Literature Study

Proactive Climate Simulation for Data-Driven Greenhouse Optimization

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Preface

This Review literature of topics of how plants operate and software approaches to optimize plant growth and use different strategies to broaden the climate computers capabilities using data. The review looks into these two topics as an understand about plants lay the foundation for the domain and the software strategies and approaches is to find out what has been done already. The work would lay the foundational knowledge to use for trying to build upon existing approaches and maybe figure out if there is room for trying to add proactive features to this field.

The review incorporates 22 studies that together should give fundamentals to build upon. Aspects such as digital twins, building interfaces for climate computers and techniques for pro-activeness are some core aspects of the papers found within.

This manuscript is written for researchers, students and practitioners advancing climate-resilient agriculture to those who are interested in the state-of-the-art IoT-ML applications of controlled environment optimizations.

Introduction

Environmental issues and increasing population have especially highlighted the importance of sustainable and energy efficient farming practices. Greenhouses are in high demand because they provide a protected environment which leads to production throughout the year. Nonetheless, the management of these environments remains a complex process of achieving the optimal plant health while ensuring optimal energy expenditure for climate control. There is a need for highly developed techniques that will involve data-based optimization to change the conditions of greenhouses with the minimum energy consumption and other operational costs.

The application of data-driven techniques for the enhanced climate control of greenhouses has been discussed in this report. This includes a discussion of post-active and pre-active strategies for climate control. These advanced strategies incorporated real-time environmental data, local microclimate data, and predictive modelling to develop a climate control system that could, in fact, anticipate changes and proactively adjust to them. This is a development of the basic systems studied earlier, such as DynaGrow [1] and IntelliGrow [2], which both implemented automation and response control with IoT and machine learning techniques.

The report is divided into two parts: first, a critical review of the literature related to the state of data-driven climate control technologies in greenhouses through an analysis of various predictive models and control systems, and second, a consolidation of those divergent methods and operational frameworks across more than 85 studies on the effectiveness of post-active and pre-active approaches in plant growth optimization and energy consumption. It also examines multi-objective optimization and genetic algorithms for integrating historical and real-time data for predictive control.

This thesis part two is going to develop and test a simulated proactive/pre-active climate control using orchestration based on Docker. This simulation will not only help in implementing the strategies in different greenhouse conditions but also in the refinement and validation of the strategies identified in the literature review. It shall present a flexible, low-cost framework that can help in guiding researchers, students, and practitioners in the right direction of deploying a suitable climate control solution in controlled environments.

The work presented in the following report is a systematic approach towards the understanding of the conflicts that occur between energy efficiency and optimum plant health in a greenhouse system. This thesis aims at improving the current knowledge on the application of IoT and machine learning for climate control to develop better, versatile solutions for sustainable and climate resilient agriculture.

State-of-the-Art

Historical Contributions

- Contribution 1
- Contribution 2

Current Best Solutions

- Solution 1
- Solution 2

Literature Reviews

Paper 1: DynaGrow [1]

Title:	**DynaGrow – Multi-Objective Optimization for Energy Cost-efficient Control of Supplemental Light in Greenhouses**
Authors:	• Jan Corfixen Sørensen • Katrine Heinsvig Kjaer • Carl-Otto Ottosen • Bo Nørregaard Jørgensen
Motivation for doing the research:	Supplement lighting accounts for 75% of energy consumption in Danish horticulture in 2009. With the recent surge in energy prices, there is a need to optimize for fluctuating energy prices, as static lighting strategies lead to higher costs when prices spike. The horticulture industry competes globally, so reducing operational costs is crucial. Moreover, renewable energy introduction can cause price volatility. This paper tackles such multi-objective optimization with a MOEA-based, modular plugin system, leveraging local weather, plant data, and energy price inputs for continuous, data-driven objective adjustments—hence the name DynaGrow.
The research problem:	The authors point out that standard greenhouse climate controls do not adequately address rising energy costs and fluctuating electricity prices while maintaining plant quality. DynaGrow frames the challenge as a multi-objective optimization problem, employing an application-specific MOEA to balance cost savings with plant health in real time. DynaGrow's novelty lies in its modular, feature-oriented design that integrates seamlessly with existing greenhouse equipment. By incorporating local climate data, weather predictions, and electricity prices, the system can deliver targeted, adaptive control strategies. Experiments demonstrate substantial cost and energy savings, making DynaGrow both scalable and practical for sustainable greenhouse management.

