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Optimization of Greenhouse Production process: An Investigation of Energy efficiency potentials

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Abstract— Political focus has in recent years focused on climate and energy efficiency as part of the global goals of a fossil-free future. The introduction of the term industry 4.0, the fourth industrial revolution, provides a solution. Industry 4.0 seeks to combine the real and virtual space to achieve maximum efficiency and autonomy. This paper aims to investigate the energy efficiency potentials in the industrial production processes with a case study of a large commercial greenhouse grower in Denmark. The discrete event simulation software- Arena is used in this study for performing the simulations of the greenhouse production. The simulation results in the total yearly electricity consumption of 1,970.83 MWh. This paper finds that there is not big energy efficiency potential in the greenhouse production process without response to the hourly electricity price signals, and the results indicate a bottleneck at the transportation from the arrival and cutting station.

Keywords—commercial greenhouse growers, production process, simulation, energy efficiency, industry 4.0

I. INTRODUCTION

All over the world, political goals have been set to reduce the use of fossil fuels in the near future, e.g. Denmark aims to become fossil-free by the year 2050. This has led to industries focussing on how they can participate in this without causing too much influence on their production or industrial processes. With this forthcoming transition, industry 4.0 is believed providing a promising solution. Industry 4.0 is used to describe the fourth industrial revolution. It describes, amongst others, what solutions can be used to improve energy efficiency and autonomy. The importance of the industry 4.0 technologies have been analysed and described along with other topics related to the development of the future smart grid structure and energy efficiency plays an important role.

Therefore, this paper aims to investigate the energy efficiency potentials in industrial processes by applying industry 4.0 technologies, analyse and optimise the production process of commercial greenhouses. Commercial greenhouses are chosen, as there is large electricity use in the greenhouse production process.

The discrete event simulation software- Arena is used in this study for performing the simulations and Arena allows to simulate with large data sets. This paper aims to simulate the greenhouse production process, with the focus of optimising energy consumption based on the electricity prices from the Nord Pool Spot market (the Nordic electricity wholesale market) and data from a large

commercial greenhouse grower in Denmark. A scenario is simulated to investigate the possibilities of energy efficiency.

II. BACKGROUND

A. Energy and Industry 4.0

Energy is considered to be the most essential resource for future economic growth, and governments and big manufacturing companies all over the world have begun placing energy efficiency on top of their agenda [1]. This has to do with the increasing awareness of global warming, rising energy prices, and consumers' steadily increasing ecological understanding [1]. Energy efficiency has proven to be not only cost effective, but it can also improve companies' productivity and energy security [2]. [2] argues that with the current technology, energy efficiency improvements can save as much as 30 % of the energy consumption. In order to do so, there is a need for detailed real-time data regarding both products and processes [2]. This is introduced with the term industry 4.0, first introduced by the German Government in 2011 to describe their future high-tech industrial development strategy [3, 4]. According to [3], industry 4.0 is often referred to as the fourth industrial revolution, hence the name industry 4.0. The aim of industry 4.0 is to combine the real and virtual space to achieve maximum efficiency and autonomy. This is done through cyber-physical systems [3]. Previously, research has focussed mostly only on reviewing and monitoring consumption in order to keep historical records of consumption and this does not provide a foundation for decision making [2]. Industry 4.0 will deeply change social production and thereby shape our lives [5, 6].

B. Key Elements of Industry 4.0

[4] gives a description of the general vision of industry 4.0 and points out four crucial points that are key features of industry 4.0:

- All production, transportation, and consumption systems and related machinery are integrated into cyber-physical systems.
- Smart factories are distributed in different places and every factory can respond as required based on global optimisation.
- The smart product system, enterprise management system, business process, and consumption system are deeply integrated, and the full life cycle of a product is used to improve its design and production.

- Smart machines in the assembly line are completely digitised and each of them can autonomously exchange information, triggering action and controlling each other independently.

Furthermore, [3] describes seven key enabling technologies of industry 4.0, and the technologies are described in TABLE I.

