasing global population, rapid climate change, and dwindling resources, the farming industry has come under significant pressure. Nevertheless, the rapid development of modern technologies in the agriculture sector offers substantial potential for boosting production efficiency year-round. The project, titled "Development of a Smart Greenhouse (SGH) for Temperate and Alpine Regions to Enhance Agricultural Farming for Future Food Sustainability," provides a controlled environment for experimenting with crops. Typically, agricultural land in the temperate regions of Bhutan remains fallow due to harsh weather conditions. During the winter, the recorded temperature drops to -4.84°C, making it impossible for crops to survive. The technique employed in developing the smart greenhouse supports the crops inside by maintaining the necessary temperature and humidity levels.

Following the prototype's development, a performance analysis of the SGH was conducted during the winter months. Before implementing the prototype, TRNSYS and OpenStudio simulation software were used to assess the thermal load demand within the SGH. The simulation results indicated that the maximum thermal load was required during December and January in the early morning hours. The necessary thermal energy is supplied by a solar water heating system installed adjacent to the smart greenhouse. The total solar irradiance received at the selected site is 4.45 kWh/m^2. After accounting for losses and heat demand, an 8 m^2 thermal collector was chosen, capable of heating 500 liters of water per day. This heated water is then directed into the greenhouse to serve as a heat source to maintain the required temperature for the crops. Depending on the crop varieties selected, the minimum temperature inside the SGH was set to 2°C, with a maximum of 35°C.

In the event that the temperature within the SGH exceeds the set limits, sensor switches activate the hot water pump and exhaust fans to bring it back within the desired range. Water sprinklers equipped with humidity sensor switches are also installed. The humidity inside the SGH was set to a range of 40-80% relative humidity (RH), and if it goes beyond these set limits, the water sprinkler pump engages to restore humidity to the required levels. Temperature and humidity levels within the SGH are recorded using a data logger. The performance of the SGH is compared to the external temperature and humidity conditions.

Objectives

The objectives of the research are;

a) To design and develop SGH suitable for temperate and alpine region and experiment with varieties of crops for one or two cycle.
b) To analyze the performance and cost-benefit analysis of SGH.
c) To enhance agriculture production efficiency in the temperate region.
d) To increase the use of cultivable land in the two regions and enhance access to healthy food round the year.
e) To demonstrate SGH to farmers and promote greener economics.

3. Outputs, Outcomes and Impacts

https://analyticsinaction.co/definition-output-outcome-impact-with-examples

Outputs	Outcomes	Impacts
• Site selection was carried out after soil parameter testing. • A Smart greenhouse was designed. • Weather data was collected for design considerations.	A CAD model was utilized to simulate the SGH design in TRNSYS and OpenStudio to assess thermal load demands during cold seasons.	Using the design simulated in the computer software, the same design was implemented using locally available raw materials, with farmers actively participating in the construction of the greenhouses and the connection of sensors.
Determining the size of the heating system and the layout of radiant pipes inside the SGH, including the number of thermal collectors, the capacity of the hot water tank, and the cold water reservoir	The water heating system was installed, resulting in a significant and dramatic improvement in the temperature inside the SGH.	Local residents were briefed on the functionality of the solar water heating system used in the SGH. During the installation of the heating system, basic training was provided, covering plumbing for the solar water heating system and pump requirements. This has made farmers more aware of how to utilize solar energy for sustainable food production.
The performance parameters of the prototype SGH were measured, with a primary focus on temperature and humidity.	The collected data were analyzed, leading to improvements in the design of the SGH.	It was concluded that SGH can be utilized in temperate regions to cultivate crops during unconventional seasons. The cultivable land, typically left barren during the cold winter season, can be transformed into year-round cultivable land with the use of SGH.
Four rounds of stakeholder meetings were conducted in collaboration with the Department of Agriculture (DoA) under the Ministry of Agriculture and Livestock in Bhutan, focusing on the implementation of SGH.	• A memorandum of agreement was signed between the stakeholder (JB Solar Solution) and the College of Science and Technology to facilitate SGH construction. • The SGH concept was presented to the	• JB Solar Solution received training in constructing SGH. • The DoA agreed to collaborate with the institute and conduct research related to SGH. • A research collaboration with the DoA was