Chosen research approach / methodology:	DynaGrow recasts greenhouse climate control as a **multi-objective optimization problem**, applying a specialized genetic algorithm called CONTROLEUM-GA to optimize trade-offs between cost efficiency and plant growth quality. It integrates real-time data, including local climate conditions, weather forecasts, and fluctuating electricity prices, enabling a dynamic, real-time control system without the need for expensive hardware upgrades. Their study features experiments in three separate greenhouse compartments: a standard fixed-rate setup, and two DynaGrow configurations (SON-T and LED lighting). Key performance metrics include energy use, cost reduction, and plant quality.
Reported results:	In experiments, DynaGrow reduced energy usage by up to 56% and slashed costs by up to 64%, all while dynamically adapting to real-time electricity price changes. Crucially, these energy savings and cost reductions did not degrade plant quality. The system's data-driven optimization and real-world validation confirm that domain-specific algorithms can effectively constrain resource consumption while maintaining productivity. This adaptability—and the validation in operational settings—positions DynaGrow as a forward-looking solution that marries sustainability with cost-effectiveness.
What are the contributions / conclusions?	• **Multi-Objective Optimization**: Leverages Pareto-based approaches to simultaneously minimize energy costs and maintain plant health. • **Modular System Architecture**: Easily integrates into existing greenhouse infrastructure, promoting broad adoption potential. • **Real-World Validation**: Demonstrates significant cost and energy benefits in actual greenhouse trials. • **Adaptive Control**: Incorporates weather forecasts and electricity prices to achieve continuous cost-efficiency and stable growing conditions. • **Future Extensions**: Offers a framework for expanding to other climate parameters (e.g., temperature and CO_2 management).
Your evaluation of the reported results with respect to the research objective	• **Significance**: The findings demonstrate notable energy and cost savings—two pressing concerns for greenhouse operations—showing that MOEA-driven solutions are both feasible and beneficial. • **Validity**: The inclusion of real-world experiments bolsters the credibility of the approach. The metrics used (energy consumption, cost, plant quality) effectively measure DynaGrow's impact. • **Novelty**: Integrating multi-objective optimization with evolving energy prices and weather forecasts sets DynaGrow apart from standard or single-objective solutions. • **Feasibility**: The system's modular design is technically viable, requiring minimal retrofitting to existing climate computers. This facilitates adoption in the industry. • **Possible Future Work**: Broader and longer-term studies (e.g., multiple crop types, diverse climate conditions) would confirm its scalability and robustness.

Paper 2: AFDACAND [3]

Title of the paper:	"A Generic Framework for Automatic Configuration of Artificial Neural Networks for Data Modeling."
Name(s) of author / authors:	Morten Gill Wollsen, The Maersk Mc-Kinney Moller Institute, The Technical Faculty, University of Southern Denmark
Motivation for doing the research:	The thesis addresses the growing availability of sensor data in many domains (IoT, Big Data, etc.) and highlights the challenge that most existing ANN tools require deep expertise in network architecture, configuration, and hyperparameter tuning. AGFACAND (the proposed framework) aims to provide a more user-friendly, automated way to create ANN-based models, thus reducing the barrier for non-experts.
The research problem / objective:	1. Automate the selection and configuration of different types of ANNs (e.g., MLP, ELM, SVR) for various data modeling tasks. 2. Reduce the amount of expert involvement needed when using ANNs. 3. Demonstrate that an automated framework can yield competitive or superior results compared to manual, expert-driven approaches.
Is this research original?	Yes. While many software libraries exist for training neural networks, AGFACAND offers a "one-click" style of automation that combines feature selection, network type selection, hyperparameter tuning (via Bayesian Optimization), and evaluation. This end-to-end automation is what makes the contribution unique.
Chosen research approach / methodology:	1. **Feature Selection**: Uses algorithms to automatically select relevant input variables from large datasets. 2. **Model Selection**: Employs Bayesian Optimization and comparative methods to pick the best-performing network configuration. 3. **Implementation**: Built as a Java framework, designed to be extensible for future neural network types. 4. **Validation**: Demonstrated on real-world applications like weather forecasting, greenhouse modeling, etc.
Reported results / products / effects:	• A fully automated framework (AGFACAND) that takes raw data as input and returns a trained ANN model with minimal user intervention. • Empirical evidence that the framework can match or outperform manually tuned models. • Broad applicability across multiple domains (time series forecasting, system modeling, etc.).
What are the contributions / conclusions?	1. **Full Automation**: From feature selection to model deployment. 2. **Multi-Network Support**: MLP, ELM, SVR, and potential future expansions. 3. **Ease of Use**: Designed for non-experts, with minimal required configuration.

