University of Toronto

Choosing to Model A Greenhouse

ESC470 - Energy Systems Capstone

Project Justification

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Abstract:

The Engineering Science Energy Systems Capstone Design Team, Class of 2020 has decided to develop a decision support system to inform Ontario's greenhouse growers in optimizing their greenhouse performance. The proposed system will assist guiding feasible and optimal choices on greenhouse energy sources and consumption based on the relationships between energy efficiency, costs and environmental impact through mathematical modelling. The system is to be judged according to its impact on stakeholders within Ontario's greenhouse market, its potential as an educational tool addressing the ambiguities of the overwhelming choices provided in the market, and for its ease of modification in the event that the interest for an improved iteration of this tool exists in the future, when the greenhouse market has likely changed further. Decision-support modelling for a greenhouse is selected because of the team's joint values in stakeholder engagement, multidisciplinary, learning, personal interests and impact.

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Introduction:

The objective of this paper is to provide a transparent justification of how and why the design team converged upon the creation of a decision support system for greenhouse design pertaining to Ontario's energy market through an analysis of what the team desires to gain from the decision support system and the desired impact the system will have on stakeholders. These stakeholders include the greenhouse growers of Ontario, whose decisions will be reinforced or contradicted by the system's output. In addition, any engineers that may have an interest in this project in the future are relevant parties to consider, whether they would be modifying the tool to reflect a change in the data or Ontario's greenhouse market or using this design as a reference for another proposed system. Finally, when it comes to the the impact this project will have on the design team, this paper will elaborate upon the educational value of coding a decision support system based upon Ontario's greenhouse market and the value of applied stakeholder outreach. Other relevant risks and considerations concerning this design were also taken into account and are described in the latter-most section of this document, such as the necessary scoping and assumptions that will be required for the proposed system.

Objective of Decision Support System:

The decision support system is made to address the variety of options available and parameters to consider for greenhouse growers in Ontario when choosing a greenhouse design by providing a simulation model of an Ontario greenhouse that inputs varying design parameters to reflect their impacts on users' objectives. The justification for this document lies not only in its ability to educate aspiring growers as to the results of their greenhouse design decisions but also to provide designers and future iterators of this project with the opportunity to further educate themselves on Ontario's dominant and developing greenhouse market and the stakeholders within that market. The input parameters of this system include the types of lights used, the method of energy generation, and the chosen produce and will output the prospective yield, the profit of the yield (with the energy bill and installation costs factored in), and the greenhouse gas output. To maximize the accuracy of the aforementioned output parameters relative to Ontario's greenhouse market , it necessitates that the sensitivity of the model's output to varying input parameters be supported with the data publicly available. The proposed system is to be coded in Python, since software libraries in Python are more known to members of this team and because Python has numerous publicly available tutorials, providing accessibility for potential future modification [1] [2].

Criteria:

The following is a list of criteria the capstone team valued during the selection process of choosing capstone design topic.

Personal Interest	A design project that could capture the interests of each group member is preferred. The team aims to create an environment of empowerment that sufficiently and equally motivates its members to learn.
Stakeholder Engagement	A design project with direct stakeholder engagement is preferred, as it could offer opportunities to deliver impact and to practice engineering consultation skills.
Multi-Faceted	A multidisciplinary design project is preferred because the capstone team consists of a group of people with a diverse skill set. A multidisciplinary project will allow the team to apply a broader range of learned skills, which is desirable for a cumulative educational project.
Extendability & Ease Of Modification	A design project that could allow for ease of modification and extendability is preferred, increasing the potential for future value with changing data or a new developer team.
Impact	A design project that has strong potential to bring direct impact to a community is preferred. As emerging engineers, the team looks forward to applying engineering skills to solve real-world problems.
Learning	A design project that could allow the team to gain new knowledge in the field of energy systems is preferred. The team values continuous learning and integration of theoretical knowledge to real world applications.

Justification:

Personal Interest

The Energy Systems Capstone team has not previously had the opportunity to learn about or explore greenhouse design. Overall, this team values the novelty of the project as well as the opportunity for learning, stakeholder engagement, and impact that it provides (see respective sections above for further details).