TABLE I. SEVEN KEY ENABLING TECHNOLOGIES OF INDUSTRY 4.0

Industry 4.0 technologies	Description
Intelligent robots	Intelligent robots have a range of sensors attached to them (including the ones controlling their own system) that allows them to mimic human senses. This allows them to make their own decisions based on the environment. These sensors include hearing, sight, touch, and movement [7].
Automated simulations	Automated simulations give the opportunity to simulate complete manufacturing cells and systems. This allows for designing and validating through both time- and event-based simulation methods [8].
Internet of Things	IoT is defined as a network of electronic units capable of gathering and sharing information through sensors. This means that IoT will allow the internet to be not only something we use, but also something our devices use. It can be used for things like agriculture, where it can monitor the grounds of humidity, temperature and quality [9].
Cloud computing	Cloud computing is the delivery of computing services over the internet (the cloud). This means that you always have access to your data no matter where in the world you are located (as long as you have an internet connection) [10].
Additive manufacturing	Additive manufacturing is the opposite of the known way of producing a good. Instead of removing material in order to produce the good, it only uses (adds) material to produce the good. A well known example of this is 3D printing [11].
Augmented reality (AR)	AR comes from the term augment, meaning to add or enhance something. This is the reason behind the name of the term, as you add or enhance the reality of the user. AR uses the natural environment and adds an overlay of virtual information on top of it, so that you can get e.g. a virtual dinosaur in your living room [12].
Big data analytics	Big data analytics is a description used for the complex process of examining large and varied data sets. This often involves complex, predictive models, statistical algorithms and what-if analysis in order to better control a large data set [13].

C. Commercial Greenhouse Growers

In recent years, energy efficiency and optimisation have risen to be on the top of governments' priority list [14], and industries such as commercial greenhouse growers have been the focus. Studies have been conducted to see how the transition to a more climate-friendly future can be done without compromising the production process, and suggestions such as replacing current lighting systems with Light Emitting Diodes (LED) lighting have proved to reduce the electricity consumption with as much as 40 percent [15]. According to [16], greenhouses have high energy consumption which can account for as much as 50 percent of the total costs of greenhouse production. In their study [16] states that the high consumption hinders further development of greenhouses that the prediction of the consumption is one of the keys to optimise and improve energy efficiency.

As part of this transition, the Danish Energy Agency (DEA) and Dansk Gartneri have entered into an agreement that secures an energy reduction of 5 percent, corresponding to 12 GWh, over the next three years (from 2018) [17]. This agreement requires commercial greenhouse growers to continuously optimise their production, which has generated an interest in optimising on an important, large energy consumer in Danish society.

Alongside with this increased focus on optimising energy consumption, the term of industry 4.0 has been introduced. One of the key enabling technologies of industry 4.0 is automated simulations, which gives the user opportunities to simulate complete manufacturing components and systems, and optimise e.g. motion and cycle times of robotic paths through time- and event-based simulation methods.

- Energy saving potential in greenhouses

A large amount of energy used at greenhouses means that there is a potential of using renewable energy in the production. Greenhouses have already use intensive and efficient renewables energy such as wind and solar power. Adding the immense amount of energy used for indoor climate conditioning and photosynthetically active radiation for plants, the potential amount of energy savings reached by implementing renewable energy sources is huge [18]. The technology used for making these savings depend on the location of the greenhouse facility. The most significant advantages and disadvantages in relation to greenhouses when implementing renewable energy sources are shown in TABLE II.

TABLE II. MAIN ADVANTAGES AND DISADVANTAGES OF USING RENEWABLE ENERGY IN A GREENHOUSE [21]

Advantages	Disadvantages
Do not consume fuels Long lifetime (10–15 years) Minimal environmental impact Low operating and maintenance costs	High initial costs Limited service access High electrical loads are needed to power a greenhouse

- Automation and Control of greenhouses

Automation and control systems can allow greenhouses' self-regulation, e.g. climate conditions. Control systems generally consist of sensors, such as heating and cooling systems, and a computer-based controller [19]. Digital systems have been used for many years in greenhouses, and advanced digital real-time systems have been introduced to improve and optimize the systems [19]. This allows greenhouse operators to constantly change greenhouse setup based on environmental conditions. Fig. 1 illustrates a diagram of a typical high-tech greenhouse.

Automation is a vital part of industry 4.0. This has to do with the possibility of creating a virtual model that can simulate the actual greenhouse production without having to change anything on site. By creating a model, the problem of creating new changes to a production without knowing the consequences is solved. Instead of changing or configuring the actual production, a model of the production will make it possible to take all parameters into account, leading to the hypothesis: If a simulation can represent the actual greenhouse production, then the process

improvement will be possible to investigate with virtual model reconfiguration.