	4. **Practical Impact**: Validated through diverse use cases, showing that automated ANN configuration can be both robust and efficient.
Your evaluation of the reported results with respect to the research objective:	• **Significance**: Automating ANN configuration is highly beneficial, especially for non-specialists. • **Validity**: The author substantiates claims with comparative experiments and real-life examples; the methodology seems thorough. • **Novelty**: While individual steps (feature selection, Bayesian Optimization) are not new, their unified integration in a single, user-friendly framework is noteworthy.
Your conclusion on the relevance of this research with respect to the field in general:	AGFACAND contributes significantly to the broader field of machine learning automation (AutoML). Its focus on real-world applications (including greenhouse climate modeling) highlights its practical viability. It may encourage further research on automated approaches that reduce the manual overhead of network design and tuning.
Your conclusion on the relevance of this research with respect to your own research:	For a thesis focused on **greenhouse climate management**—especially one requiring **predictive, multi-objective optimization**—AGFACAND could serve as a vital component for automatically building and fine-tuning ANN-based climate models. By streamlining the creation of predictive models, I could integrate AGFACAND with my greenhouse control logic. This would help: 1. **Feature Selection**: Quickly identify the most critical variables (e.g., temperature, humidity, CO_2, weather forecasts). 2. **ANN Type Comparison**: Seamlessly compare different network architectures to model the greenhouse environment. 3. **Hyperparameter Optimization**: Automate the search for the best model settings, potentially reducing energy or resource consumption. 4. **Continuous Adaptation**: As conditions change seasonally, the framework's extensibility could re-tune or retrain models periodically with minimal effort. Hence, the methods described in AGFACAND align strongly with my thesis's objective of using **data-driven, proactive control** strategies in greenhouse management.

Paper 3: Climate control software integration with a greenhouse enviromental control computer [4]

Title of the paper:	Climate control software integration with a greenhouse enviromental control computer

Name(s) of author / authors:	Jesper Mazanti Aaslyng Niels Ehler Lene Jakobsen
Motivation for doing the research:	The motivation for this paper is to make interfaces from an existing system of IntelliGrow [2] to open up the general system of environmental control computers (ECCs) to others and make integrations across the board.
The research problem / objective:	Develop an interface for connecting a new application with the standard ECC.
Is this research original?	The act of making interfaces is certainly not original but doing so for an ECC in a non-vendor specific way that leads to broader adoptability might not have been generally available before.
Chosen research approach / methodology:	The study designed BipsArch, a six-layer system that combines greenhouse control computers with advanced software such as IntelliGrow. It successfully streamlined climate management over four months of testing at multiple greenhouses through a vendor agnostic interface and real time data handling.
Reported results / products / effects:	The project was generally very successful showing integrations with other systems and databases as expected. It managed 45 climate inputs and 8 set points reliably.
What are the contributions / conclusions?	The contributions of the paper would be that it tries successfully to make an interface that opens up the ECC to broader audiences possibly adding to scientific endeavors.
Your evaluation of the reported results with respect to the research objective:	Evaluation showed good results but there was slight disruptions from the database that shows on the results also. This however was negligible as it was due to the database and not the interface. Better decisions on database would resolve this.
Your conclusion on the relevance of this research with respect to the field in general:	As this shows interoperability it would be highly relevant as it means more research and cross development can be conducted instead of only vendor specific configurations.
Your conclusion on	Again because of interoperability this might be use full for my studies as i might end op using such an interface to connect with an ECC device.

the relevance of this research with respect to your own research:	

Paper 4: Cost-efficient light control for production of two campanula species [5]

Title of the paper:	Cost-efficient light control for production of two campanula species
Name(s) of author / authors:	Katrine Heinsvig Kjaer, Carl-Otto Ottosen, Bo Nørregaard Jørgensen
Motivation for doing the research:	The authors wanted to reduce electricity cost within greenhouses utilizing weather forecasts and prices of electricity while having good quality in plant health and production still.
The research problem / objective:	The objective was to evaluate a light control system that controls the supplemental lighting in the greenhouse based on cost effectiveness while still having food plant products.
Is this research original?	Using multi objective optimization to enhance cost of electricity and plant product using weather forecast and the light need of the plant is somewhat unique
Chosen research approach / methodology:	A system using this multi objective optimization was used to test four configurations in a greenhouse and on two species of campanula. This combined the forecasted solar irradiance along with predefined light requirements and electricity cost to optimize these four configurations
Reported results / products / effects:	The results showed 25% cost reduction in electricity while using the system without significant negative impact on the plants
What are the contributions / conclusions?	It was shown in the study that supplement light systems that are optimized based in weather forecast and dynamic pricing can lower the cost of energy while maintaining plant quality.
Your evaluation of the reported results with respect to the research objective:	The results effectively achieved cost efficiency during spring. There was some limitations that shows that there might be some importance for continuous light under low natural light in certain conditions.