Stakeholder

The team values stakeholder engagement as an important step for ensuring impact as well as following proper engineering design processes. The Ontario greenhouse sector is booming, and there are several potential stakeholders who could provide valuable input into the project. Greenhouse manufacturers, such as DeCloet and CGS Structures, are key players in the sector and have years of experience building greenhouse facilities for a wide range of customer needs [3] [4]. There are several major private companies that have sizable operations in Ontario, including NatureFresh and Mucci Farms. Well-designed greenhouses are integral to their business models, and if a decision support system were to be successful in optimizing performance, the companies could see improvements to their facilities. As an additional industry group to consider, non-profit organizations such as the Ontario Vegetable Greenhouse Growers and the Ontario Greenhouse Alliance serve to connect industry members to government agencies and suppliers to advocate for growers' needs [5] [6]. At a more local level, the University of Toronto has a greenhouse on campus in the Earth Sciences department [7]. While this facility is intended primarily for educational purposes and not commercial agriculture, insight into the operations and design history of the facility can yield valuable considerations into scoping the model.

The abundance of potential stakeholders from different positions in industry and academia offers a strong opportunity for the team members to practice stakeholder engagement while also strengthening the potential impacts of the project by connecting it to the real world.

Multi-Faceted

Greenhouses are integrated systems and modeling a greenhouse requires an understanding of its biological ecosystem, as well as knowledge of how technology use and economics influence this system and any decision-making:

- Understanding the *Biological Ecosystem* of a greenhouse depends on understanding optimal, suboptimal, and destructive crop growing conditions, as well as the energy costs of maintaining these conditions [8]. This includes knowledge of crop responses to heat, light, humidity, fertilizer, internal atmospheric composition, temperature, and many other factors. Location-dependent factors external to the greenhouse, such as weather, temperature, and sunshine, also influence the biological ecosystem of the greenhouse.
- *Technology use* can support crop growth and yield in a greenhouse. This can include systems to provide energy, heating, lighting, fertilization and irrigation, as well as, systems to support

plantation and harvest of the produce [9]. The team will also have the chance to investigate various energy generation and storage technologies for consideration in the model.

- The key *economic factors* involved in this project are costs and risks. This requires a detailed breakdown of costs (capital expenses, operational expenses, labour costs, etc). Each technical system added to the greenhouse will increase expenses, and cost-benefit analysis will be required. Risks must also be understood, and mitigated or avoided.

Therefore, creating this model will require thorough knowledge of all the multiple facets of greenhouse construction, operations, and maintenance, in order to make tradeoffs and recommendations through our greenhouse decision support system. The multi-faceted nature of this project allows for integration of a variety of skill-sets, and thus, leverages the strengths of all team members.

Extendability & Ease Of Modification

In order to increase the future value of the project, the team felt that it is necessary to consider how the model can be modified after the capstone term is complete. As data may change over time, whether concerning greenhouse design or optimal produce growing conditions, the ease and opportunity for modification for potential future iterators on this tool is significant. Since future engineering students may be future developers of the project, it is important to consider how likely they are to be able to understand the code. Python is a coding language popular with the programming community due to its perceived simplicity and superior readability when compared to other languages [1] [2]. Furthermore, there are many publicly available tutorials for its existing libraries, adding to the ease and likelihood that one unfamiliar with this language may self-educate if the need arises [1] [2]. With sufficient documentation, this project can be continued to allow for continued improvement as data becomes more updated and available.

Impact

The IESO has issued a request for proposals to address the more than 1,300 MW of greenhouse load seeking to connect to the Ontario grid by 2025 [10]. The greenhouse market in the province is projected to face significant change within the foreseeable future; greenhouse lighting, energy consumption, and produce choice are examples of areas subject to these forthcoming changes [9]. Consequently, the options available to greenhouse growers (both aspiring and practicing) have expanded and in the context of Ontario's already dominant greenhouse market relative to the rest of Canada, it is reasonable to state that the directions greenhouse growers in constructing a greenhouse are arguably overwhelming [9]. Furthermore, without the ability to predict the relevant consequences of choosing one of the many options available such as product yield, revenue, and greenhouse gas emissions, growers (particularly prospective growers) are left without a foundation to strongly support their greenhouse design decisions, providing a design opportunity with direct impact to Onatrio's greenhouse and energy sector.