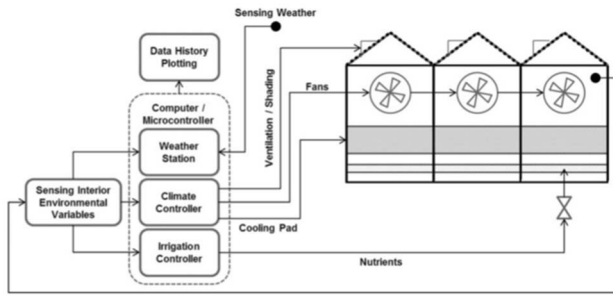


Fig. 1. Diagram of typical high-tech greenhouse [22]

III. METHODOLOGY

This paper simulates the greenhouse production process of a large commercial greenhouse grower in Denmark. A scenario is performed to investigate the optimization of energy consumption in the production process with the electricity prices from the Nord Pool Spot market (the Nordic electricity wholesale market).

The simulation is designed with the discrete event simulation software- Arena. Simulation software is a tool used in system optimisation. It represents the complete digital footprints of existing systems, and simulation models allow for e.g. business managers to understand the consequences and benefits of their decisions without taking any risk [20]. To represent the physical system of greenhouse production, this paper collects data from a large commercial greenhouse grower in Denmark. Greenhouse production and layout are shown in Fig. 2.

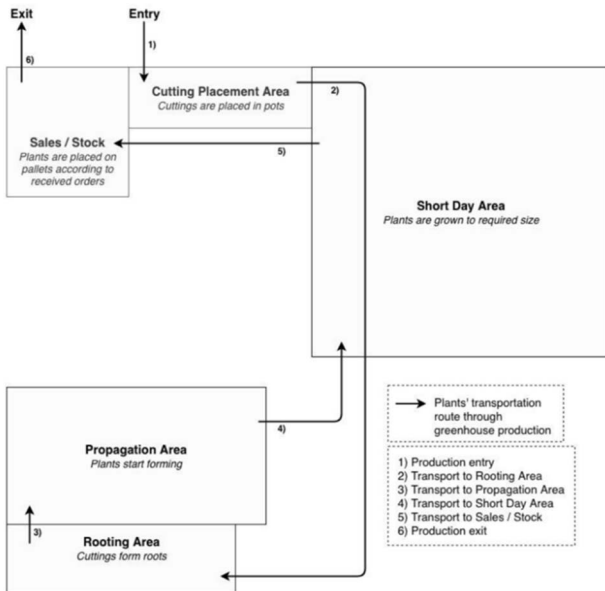


Fig. 2. Greenhouse layout

A. Greenhouse Production and Layout

The entry of greenhouse production is the cutting placement area. The arriving cuttings proceed through the greenhouse as follows: The cuttings arrive at the greenhouse in batches of 5,000 each 24 hours from a remotely located

grower in Turkey, where they have optimal conditions for growing cuttings.

Upon arriving at the greenhouse facility, the cuttings are transported to the first station in the process. At the cutting station, cuttings are manually placed in separate pots by 3 persons operating the station. They are placed in small pallets and continue by a conveyor belt to the rooting area. Just before entering this station, the plants are sprayed with anti-fungi to prevent them from rot, unwanted bacteria, or missed growth.

The plants enter the rooting area, which is optimised for the cuttings to grow a small network of roots. While in this stage, the cuttings are subjected to a temperature in the range of 22 - 24 °C and LED lighting of 40 micromoles. In order to represent an optimal day containing the correct amount of daylight, the daylight cycle is set to 17 hours of light and 7 hours of dark. The cuttings stay in this area for ten days and proceed to the propagation area by conveyor belt.

In the propagation area, which purpose is to grow the plants from cuttings with small roots into small actual plants, the temperature is set to 19 °C during the day and 21 °C during the night, where the daylight cycle is set to 17 hours of daylight and 7 hours dark. While in the propagation area plants are subjected to a combination of High-Pressure Sodium (HPS) light of 100 micromoles and 25 micromoles LED lighting. After being held in the propagation area for 18 days, the plants are placed on a new conveyor belt and are transported to the largest greenhouse at the facility, the Short-Day Area.

In the Short-Day Area, the plants are grown to the required size and height, a process lasting for 72 days. Here the small plants are exposed to 100 micromoles HPS lighting and a temperature of 19 °C during daytime and 21 °C during night time. The daylight cycle is 10 hours of daylight and 14 hours dark. When the plants have been at this stage for 72 days, they proceed to either stock or sell. On the conveyor belt traveling the plants, a sorting machine is placed. This makes sure that all plants can meet the strict requirements of the grower. If they do not meet the requirements, the plants are transported back to the Short-Day Area for further growth.