	Department of Agriculture (DoA). • Local farmers and academicians were taken on a field trip to Nepal to observe modern agricultural practices.	established, and three faculty members from the Electrical Engineering department at CST were nominated as experts for research collaboration. • Farmers and academicians who participated in the Nepal trip gained a comprehensive understanding of how modern technologies are applied in farming practices.
Starting from November 2022 (the beginning of the winter season), various crops were experimented with in the 12 x 7.5 m prototype greenhouse.	During the winter season, we were able to harvest broccoli, cabbage, beans, cucumbers, and spinach.	SGH implemented in temperate region was working exceptionally well and can be applied on a large scale to increase food production

4. Key facts/figures

- Local people, primarily farmers, were actively involved in the project, from the construction of the smart greenhouse to the conclusion of the experimentation.
- Farmers received training in monitoring the SGH.
- Four rounds of stakeholder meetings were conducted to disseminate the project concepts.
- Project experts were invited to observe the implemented SGH, and ideas were exchanged for further implementation.
- More than 50 individuals attended the inauguration of the SGH.
- Two journal papers were submitted for review: one to the Smart Agriculture Technology Elsevier Journal and the other to the APN Science Bulletin.
- Project information was posted on the College of Science and Technology (CST) website.

5. Publications

Dorji, G., Tenzin, N. & Lhendup, T. (2023). Performance Analysis of Smart Greenhouse at Temperate Regions for Future Food Sustainability. Elsevier Smart Agriculture Technology Journal. Under peer review. First draft submitted on 10th Oct 2023.
Dorji, G., Tenzin, N., Lhendup, L., Chojey, N., Alam, M.S., Haque, M. & Bastakoti, N. (2023). Green Technologies to Enhance Sustainable Food Production in Colder Regions via Adoption of Smart Greenhouse, Submitted in APN Science Bulletin for review.

6. Media reports, videos and other digital content

1. Featured in CST webpage about the smart greenhouse project. Asia-Pacific Network for Global Change Research (cst.edu.bt)
2. Featured in JB Solar Solution Facebook page https://fb.watch/nGddL2LkrB/ https://fb.watch/nGdeLDo16L/
3. Featured in SSRN Elsevier Preprint paper Performance Analysis of Smart Greenhouse at Temperate Regions for Future Food Sustainability by Gom Dorji :: SSRN

7. Pull quotes

"The price of food rises, but we can't forgo eating due to cost concerns. Despite the high cost of smart greenhouses, they are pivotal for future food sustainability. Engineers must incorporate technology into agriculture, especially in temperate regions, where smart greenhouses expand cultivable land and enable year-round crop harvesting."

Mr. Gom Dorji, Project leader, CST, RUB, Bhutan.

"The best part of this project is working with the partners from diverse backgrounds, perspectives, and experiences and how the Lead Researcher was able to coordinate and embrace diversity to solve the problem."

Dr. Tshewang Lhendup, President, JNEC, RUB, Bhutan.

"The Smart Greenhouse (SGH) project in Bhutan utilizes solar power to extend crop cultivation during off-seasons, addressing food sustainability challenges in temperate and alpine regions. Successful crop growth during peak winter demonstrates promising results. Recognizing the need for individualized environmental settings for different crops is a practical insight, and future experiments in this direction could enhance the system's efficiency. Future work should incorporate a cost-benefit analysis to ensure economic viability, facilitating scalability and long-term sustainability."

Mr. Mainul Haque, Project Member, City University, Bangladesh.

"As a project partner, the epitome is not just the successful completion of a project, but also the deeply shared understanding among diverse collaborators. Commitment, dedication, and communication are the fundamental things"

Mr. Ngawang Chojey, Project Member, JNEC, RUB, Bhutan

8. Acknowledgments

The Smart Greenhouse project team would like to express our sincere gratitude to the Asia Pacific Network for Global Change Research (APN) for generously funding this project. Thanks to their financial support, we were able to conduct detailed experiments without facing any financial constraints.

We would also like to extend our appreciation to the College of Science and Technology at the Royal University of Bhutan, Jigme Namgyel Engineering College, Bangabandhu Sheikh Mujibur Rahman Agricultural University, City University, Bangladesh, and Kathmandu University, Nepal. Their unwavering support from their faculty greatly contributed to our research activities.

Furthermore, we wish to acknowledge J B Solar Solution, the farmers of Genekha, and the Department of Agriculture for their participation in our dissemination workshops and their invaluable assistance during the construction of the smart greenhouse.

Thank you to all individuals and organizations who played a significant role in the success of this project.

9. Appendices

Appendix 1: First stakeholder meeting with JB solar solution and signed memorandum of Agreement to construct Smart Greenhouse on 1st April 2022.