Learning

Given the multifaceted nature of a greenhouse's design, there are a significant number of tasks, disciplines, and interacting systems involved that must be understood and modelled for this project. This provides ample opportunity for learning and knowledge building.

This modelling project is a tangible, real world application of the systems thinking, problem-solving and engineering design strategies team members have learned over the course of their respective engineering educations thus far. The project also has a strong connection to energy, as greenhouses are predicted to be a very large load on the grid in the near future [10]. Several generation and storage options have to be considered, and the team will have the chance to learn more about how they integrate to this specific use-case. Building this model will leverage our knowledge and understanding of energy systems, and gives us opportunity to further explore how demand, efficiency, on-site power generation, storage, and a variety of other factors will influence greenhouse energy usage and grid load.

Other Risks and Considerations:

While the team is confident in the potential value of the project to all relevant stakeholders, there are several risks and challenges that need to be addressed for the project to be successful.

Scoping

Modelling a greenhouse system is incredibly complex and requires significant attention to details for the outputs to have reliable value. The team recognizes that not all greenhouse parameters can be factored into the calculations, and certain features must be scoped out due to time and resource constraints. The main strategy to tackle this challenge will be to proceed towards the final product iteratively, with several intermediate prototypes to reassess scope. Specifically, the initial model will consider a limited number of input parameters in order to establish the baseline model structure. From there, the addition of each new parameter will be preceded by research into the data and necessary calculations in order to determine how the parameter can be effectively modeled. Through this process, the team will aim to identify the most significant parameters and outputs in order to optimize the value of the model given the resource limitations.

Stakeholder consultations will also yield valuable insights into the scoping process, as experts in the field will likely have experiential knowledge of the importance and feasibility of considering the factors identified through research. The availability of desired data will also impact the scoping of the project, which will be an ongoing process throughout the term.

Data Limitations

While there is significant research on several aspects of greenhouses, such as optimal ambient conditions for crops and growth light features, the vast majority of this data has not been aggregated in detail. For example, greenhouse design handbooks can walk through steps that consider multiple input parameters, but if the analysis is not exhaustive, then there is a chance for additional interplay between variables that has not been studied. In addition, the most widely available data concerns optimal operating conditions, which makes it more challenging to model sub-optimal regions. This applies to several aspects of the design, including lighting, irrigation, as well as temperature, all of which are significant energy costs in the greenhouse.

The team will conduct research and consider a broad range of resources. This will include academic papers, where more detailed data may be available for lab-verified parameters, such as plant behaviours to varying light. Design handbooks can help provide some of the high-level considerations for how certain controllable features may impact performance based on practical experience. Manufacturers' data sheets will be used to obtain detailed information about purchasable products such as lighting or generators. Through surveying such a variety of resources, the team hopes to be able to combine datasets to be able to justify the built-in features of the model.

Another strategy to combat limitations is to ensure that all data is stored as parameters within the model and can be easily modified. This will allow future users and developers to update the model if they own or encounter new, more reliable data. In addition to revisiting scoping as data is gathered, the team will also be required to make several assumptions to bridge gaps between available and desired data.

Assumptions

A potential flaw with such a model is that the systems are occasionally oversimplified or the details are inaccurate, leading to the insights drawn from the model being unreliable. Due to the two issues discussed above, the team will need to make several assumptions in design to build into the model itself. The team recognizes that these assumptions will need to be made with adequate consideration of the impacts, and the decisions will be properly documented to inform future users and developers of the model. In addition, assumptions will be backed up and verified by research throughout the design of the final product. When the model is complete, the team will aim to verify the outputs primarily through research into known greenhouse behaviours, however disaggregated data on this is fairly limited in the public sphere.

The required assumptions will add to the educational value of the product for future students, as the model will provide an example of how limitations can be overcome with properly justified assumptions. As an integral part of the design process, these assumptions will also allow the team to practice engineering decision-making, adding to the value as a Capstone design project.

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