Spring 5-15-2022

A Model for the Sustainable Achievement of the Optimum Return for Crops in Greenhouses

Eman ElNahas
emnahas@aucegypt.edu

The American University in Cairo

School of Science and Engineering

A MODEL FOR THE SUSTAINABLE ACHIEVEMENT OF THE OPTIMUM RETURN FOR CROPS IN GREENHOUSES

Construction Engineering Department

In partial fulfillment of the requirements for the degree of Master of Science

By

Eman Mohamed El Nahas

Bachelor's degree of Engineering

Under the supervision of:

Dr Ossama Hosny

Professor and Graduate Program Director, Construction Engineering Department, AUC

Dr Amr Serag-Eldin

Professor, Mechanical Engineering Department, AUC

March 2022

DEDICATION

This thesis is dedicated in memory of my valued and precious father Eng. Mohamed El Nahas who passed away in 2019. His continuous support, motivation, and love never failed to build me up and be who I am today. I pray for his great soul to continue to rest in perfect peace. I also dedicate this dissertation to my mother, husband and son. Their non-stopping support, encouragement and love have sustained me throughout my life. Many thanks to my family and friends who are always by my side and support me throughout the process. I am extremely grateful to have you all in my life.

ACKNOWLEDGMENTS

I would like to express my special thanks of gratitude to my supervisors Dr Ossama Hosny and Dr Amr Serag-Eldin who gave me the golden opportunity to do this wonderful thesis project and for their continuous guidance and support throughout this research. I feel immense pleasure to Bartlett funds which has been used for a noble and generous cause. A special thank you is addressed to Dr Ahmed Abdel Hady for his enormous support especially in the crops' section. I would also like to thank all involved professors, professionals and companies who either directly or indirectly helped in the completion of this research. Thank God for his endless blessings, knowledge and strength to make this research finally see the light.

ABSTRACT

This study provides a tool for accurate estimation of the irrigation water needs for various crop combinations under different environmental conditions; and employs a genetic optimization algorithm to reach optimum combinations. In the interest of sustainability, the source of energy required to drive the pumps is selected to be a renewable source, namely solar energy, which is converted to electricity employing photovoltaic (PV) modules. Having a single crop will lead to an uneconomical system because the PV installed capacity will not be exploited most of the time.

This research was conducted by establishing the required database, generating different scenarios, assessing the economic performance along its life, forming the optimization model using genetic algorithm (GA), and implementing the model using *Microsoft-Excel.* The database includes data on greenhouse crops' irrigational requirements, crop prices and cultivation costs, as well as data on PV water pumping (PVWP) system. The application of the model is demonstrated for the case of optimizing the selection of a combination of crops in greenhouses from a pool of different crops, for the maximum equivalent annual return for two selected sites in Egypt. The water needed for irrigation was correlated to ambient temperature, soil type, water source, crop type and planting season which led to better determination for the required pumping energy. The output from the irrigation pumps depends on the matching of the characteristics of the PVWP system with the locally available instantaneous solar energy, and on meeting the dynamic characteristics required from the irrigation system.

Two optimization criteria are presented: one for the minimum required PV capacity, and the other for the combination producing maximum return on investment. Moreover, using the developed tool, the PVWP system is compared to a conventional diesel driven pumping system taking into consideration the effect of the most sensitive economic and environmental parameters such as crops' price, irrigation water requirements and groundwater depth. The results show that the PVWP system is more economical than the conventional diesel system, in addition to the environmental gains.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

Abbreviation	Description
PV	Photovoltaic
PVWP	PV Water Pumping
GA	Genetic Algorithm
NREA	New and Renewable Resources Authority
EACF	Equivalent Annual Cash Flow
IIC	Initial Investment Cost
LCCA	Life Cycle Cost Analysis
ToP	Type of Panel
DC	Direct Current
AC	Alternative Current
WRDC	World Radiation Data Center
NASA	National Aeronautics and Space Administration
FAO	Food and Agricultural Organization at the United Nations
LR	Leaching Requirement
MPPT	Maximum Power Point Tracker
LCOE	Levelized Cost of Energy
NPV	Net Present Value

NOMENCLATURE

Symbol	Description	Unit
β	Slope of installed Panels	°
γ_S	Sun Azimuth Angle	°
Ψ	Azimuth Angle of Installed Panels	°
α	Solar Altitude Angle	°
θ_Z	Zenith Angle	°
θ	Incident Angle	°
Φ	Latitude	°
H_{TE}	Total Head Losses	m
H_{OT}	Vertical Head from Water Surface to the Ground	m
H_{ST}	Static Head	m
H_{DT}	Dynamic - Kinetic Head	m
H_F	Fractional – Pressure Head	m
ET_O	Reference Evapotranspiration	m
ET_C	Crop Evapotranspiration	m
K_C	Crop Coefficient	
LR	Leaching Requirement	m
EC_{iw}	Electrical Conductivity of the irrigation water applied	dS/m
EC_e	Soil Salinity	dS/m
E_H	Hydraulic Energy	kWh/day
E_A	Actual Energy	kWh/day
Q	Flow Rate – Discharge	m^3/day
η_N	Efficiency of Irrigation Method	%
η_F	Efficiency of Irrigation System	%
η_S	Efficiency of Subsystem (Inverter-Motor-Pump)	%
η_{PV}	Efficiency of PV Module	%
P_{el}	Nominal Power Capacity	W