B. Simulation

The purpose is to develop a scenario that represents the production line at the commercial grower. By developing a virtual production line, any change in production can easily be simulated without compromising the actual production. The scenario can also be used for developing further scenarios for investigating future improvements with the consideration of electricity price, weather data, and gas price. To represent the production line, essential data about the entire greenhouse production is needed. The data includes the number of cuttings arriving per batch, the arrival interval, and the length of conveyor belts, etc. The data needed to develop a complete model of greenhouse production is shown in TABLE III below.

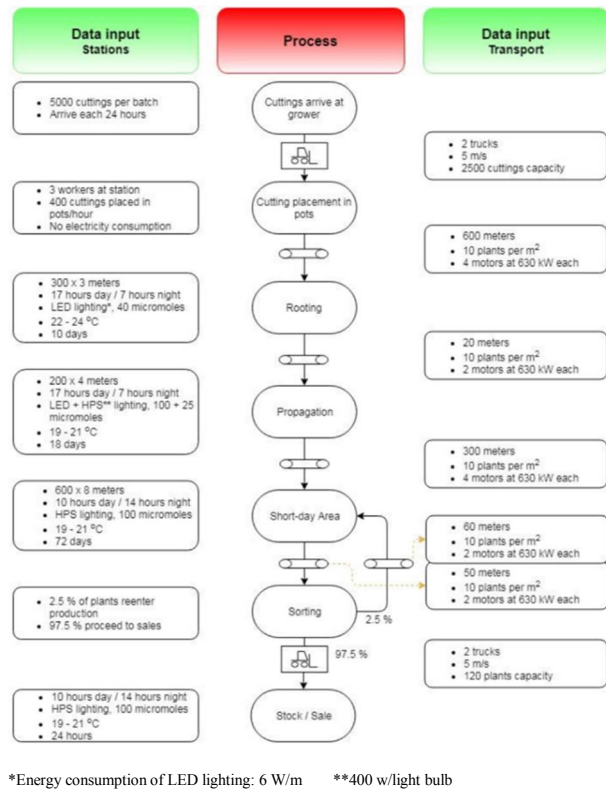
TABLE III. DATA INPUT FOR THE MODEL

Process	Entry of cuttings	Transport	Cuttings	Transport	Rooting	Transport	Propagation
Info needed from grower	How many cuttings per batch	What kind of transport?	How many workers per shift?	Length	Lighting: Effect, usage	Length	Lighting: Effect, usage
	How often do they arrive?	If truck, how many are used?	How many cuttings per hour?	Electricity usage	Heating: Effect, usage	Electricity usage	Heating: Effect, usage etc.
		Length of transport	Greenhouse capacity	Plants per m ²	Greenhouse capacity	Plants per m ²	Greenhouse capacity
Process	Transport	Short-day area	Transport	Sorting	Transport	Stock	Sale
Info needed from grower	Length	Lighting: Effect, usage	Length	How many plants re-enter production?	Length	Lighting: Effect, usage	
	Electricity usage	Heating: Effect, usage etc.	Electricity usage		Electricity usage	Heating: Effect, usage	
	Plants per m ²	Greenhouse capacity	Plants per m ²		Plants per m ²	Capacity	

IV. CASE STUDY

A. Assumptions

Some assumptions are set up, as the greenhouse production process is a very complex system. The model only implements electricity consumption, not heating, as the main energy consumption of greenhouses is the lighting. Some consumption is not considered to simplify the model, e.g. it is assumed that there is no energy consumption at the cutting station, as pots are manually placed at the cutting station. Fig. 3 shows an overview of greenhouse production processes with the assumptions has been made.



*Energy consumption of LED lighting: 6 W/m **400 w/light bulb

Fig. 3. Flowchart of the Arena model with assumptions

B. Simulation

The production processes at the commercial grower are modeled using the simulation software Arena. Fig. 4 depicts the Arena model for the production, consisting of four main segments: 1) Cutting arrivals (red square), 2. Plant transportation (green square), 3. Plant processing (blue square), 4. Plant departure (black square). The developed model of the greenhouse production is set to run for a full year, as this yields a more exact replication of the production. Fig. 4 also shows the simulation while running. From the simulation, the results regarding electricity consumption are presented in TABLE IV.

From TABLE IV, it is evident that the largest amount of electricity is consumed by the short-day process, which is expected because the Short Day Area is the largest process in production. The results also conclude that the amount of energy consumed in the transportation section is higher than in production.