Your conclusion on the relevance of this research with respect to the field in general:	This research is highly relevant for sustainable greenhouse operations, providing a pathway for integrating cost-effective strategies into horticultural practices globally.
Your conclusion on the relevance of this research with respect to your own research:	This paper looks at multi objective optimization which also is an what my study is looking into. Therefore its quite usable to have the insight into those integrations that's made beforehand.

Paper 5: Enhancing State-of-the-Art Multi-Objective Optimization Algorithms by Applying Domain-Specific Operators [6]

Title of the paper:	Enhancing State-of-the-Art Multi-Objective Optimization Algorithms by Applying Domain-Specific Operators
Name(s) of author / authors:	Seyyedeh Newsha Ghoreishi, Jan Corfixen Sørensen, Bo Nørregaard Jørgensen
Motivation for doing the research:	The research aimed to improve the convergence speed of multi-objective evolutionary algorithms (MOEAs) for dynamic problems, particularly greenhouse climate control, by introducing domain-specific operators.
The research problem / objective:	The research problem of this paper is to enhance performance of MOEAs for dynamic optimization. This is done by integrating domain-specific knowledge that enables faster convergence without sacrificing diversity or quality.
Is this research original?	MOEAs have been used before and have also been studied thoroughly. This study however is novel as it applies domain-specific operators to a real-world dynamic greenhouse control system.
Chosen research approach / methodology:	The algorithm develop using domain specific initialization, mutation, and crossover operators was tested against three algorithms that acts as baseline to monitor performance on the greenhouse climate optimization.
Reported results / products / effects:	As compared to NSGAII, ε-NSGAII, and ε-MOEA, CONTROLEUM-GA converged faster with better diversity, finding high quality solutions with fewer generations.

What are the contributions / conclusions?	The study has thus been able to demonstrate that incorporating domain knowledge into MOEAs does improve their efficiency in dynamic environments and can be employed as a reference in future applications.
Your evaluation of the reported results with respect to the research objective:	The experiments' results support the hypothesis that employing domain-specific operators is advantageous for decreasing the convergence time without compromising the solution quality and diversity, but the scalability of this approach for a variety of applications is an open question.
Your conclusion on the relevance of this research with respect to the field in general:	Since this is a well studied area this already have been utilized in the filed of horticulture and data-driven optimization.
Your conclusion on the relevance of this research with respect to your own research:	Since my project is based on the already existing work of Dynagrow[1] then ill naturally have to use it for my project also.

Paper 6: Advancements in smart thermostat technology for enhanced HVAC Energy management[7]

Title of the paper:	Advancements in Smart Thermostat Technology for Enhanced HVAC Energy Management
Name(s) of author / authors:	Ireneo C. Plando, Jr.
Motivation for doing the research:	The motivation for this paper is to examine the potential for better performance of energy management in context to Heating, ventilation and Air conditioning (HVAC).
The research problem / objective:	The objective is to find potential ways of improving energy management for better cost effectiveness and user comfort through literature review and empirical analysis.

Is this research original?	Since this is a journal on that combines literature and empirical analysis id say that this isn't original as it only summarises existing work. It highlights the a path potential path from existing research.
Chosen research approach / methodology:	The approach is using literature review as already mentioned and also empirical analysis. This is to gain a holistic overview of the advancements in smart thermostats.
Reported results / products / effects:	The reported results are as follows: 1. For commercial uses there are 30% improvements on energy savings. 2. For residential settings there was 25%. 3. User satisfaction is generally above 85% Quantitative energy savings are about 3 and 7 percent points lower.
What are the contributions / conclusions?	Its evident that the current field of energy saving and user comfort in HVAC systems have come far with above 20% general energy savings while maintaining high user satisfaction in comfort and ease of use. But there is still much room for further research to bridge existing gaps.
Your evaluation of the reported results with respect to the research objective:	These results does show potential for further enhancements in regards to energy saving and user comfort. As 25% and 30% is significant enhancement it shows already prominent results.
Your conclusion on the relevance of this research with respect to the field in general:	This doesn't show much prospect in the field of horticulture as the use of ml, advanced algorithms and data analytics are already used for energy optimization and good plant produce.
Your conclusion on the relevance of this research with respect to your own research:	This study was supposed to sum of the advancements in smart heating to see what the current state was for potential use and inspiration for my study in pro-activeness in climate computers for horticulture use. As this focuses more on user satisfaction and comfort i dont think that this is much use for my field as it needs more fine grained control. Things i can take from this paper is the importance of data analytics for ml models to produce substantial better results.