P_{max}	Rating Power of PV Module at Standard Conditions	W
S	Overall Solar Area	m^2
T_C	Temperature of PV Cell	℃
$T_{C,STM}$	Referential Temperature of PV Cell	25 ℃
T_a	Ambient Temperature of the surrounding	℃
T_{cn}	Nominal Operating Cell Temperature	℃
α_P	PV Cell Temperature Coefficient	$℃^{-1}$
I_T	Collected Solar Radiation on Inclined PV Surface	kWh/m^2
I	Average Hourly Solar Radiation	kWh/m^2
H	Average Daily Solar Radiation	kWh/m^2
R_t	Net cash flow at time t	US$
i	Real Discount Rate	%
t	Time of Cash Flow	$year$

CHAPTER 1 – INTRODUCTION

1.1 General Background

As the world population continues to increase, the need for food resources increases in direct proportion. Greenhouse production has many advantages over the open-field production as better monitoring for climate conditions and proper maintenance techniques which allows to have off-season year-round production and higher yield. Greenhouse can produce up to 15 times more yield per area compared to open-field production (Padmanabhan et al., 2016). Greenhouses are categorized according to the applied technology inside them. The traditional greenhouses structure in Egypt is the single span greenhouse with 40 m length, 8.5 m width and 3.3 m height. One of the drawbacks of the single span greenhouse is the poor ventilation. During the last 25 years, Egypt has applied new greenhouse structures with double span that have better ventilation and easier management. In the middle of 1990s, new investigators in Egypt started to use multi-span greenhouses as double span ones don't suit large farming. During the last 15 years, farmers adopted Parron system to greenhouses by using wooden structure with higher height and more ventilation. They implement such technique to have better production for vegetables and tropical fruits inside greenhouses. Using wooden structures instead of steel structures will reduce the capital cost of the project so motivating more investors to start apply protective farming (Abdrabbo et al., 2019). During 1980s, low technology greenhouses started to shift to modern technology greenhouses to reduce the environmental hazards such as soil fertility degradation, and groundwater pollution that occur because of the excess use of pests and chemicals inside the low technology greenhouses (Abou-Hadid et al., 1993).

In addition, adequate and suitable water irrigation resources are essential for growth of crop producing food; indeed, there are barriers that face the reclamation of large areas of desert land such as the lack of suitable water resources and the high cost of providing water. Although surface irrigation water is insufficient on a global scale to meet our demands, there is an abundance of salt water in Earth's seas and oceans, covering 2/3 of the area of the world, as well as brackish water on land. Both of which may be adequately desalinated using techniques such as reverse osmosis, provided that sufficient energy is available. In addition, with sufficient energy we can also draw water from deep aquifers and bring them to the surface to water the crops, as well as reduce their salinity if need be. Hence long-term development requires a sustainable source of energy to be used to fill the gap in the available irrigation water resources.

The agricultural sector dependency on energy resources has been increased like other sectors (Bekhet & Azlina, 2010). The reason behind that is the modernization of many agricultural production operations such as irrigation using new techniques to save time and water loss (Isaías et al., 2019). Globally, irrigation pumps consume about 62,000,000 MWh of electricity annually (*Solar Pumping for Irrigation*, 2016). Some areas don't have access to the grid, therefore; they have to find an alternative way to get electricity. Most of these areas mainly depend on diesel, gasoline, and kerosine pumps to pump water for irrigation. Diesel pumps are the most used for crop irrigation (Argaw et al., 2003; Khattab et al., 2016). However, this might not be a proper solution especially for remote areas, as transportation cost and cost of maintenance for pumps are relatively high (Abu-Aligah, 2011). Some experts estimate that the remaining fossil fuel will be fully used within 50 years as the annual increase rate of energy consumption is assumed to be 1.4% from 2008 to 2035 (Kim et al., 2016).