The utilization of the stations, cutting flow and waiting times, and utilization of stations are shown in Fig. 5, Fig. 6, and Fig.7. The figures show that there is a bottleneck at the transport from arrival and transport from the cutting station. These issues can be handled by e.g. using more trucks at these stations or upgrading the capacity of trucks.

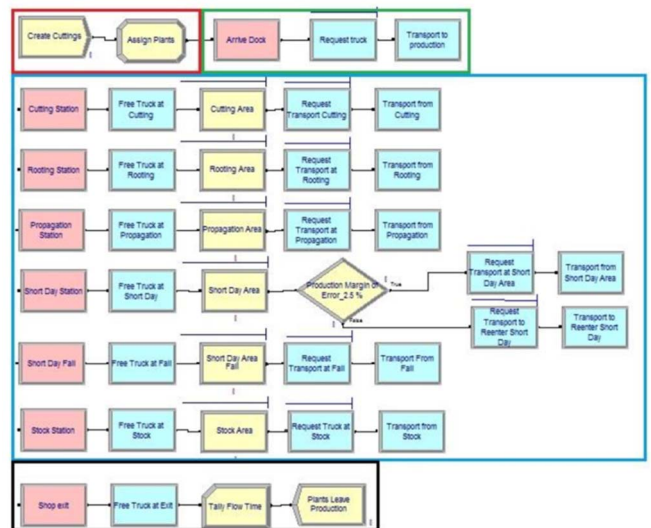


Fig. 4. Arena model of commercial grower production

TABLE IV. ELECTRICITY CONSUMPTION OF PRODUCTION

Process	MWh / year
Truck Transport from Arrival	8.176
Cutting Process	-
Transport to Rooting	958.125
Rooting Process	1.396
Transport to Propagation	31.937
Propagation Process	83.974
Transport to Short Day Area	479.062
Short Day Process	292.0
Sorting Transport (back to Short Day Area)	95.812
Transport to Stock	8.176
Stock Process	12.166
Total production consumption	1,970.826

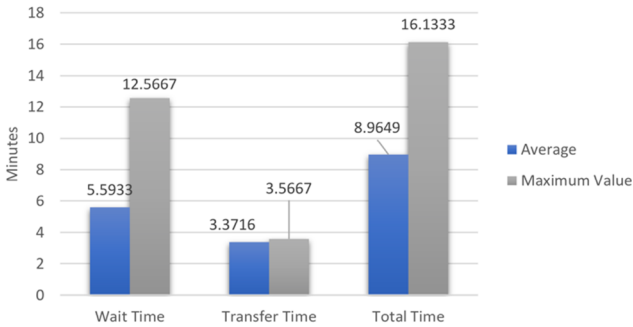


Fig. 5. Waiting and transfer times of plants

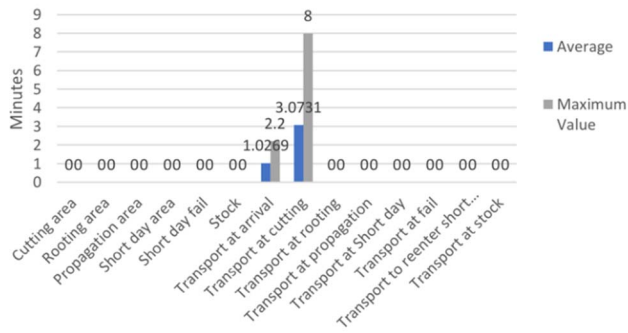


Fig. 6. Waiting time at processes

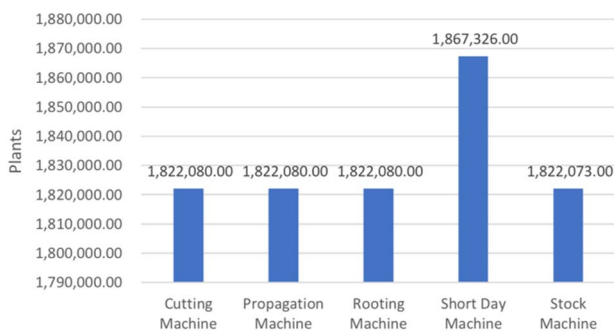


Fig. 7. Plants processed by stations

Resource - Basic Process									
	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics
1	Cutting Machine	Fixed Capacity	1800	0.0	0.0	0.0		0 rows	<input checked="" type="checkbox"/>
2	Rooting Machine	Fixed Capacity	1800	0.0	0.0	0.0		0 rows	<input checked="" type="checkbox"/>
3	Propagation Machine	Fixed Capacity	1600	0.0	0.0	0.0		0 rows	<input checked="" type="checkbox"/>
4	Short Day Machine	Fixed Capacity	96000	0.0	0.0	0.0		0 rows	<input checked="" type="checkbox"/>
5	Stock Machine	Fixed Capacity	400	0.0	0.0	0.0		0 rows	<input checked="" type="checkbox"/>