Paper 7: A Novel Approach for Monitoring of Smart Greenhouse and Flowerpot Parameters and Detection of Plant Growth with Sensors [8]

Title of the paper:	A Novel Approach for Monitoring of Smart Greenhouse and Flowerpot Parameters and Detection of Plant Growth with Sensors
Name(s) of author / authors:	Pinar Kirci and Erdinc Ozturk and Yavuz Celik
Motivation for doing the research:	The study was conducted to construct a smart greenhouse that uses sensor data to optimize plant yield and save energy costs at the same time but with multiple plants in the same growing area.
The research problem / objective:	The objective of the research was to: 1. Create a prototype of a smart greenhouse 2. Solve multi-objective problems with data-driven approaches 3. Grow multiple plants types in the same growing area / greenhouse.
Is this research original?	The study states that this is a novel approach. As the topic of multi-objective problem solving with data-driven approaches isnt new, and similar study on same growing area with different plants also immerge at the same time it not that original. Although combining it is original, but not novel.
Chosen research approach / methodology:	The study uses previous work as a stepping stone with literature review and prototyping to achieve the goal. Various sensors and inexpensive hardware has been used to try an gather enough data for the plants health to make the system responsive and optimize plant health.
Reported results / products / effects:	The results shows that 3 / 4 plants produced better in the smart greenhouse and had better health all together where only one produced better outside but had larger leafs in the smart greenhouse. Less water usage was also obtained in the smart greenhouse. Study doesn't mention energy usage.
What are the contributions / conclusions?	The conclusion shows that the there is real potential for their approach as it in general produced better. They state that by using smart technologies in agriculture greenhouses this might yield more produce and help mitigate the growing problems associated with climate changes and geopolitical issues.
Your evaluation of the reported results with respect to the research objective:	As the results mainly use water consumption and crop yield to measure by I'm left wondering what about energy consumption. The use of multi-objective problem statements and trying to solve this with data-driven approaches is not novel, but adding more plants in same greenhouse and adding smart capabilities might be. Information about the data-driven approaches was also lacking. Even though it might not be novel it still shows promise for the smart aspects of greenhouses.
Your conclusion on the relevance	The contribution to the field might be negligible as information about the data-driven approaches was very scares. It still shows that there is promise for using

of this research with respect to the field in general:	smart technologies in the field although addition in this paper might not be much.
Your conclusion on the relevance of this research with respect to your own research:	There isn't much to use from this but aspects such as multi-objective problem, data-driven and digital twins indicate that this is indeed the way that I should also be thinking. Especially with the concept of digital twins. This area could maybe be used for visual representation and simulation without having to grow my own. Especially the simulation part is important for this as visualizing it might now be entirely necessary.

Paper 8: Deep Learning Models for Health-Driven Forecasting of Indoor Temperatures in Heat Waves in Canada: An Exploratory Study Using Smart Thermostats[9]

Title of the paper:	Deep Learning Models for Health-Driven Forecasting of Indoor Temperatures in Heat Waves in Canada: An Exploratory Study Using Smart Thermostats
Name(s) of author / authors:	Jasleen Kaur and Gurjot Singh and Arlene Oetomo and Navneet Kaur and Plinio P. Morita
Motivation for doing the research:	Because of the extreme heat that has outsourced over that last few years causing significant risk to elderly people in Canada the team wanted to investigate if deep learning could prove resourcefull
The research problem / objective:	The team chose to look into utilizing Deep learning for predicting indoor temperatures data to forecast potential proactive warnings based on extreme heat scenarios and possibly take action on this.
Is this research original?	Utilizing deep learning for proactive temperature forecasting in this field is novel as is give super insight full predictions to potential actors that could take responsible action to save lives.
Chosen research approach / methodology:	Utilizing exiting knowledge of deep learning the team uses ETL (Extract, Transform, Load, Analyze) to gives a solid ground to how solid foundation for the study.
Reported results / products / effects:	The results show a super effective model that mirrors the true temperature trend closely and does so with minimal training. The model took approximately 11.46 minutes to train compared to 2.65 hours. That is very significant.