Appendix 2
Stakeholder meeting with Department of Agriculture (DoA), local farmers and academicians
Objectives of meeting and Photos added

Appendix 3
Project experimentation, Field trip to Nepal and expertise invitation to Bhutan.
Objectives and photos added

Appendix 4
Publications

Appendix 1: First stakeholder meeting with JB solar solution and signed Memorandum of Agreement (MoA) to construct Smart Greenhouse on 1st April 2022.

The first project activities began with the signing of a Memorandum of Agreement (MoA) between the College of Science and Technology and the private firm J B Solar Solution. The stakeholder meeting commenced with a brief presentation by the Project leader, Mr. Gom Dorji. His presentation included the overall project objectives and the main tasks involved in the MoA. The event was attended by the Head of the institute, Dr. Cheki Dorji, the President, officiating Dean of Research and Industrial Linkages, Mr. Yeshi Wangchuk, the Head of the Electrical Engineering Department, Mr. Manoj Sharma, and department faculty members. In his opening remarks, Dr. Cheki emphasized the importance of collaboration between academics and stakeholders to address any issues in the field of agriculture.

To fulfil one of the project objectives, which is "To demonstrate a Smart greenhouse to farmers and promote a greener economy," an MoA was established between the College of Science and Technology (as the project leader) and J B Solar Solutions for the execution of the smart greenhouse. J B Solar Solution specializes in the design and installation of solar photovoltaic and thermal systems. With their expertise, local farmers were also trained in methods of constructing the automated greenhouse. The training covered material selection, sensor installation, data loggers, and plumbing circuits. The College of Science and Technology will be responsible for designing the smart greenhouse (SGH), including control systems, while J B Solar Solution will handle the practical implementation. This collaboration fulfils the general objectives of capacity development for local farmers.

The construction of the SGH began in October 2022, and experimentation started in November 2022. The project implementation date was delayed by a few months due to the COVID-19 pandemic. However, this did not affect the data collection period, as the project's target is to monitor the SGH during the winter season when the cultivable land lies fallow. The photos of the MoA signing and the construction of the SGH are shown below.

Figure 1. MoA signing between CST and J B Solar Solution

Figure 2. Foundation of smart greenhouse

Figure 3. Structure component of Solar water heating system

Figure 4. Overview of smart greenhouse

Figure 5. Sealing of leakages in smart greenhouse

Appendix 2

2nd and 3rd Stakeholder meeting with Department of Agriculture (DoA), local farmers and academicians.

On November 25, 2022, the construction of the smart greenhouse was completed, and the inauguration and experimentation of crops began. During the event, more than 50 participants attended from various sectors, including local leaders, farmers, the Agriculture Research and Development Centre (ARDC), Food Security and Agriculture Productivity (FSAPP), the Food and Agriculture Organization (FAO), the Agricultural Machinery Center (AMC), J.B. Solar Solution, and academicians from Jigme Namgyel Engineering College and the College of Science and Technology. The event commenced at 10:30 AM and concluded at 2:15 PM.

The main event officially started at 11:30 AM with a welcome speech by the project leader, followed by an explanation of the smart greenhouse construction procedures to the farmers. The event also emphasized the importance of vegetables and energy in crop growth and development. Mr. Ngawang Chojey, an expert in crops, delivered a presentation on this topic. Below, you can see some highlights from the event.

Figure 1. Welcome speech to stakeholders.

Figure 2. Event attendee

Figure 3. Technical team

After the successful completion of the smart greenhouse construction, the Department of Agriculture under the Ministry of Agriculture and Livestock in Bhutan appreciated the idea, and collaborative research was initiated between the College of Science and Technology (CST) and the NCOA. The CST team presented an overview of the workings and advantages of the smart greenhouse to the members of the NCOA. Two rounds of meetings were held before the start of the collaborative research. Below, you can find some highlights from this event.

Figure 4. Presented smart greenhouse concept to DoA.

Figure 5. Discussion for way forward.

The National Centre for Organic Agriculture, Ministry of Agriculture and Forests, invited faculty members from the Centre for Renewable and Sustainable Energy Development (CRSED) and the Electrical Engineering Department at the College of Science and Technology (CST), Royal University of Bhutan, as well as researchers from the Agriculture Machinery and Technology Centre, Ministry of Agriculture and Forests, for a two-day workshop on the Design, Development, and Planning of Smart Greenhouses and Automation of Greenhouses. The workshop took place at Druk Hotel in Phuentsholing on July 28th and 29th, 2023. This workshop involved the sharing of ideas from three different stakeholders, each with different expertise, to develop a smart greenhouse in Yusipang, Thimphu

Figure 6. Information dissemination and collaboration

Appendix 3
Project Experimentation, Field trip to Nepal and Expertise Invitation to Bhutan.