Fig. 8. Dialog spreadsheet of the Resource module

V. DISCUSSION

The simulation model is developed from a starting point in the actual production of a commercial greenhouse grower. All inputs of the model are defined for each section in the production process. The plants are defined to arrive in batches of 208.33 every 60 minutes, and the factors subject to calculations are defined. The sequence that each plant follows in the production is defined in the model along with the transportation required for each process. The distance between each station is outlined as well. The process of the plants at each station is specified including the processing time, energy consumption, and capacity. As in general greenhouses experience a production error of 2.5 percent that plants do not meet the requirements, a decide module was implemented to represent this occurrence. Finally, the plants are defined to leave the production with the flow times and energy consumption as the model output.

To develop a complete model, some assumptions have been made. Firstly, the plants are set to proceed to the production as separate entities. This deviates from the actual production that plants move on pallets in units of an unknown number of plants. To compensate for this assumption, each station is given a capacity equivalent to the number of plants the individual station is capable of handling at a time, as shown in Fig. 8.

Other assumptions such as 5,000 plants enter the production every 24 hours, the truck capacity, and length and effect of conveyor have been assumed due to limited data access. The values used in the model may, therefore, deviate from the actual value. However, the values give an indication of how a greenhouse production functions in practice and are therefore considered valid in terms of the development of a model representing the production of a commercial grower.

The simulation model indicates that the largest energy consumption is from the transportation section. Actually, large energy consumption in production is not considered. For instance, the model only considers lighting consumption in different processes. In reality, there are numerous other consumptions such as heating, ventilation, and the machinery itself. This is not included in the model due to limited access to data, but would result in greater energy consumption at the stations themselves. A complete model would in terms yield a more precise simulation of the production process and the energy consumption at the greenhouses and would be the next step in the development of a general model, that can be used as a template to simulate the production and energy consumption of any commercial greenhouse grower.

VI. CONCLUSION

Climate change and energy efficiency as a part of the global goals of reducing the use of fossil fuels. There is an increasing focus on industries for optimizing production from both financial and energy saving without compromising production processes. Industry 4.0 plays an important role in optimizing the production of industries, since automated simulations and big data analytics is used to complete this task.

The paper investigates energy efficiency potentials in commercial greenhouses. Commercial greenhouses have been found to have immense potential in terms of using renewable energy sources to supply greenhouses with electricity. To investigate the energy efficiency potential in greenhouses, one of the largest greenhouses in Denmark was chosen as a case investigation.

To simulate the greenhouse production process, the software Arena Rockwell was used based on its possibilities to simulate and analyze existing and proposed systems. Arena Rockwell was used to developing the model that represents the greenhouse production process as a virtual model can easily be altered, and any change in the production can be simulated without compromising production. In the development of the models, the assumption regarding the production had to be made. The most important one being that the models only consider lighting as an energy consuming factor, not heating or ventilation. The model simulation results showed that the total yearly production consumption was 1,970.826 MWh. The result also indicated a bottleneck at the transportation from the arrival and cutting station.

This paper finds that there is not big energy efficiency potential in the greenhouse production process without response to the hourly electricity price signals. For example, the rooting process is an intolerable process, because production quality does not allow for any gap in the daylight cycle. It is strictly needed to subject the plants to 17 hours of light without interruptions. Therefore, a future scenario representing the production at commercial greenhouses can consider how to optimize production under these conditions.

In the commercial greenhouses, the lighting schedule management, to some extent, can be changed as long as the requirements of the plant's growth is maintained. This paper recommends investigating a scenario with the integration of response to the hourly electricity prices and weather data to greenhouse production. This scenario can investigate the energy flexibility potentials in the greenhouses via implicit demand response programs. Demand Response (DR) is defined as consumers change of normal electricity usage in response to changing electricity prices over time [21]. By using implicit DR, the commercial greenhouse growers would define a threshold value of the electricity price, and determine to response hours with extreme electricity prices. The developed scenario can be used for developing further scenarios with the consideration of electricity price, weather data, and gas price. Based on this commercial greenhouse growers can reschedule their production to match the optimum.

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