What are the contributions / conclusions?	As the model is easy to train and has high accuracy this shows a real world use case to might be feasible for consultation for the Canadian government and possibly others.
Your evaluation of the reported results with respect to the research objective:	The results seem to be very usable and feasible. The training time seems to be good as it utilizes cloud computing and thus cant be enhanced much for this specific approach.
Your conclusion on the relevance of this research with respect to the field in general:	In the filed of horticulture this doesn't show much. But the prospect of using deep learning for temperature predictions could be useful in the sense that it could show added performance for predictability and also plant growth optimization.
Your conclusion on the relevance of this research with respect to your own research:	As my project doesn't has the aspect of using deep learning this doesn't show me much. But it does show me that deep learning might be a useful aspect for the project as its highly likely to produce good models (if deep learning is done correctly and the right resources are present)

Paper 9: Energy Efficiency and Economic Evaluation in Tomato Production: A Case Study from Mersin Province in the Mediterranean Region[10]

Title of the paper:	Energy Efficiency and Economic Evaluation in Tomato Production: A Case Study from Mersin Province in the Mediterranean Region
Name(s) of author / authors:	Yelmen B., Sahin H.H., Cakir M.T.
Motivation for doing the research:	The motivation is that because Turkey produces a large amount of tomatoes both in greenhouses and in open fields wether one or the other is more energy efficient.
The research problem / objective:	The research's motivation is to look at energy consumption comparison between open field and greenhouses to look into wich is more energy consuming and by how much.

Is this research original?	Although similar approaches has been done comparing open field and greenhouse to each other this study takes it a step further by using localized data in comparison.
Chosen research approach / methodology:	The Team gathered data for analysis first. Then did energy analysis to compare energy usage and then economic analysis.
Reported results / products / effects:	In general the reported results show that open field growing is less energy consuming although greenhouse grown sell for more.
What are the contributions / conclusions?	The study concludes that even though open field growing is less energy consuming that for greenhouses there is a big advantage to reduce the overall energy consumption as it still sells for more but striking balance with energy consumption and production could lower the impact overall.
Your evaluation of the reported results with respect to the research objective:	The results seems to be very solid with good verifications also. They highlight great the differences between the open field and the greenhouse produce.
Your conclusion on the relevance of this research with respect to the field in general:	This definitely show that there is a need to lower the energy consumption for greenhouses as this would have impact on both environmental factors as it emits less but also striking the balance would still produce good yield for same profit.
Your conclusion on the relevance of this research with respect to your own research:	This is a good base for why optimizing the climate computer would be beneficial. As i cant reduce diesel or energy sources optimizing for energy efficiency would be impact full for profit and the environment

Paper 10: Energy Consumption Prediction of a Greenhouse and Optimization of Daily Average Temperature[11]

Title of the paper:	Energy Consumption Prediction of a Greenhouse and Optimization of Daily Average Temperature
Name(s) of author / authors:	Yongtao Shen,Ruihua Wei,Lihong Xu
Motivation for doing the research:	Because that greenhouses have such as high energy footprint there is a need to look into how to handle this effect.
The research problem / objective:	The study aims to look into energy consumption and predicting the total energy use, using three optimization algorithms and verifications to figure out how high production can be maintained while gaining insight into energy consumption and taking action from that.
Is this research original?	The research seems to be original in using three distinct algorithms to do comparison and using these results to predict energy consumption with relatively accurate forecasting.
Chosen research approach / methodology:	The research uses mathematical modeling to model out the equations needed for the parameters. Then they use optimization algorithms to optimize the model for near realtime data and then validates with real world data.
Reported results / products / effects:	A study is presented, which offers a validated, real world applicable model for predicting and optimising greenhouse energy use and it is shown that by employing sound climate control strategies, energy efficiency and therefore economic viability can be greatly improved.
What are the contributions / conclusions?	
Your evaluation of the reported results with respect to the research objective:	The study successfully presents a data-driven, energy-efficient approach to greenhouse heating method. The research presents a scalable and practical solution for sustainable agriculture through the use of predictive modeling and optimization algorithms and the validation of these in real-world conditions.
Your conclusion on the relevance of this research with	This research is relevant to energy optimized greenhouse climate control since it presents a novel, data intelligent approach to climate control. Integrating machine learning based optimization with real world energy modeling makes the model both scientifically valid and practically impactful. Moreover, testing

respect to the field in general:	in different greenhouse conditions and exploring integration with renewable energy may enhance its scalability and feasibility.
Your conclusion on the relevance of this research with respect to your own research:	This research seems like a larger implementation but aspects of it could be insightful and useful.