After the construction of the smart greenhouse project in temperate region, experimentation with few crops was conducted. The parameters monitored during the experiments were temperature and humidity. It was observed that when the outside temperature dropped below freezing, the inside temperature could be maintained according to the crops' requirements. The figure below displays the crops that were experimented with inside the smart greenhouse during the peak winter season.

Figure 1. Smart greenhouse and weather station

Figure 2. Experimented crops; broccoli, cabbage, radish, beans and garlics.

Figure 3. Yield from smart greenhouse.

The project milestone was accomplished through a field visit in Nepal from 25th – 30th January 2023 to observe agricultural practices. The field visit included stakeholders, farmers, and academicians who were hosted by Mr. Niranjan Bastakoti, a project member from Kathmandu University. The team visited Panauti, Kathmandu, Nepal, to observe agricultural practices in a similar region. Since Nepal and Bhutan are both located in the Himalayan region, the same agricultural techniques can be applied. During the visit, the team discovered that the smart greenhouse developed in Bhutan had issues with moisture seeping into the roof of the greenhouse. To address this issue, the team learned from the Nepal trip that using a net inside the greenhouse can prevent this problem. Additionally, they observed effective pest control methods, such as using pest glue and water extracted from chili plants, as some of the best natural practices in the greenhouse at Panauti, Nepal. The preparation of saplings was also practiced professionally. The team also had the opportunity to meet with the Dean of Research at Kathmandu University to discuss potential future research collaborations. Images from the field trip are presented in the figures below.




Figure 4. Field trip to Nepal

To disseminate the concept of a smart greenhouse to our partner countries, the project team members were invited to observe the performance of the smart greenhouse in Bhutan from the 24th of February to the 1st of March 2023. Their visit added value by improving the design of the smart greenhouse and also demonstrated its excellent performance in temperate regions. The figure shows their visit to smart greenhouse.

Figure 5. Research collaborators at the smart greenhouse site.

Appendix 4
Publications.

1. **Performance Analysis of Smart Greenhouse at Temperate Regions for Future Food Sustainability- under review, submitted in Elsevier Smart Agricultural Technologies Open Access Journal.**

Abstract: Amidst climate change, diminishing resources, and a growing population, the farming industry has come under significant pressure. Nonetheless, rapid advancements in modern agricultural technologies offer substantial potential to enhance production efficiency. The proposed smart greenhouse (SGH) provides a controlled environment for the crops within it. Equipped with sensors and communication technologies, a smart greenhouse automatically measures and delivers information around the clock, activating the heating, ventilation, and air conditioning (HVAC) systems in the greenhouse. The pilot SGH developed in Genekha, Thimphu, has integrated sensors and renewable energy technology as an energy source to supplement during the cold winter season. No external heating sources are required during the summer period. The SGH was initially simulated using TRNSYS and OpenStudio simulation software. Performance parameters such as temperature and humidity inside and outside the SGH were collected and analyzed. Additionally, parameters like soil pH and nutrient content were measured. The time required for crops to grow and be harvested was recorded and is presented in this paper. The paper also concludes by highlighting some of the limitations of the current design and providing recommendations for future improvements.
Keywords: smart greenhouse, humidity, temperature, temperate region

2. **Green Technologies to Enhance Sustainable Food Production in Colder Regions via Adoption of Smart Greenhouse. Submitted in APN science Bulletin**

Abstract: Amidst climate change, dwindling resources, and a growing population, the farming industry has faced significant pressure. Nevertheless, rapid advancements in modern agricultural technology offer substantial potential for increasing production efficiency in colder regions. The proposed Smart Greenhouse (SGH) provides a controlled environment for crops. The SGH consists of heat source from 8 m2 solar water heating system, weather stations to monitor the outside SGH temperature and humidity, light sensor, humidity sensor and temperature sensors inside SGH to monitor SGH performance. Several selected crops were experimented with and grown inside the developed SGH during the cold winter when cultivable land is typically left fallow due to extreme cold weather conditions. The prototype SGH results depicts improved environmental conditions compared to the outside of the SGH, with a temperature difference of 6°C and a humidity level of 25% RH. This paper also discusses the limitations of current SGH system designs and proposes future design improvements.

Keywords**:** smart greenhouse, humidity, temperature, temperate and alpine region