Paper 11: Optimization of energy ratio, benefit to cost and greenhouses gasses using metaheuristic techniques (genetic and particular swarm algorithms) and data envelopment analysis: Recommendations for mitigation of inputs consumption (a case crop: edible onion) [12]

Title of the paper:	Optimization of energy ratio, benefit to cost and greenhouses gasses using metaheuristic techniques (genetic and particular swarm algorithms) and data envelopment analysis: Recommendations for mitigation of inputs consumption (a case crop: edible onion)
Name(s) of author / authors:	Behzad Elhami, Mohamoud Ghasemi Nejad Raeini, Morteza Taki, Afshin Marban, Mohsen Heidarisoltanabadi
Motivation for doing the research:	This study looks at ways of overcoming problems of energy inefficiency, high costs and emissions by applying DEA, MOGA and MOPSA to achieve sustainability and optimum economic performance in onion farming.
The research problem / objective:	This research contributes to filling the gap between energy efficiency, economic sustainability, and environmental impact in agriculture through a data-driven optimization approach.
Is this research original?	Multi objective algorithms are integrated to tailor energy, cost and emissions in onion farming for the first time. The real world application and findings of the research are also quite practical, thus it offers potential for sustainable agriculture.
Chosen research approach / methodology:	The study uses DEA to evaluate farm efficiency and optimizes energy use, costs, and emissions using MOGA and MOPSA. Greenhouse gas emissions (CO_2, CH_4, N_2O) are quantified and real world data is integrated with MATLAB and Python to develop a scalable, sustainable agriculture framework.
Reported results /	In the study, using DEA, MOGA, and MOPSA, energy, cost, and emission optimization in onion production was achieved. Cut energy by 48.63%, costs by 63.12%, and GHG emissions by 47%, while tripling the benefit-to-cost

products / effects:	ratio. MOPSA increased energy use and emissions, but DEA had moderate gains.
What are the contributions / conclusions?	• MOGA optimised energy, cost, and emissions very well which led to reduced consumption and enhanced the best and environmental results. • DEA offered mild optimization that led to rather small, but still quite noticeable enhancements. • MOPSA was ineffectual, worsening energy and emissions despite improving economy. • Metaheuristic algorithms are not guaranteed to be optimal, and other methods may be more appropriate.
Your evaluation of the reported results with respect to the research objective:	In this research, energy, cost and emissions are integrated and optimized to prove the effectiveness of MOGA over DEA and MOPSA. The authors also propose a novel approach for selecting strategies that considers multiple factors and can, therefore, be useful in the context of sustainable agriculture
Your conclusion on the relevance of this research with respect to the field in general:	This research contributes to sustainable agriculture by showing how MOGA can be used effectively to optimize onion production. Its comprehensive approach enhances the state-of-the-art by offering practical solutions for energy efficiency, cost reduction and emission control.
Your conclusion on the relevance of this research with respect to your own research:	In this research, they have optimized energy use, costs, and emissions this complements my work on data-driven greenhouse climate control. Multi-objective algorithms enhance efficiency and sustainability. Integrating these methods will refine predictive climate models for better resource management.

Paper 12: Prediction of Greenhouse Indoor Air Temperature Using Artificial Intelligence (AI) Combined with Sensitivity Analysis [13]

Title of the paper:	Prediction of Greenhouse Indoor Air Temperature Using Artificial Intelligence (AI) Combined with Sensitivity Analysis
Name(s) of author / authors:	Pejman Hosseini Monjezi, Morteza Taki, Saman Abdanan Mehdizadeh, Abbas Rohani, Md Shamim Ahamed

Motivation for doing the research:	The research was carried out in order to solve the problems of precise prediction and management of the greenhouse indoor air temperature. The aim was to establish the possibility of applying AI based models such as RBF, SVM and GPR in the estimation of indoor air temperature in an even-span polycarbonate greenhouse.
The research problem / objective:	The research problem is to build precise machine learning models that can estimate the indoor air temperature of an even-span polycarbonate greenhouse. The objectives of the research are as follows: • AI based models for estimating the indoor air temperature of the greenhouse are investigated. • The performance of the models is compared and the best performing model is identified. • The selected model is optimized by tuning the input parameters and the dataset size. • The spread factor and the number of neurons in the hidden layer are investigated in relation to the accuracy of the model.
Is this research original?	The research compares the performance of three different artificial intelligence based models for predicting the indoor air temperature of a greenhouse where i would mean it is original.
Chosen research approach / methodology:	This study looks into exploring the use of AI–based models for accurate and optimal prediction of greenhouse indoor air temperature. This paper looks at the problem of exact temperature control as a critical factor that can improve plant yield and resource utilization.
Reported results / products / effects:	The study focuses on AI based models to predict greenhouse indoor air temperature to increase the accuracy and efficiency. This is because precise temperature control is important in plant growth and energy management hence accurate forecasting is crucial for proper climate control.
What are the contributions / conclusions?	The main contributions or conclusions from the research are as follows: • The RBF model is the best in predicting the indoor air temperature of the greenhouse. • The accuracy of the RBF model is a function of the dataset size, the value of the spread factor, the number of neurons in the hidden layer, and the type of training algorithm. • The RBF model can be applied to the development of a smart control system for greenhouses to optimize energy use and improve crop production. • Controlling the energy flow in a greenhouse using intelligent ANN models may result in a substantial reduction in energy consumption and costs.
Your evaluation of	To train RBF, SVM, and GPR AI models, environmental sensors gather information on temperature, humidity, solar radiation, and wind speed. The

the reported results with respect to the research objective:	sensitivity analysis is performed on inputs; hence, RBF is further tuned by adjusting the spread factor and neurons. In addition, this improves the greenhouse air temperature forecasting.
Your conclusion on the relevance of this research with respect to the field in general:	This research is helpful in enhancing the domain of smart agriculture by showing the efficiency of AI-based models in predicting the greenhouse indoor air temperature which can then be used in the control systems to improve the climate and increase the yield of crops.
Your conclusion on the relevance of this research with respect to your own research:	In this regard, the research I have conducted is in harmony with my project of creating a data-driven greenhouse climate control system. The effectiveness of AI based models in predicting greenhouse indoor air temperature as found in this study is directly applicable to my work and the development and implementation of my climate control system.

Paper 13: Optimal Solar Greenhouses Design Using Multiobjective Genetic Algorithm [14]

Title of the paper:	Optimal Solar Greenhouses Design Using Multiobjective Genetic Algorithm
Name(s) of author / authors:	Bahram Mahjoob Karambasti, Mohamad Naghashzadegan, Maryam Ghodrat, Ghadir Ghorbani, Roy B. V. B. Simorangkir, and Ali Lalbakhsh
Motivation for doing the research:	The motivation is to improve the ineffective energy consumption in greenhouses especially in the subtropical climate areas. The study was conducted to find the best physical parameters of common greenhouses in the northern Iran to maximize the solar energy harvesting in a year.
The research problem / objective:	The purpose of optimizing greenhouse design was to achieve the maximum use of year round solar energy, due to low efficiency in subtropical climates. The study was aimed at determining the optimal parameters for even-span, modified arch and Quonset greenhouses. The aim was to improve solar gain in winter without overheating in summer.
Is this research original?	A new approach uses multi objective genetic algorithms for optimization of solar efficiency in greenhouse in all seasons. New design parameters and thermal modelling are incorporated to enhance energy performance. This framework is scalable, sustainable and cost effective for agricultural practices.

Chosen research approach / methodology:	Multi-objective genetic algorithms optimized greenhouse design for year-round solar efficiency. Thermal modeling and simulations determined ideal structural parameters. The approach enhances energy use and adaptability across climates.
Reported results / products / effects:	A multi objective optimization framework balance solar gain in winter and minimize overheating in summer to increase greenhouse energy efficiency. Genetic algorithms are used to optimize the structures which reduce energy consumption by 15-25% and improve light distribution. The model is general for sustainable greenhouse farming and energy efficient agricultural infrastructure.
What are the contributions / conclusions?	• An optimal greenhouse design developed using genetic algorithms for year-round solar efficiency. • Improved energy use by 15-25% through better thermal performance. • Simulated balanced solar capture to avoid overheating. • Introduce Ellipse Aspect Ratio (Z/W) for improved light distribution. • A scalable and adaptable model for a variety of climates and different types of greenhouses. • Boosted sustainability by enhancing energy efficiency and decreasing the carbon footprint.
Your evaluation of the reported results with respect to the research objective:	The research makes a useful contribution by introducing a systematic, data-driven way to solar greenhouse design optimization. It is scientifically sound, an original approach, and could have useful application to sustainable agriculture. But further adding to its geographical scope, incorporating real-time regulation, and looking at combined energy systems would increase its relevance even more.
Your conclusion on the relevance of this research with respect to the field in general:	Through the integration of genetic algorithms, this research improves the design of solar-efficient greenhouses with a reduction in energy consumption of 15-25%. It improves the structural parameters to enhance the thermal performance of the building throughout the climates. The results of this research are useful for sustainable agriculture and the improvement of resource management.
Your conclusion on the relevance of this research with respect to your own research:	From this research, I could incorporate a genetic algorithm-driven optimization to enhance my climate control system's predictive modelling. Its finding on the solar energy efficiency is consistent with my objective of cutting down the greenhouse energy consumption while optimizing plant growth. The methodology can be used as a starting point for improving multi-objective optimization in my simulations. and so a genetic algorithm based on the parent algorithms is proposed to solve the optimization problem of the model.

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