This raises the importance of using renewable energy sources such as solar, wind, and biomass which are available in unrestricted quantity. In particular, solar energy is expected to have an effective role in renewable and sustainable energy development especially in remote areas (Hong et al., 2014). The installation capacities of global PV system were only 5 GW in 2005 and increased to 96 GW in 2018 (Jaganmohan, M., 2021). As for 2020, PV market went up to 106 GW (*Solar PV – Renewables – Analysis*, 2020). In Egypt, according to New and Renewable Energy Authority (NREA), the total installed capacities is around 15 MW, most of them are stand-alone systems to power different applications such as lighting systems (27%), cell phone networks (25%), advertising lighting systems (16%), communication systems (13%), cathodic protection systems (7%), water pumping systems (6%), rural electrification, refrigeration and others (6%) (Comsan, 2010). Generally, the most abundant source of renewable energy in the areas of the world which suffer most from shortage of irrigation water, such as the Sahara Desert region, is the solar energy. This also raises the importance of installing PV system to generate electricity to drive deep submersible pumps to draw water from boreholes. The PV system are characterized by durability, low carbon emissions, easy maintenance and relatively low cost for maintenance (Cossu et al., 2018; Mohamed & Abd El Sattar, 2019). The output of the PV installations is continuously variable and depends on both the characteristics of the PV modules and their components (I-V characteristic, temperature coefficient, yearly drop in efficiency, power conditioning efficiency) and the instantaneous atmospheric conditions (solar irradiation and ambient temperature).

In Egypt, the annual global solar radiation ranges between 2,000 to 3,200 kWh m^{-2} from north to south which gives a great potential for applying PV systems (Comsan, 2010; Rezk & El-Sayed, 2013). PVWP system can be a useful source to sustain agricultural production. Several studies investigated the different water pumping systems (Aliyu et al., 2018; Chandel et al., 2015; Wazed et al., 2017). However, few researchers have focused on irrigation on remote areas where water is available underground, so energy is required to draw water from boreholes to be used for irrigation. Therefore, this study contributes to study the effect of having different water static water heads, representing different allocation for the pump (surface and submerged), on sizing of the PVWP system and on the equivalent annual return.

On the demand side, the amount of daily water requirements for irrigation fluctuates widely with location, climate, season, soil type, water type and crop type. Hence if PV system is used to meet the irrigation needs of one single crop, it may be dormant most of the time if this crop is seasonal, and highly oversized the rest of the time if the summer and winter demands vary widely as the case with most crops. Hence this situation will be highly uneconomical and is also waste of energy resources.

1.2 Research Significance

Adequate and suitable water for irrigation is essential for the quality and the quantity of crops. Drawing water from deep boreholes requires a huge amount of energy that needs a sustainable source of energy to maintain the irrigation quality. A great potential for applying PV system especially in Egypt as it is characterized by high solar irradiance. The initial investment costs (IIC) of PVWP system are high which may be an obstacle that faces investigators while implementing it. Therefore, the PVWP system has to be optimized to minimize the IIC of the PVWP system. Optimizing the PVWP system requires a precise calculation for the energy needed (hydraulic energy E_H) where several factors have to be identified such as the required discharge (Q), the total head loss (H_{TE}) and system efficiencies (EL-Shimy et al., 2017). The problem that faces most of investigators is that the water discharge (Q) assumed by farmers always exceeds the optimum required amount to be in safe side. However, overestimation of the required Q will lead to over design of the PVWP system which means higher IIC. On the other hand, underestimation will lead to have improper Q which will have negative effects on the quality and the quantity of the crops.

This research investigates the optimum size of the PVWP system required to meet the hydraulic requirements for a combination of crops that have the maximum equivalent annual cash flow (EACF). It also studies the effect of changing the water source level, i.e., different static heads (H_{ST}), used for irrigation on sizing the PVWP system and on the EACF. The effect of increasing the crops' costs and decreasing the crops' price is analyzed as well. In addition to a cost analysis between the PV system and diesel generator is done to identify the cost of electricity produced from both techniques.

The significance of this research lies in finding the best utilization of the land through developing an optimization model for selecting a combination of crops that have the maximum EACF grown inside greenhouses and irrigated using PVWP system. In addition, developing a model to accurately estimate the required discharge (Q) based on climatic and soil parameters. Also, a precise estimation of the collected solar energy on tilted PV surface is identified through studying the parameters that affect the performance of the PV modules such as slope (β), type of panels (ToP), azimuth of panels (Ψ), ambient temperature (T_a) and calculating the average hourly solar radiation through developing an empirical model.

1.3 Objectives of this Research

This research has a main objective which is finding the best combination of crops inside greenhouses that have the maximum return using EACF approach; hence, providing a tool for agricultural industry to aid investigators to identify the optimum PVWP system required to irrigate the combination of crops inside greenhouses. In addition to other subordinate objectives as the following:

- Developing a model for estimating the required discharge (Q) for the combination of crops.
- Developing a model for estimating the collected solar energy on tilted PV modules considering the effect of the ambient temperature.
- Developing a life cycle economic model using EACF approach to conduct the LCCA.

1.4 Research Methodology

This Research passed through the following phases to find the maximum EACF for combination of crops grown inside greenhouses and irrigated using PVWP system as shown in Figure 1.

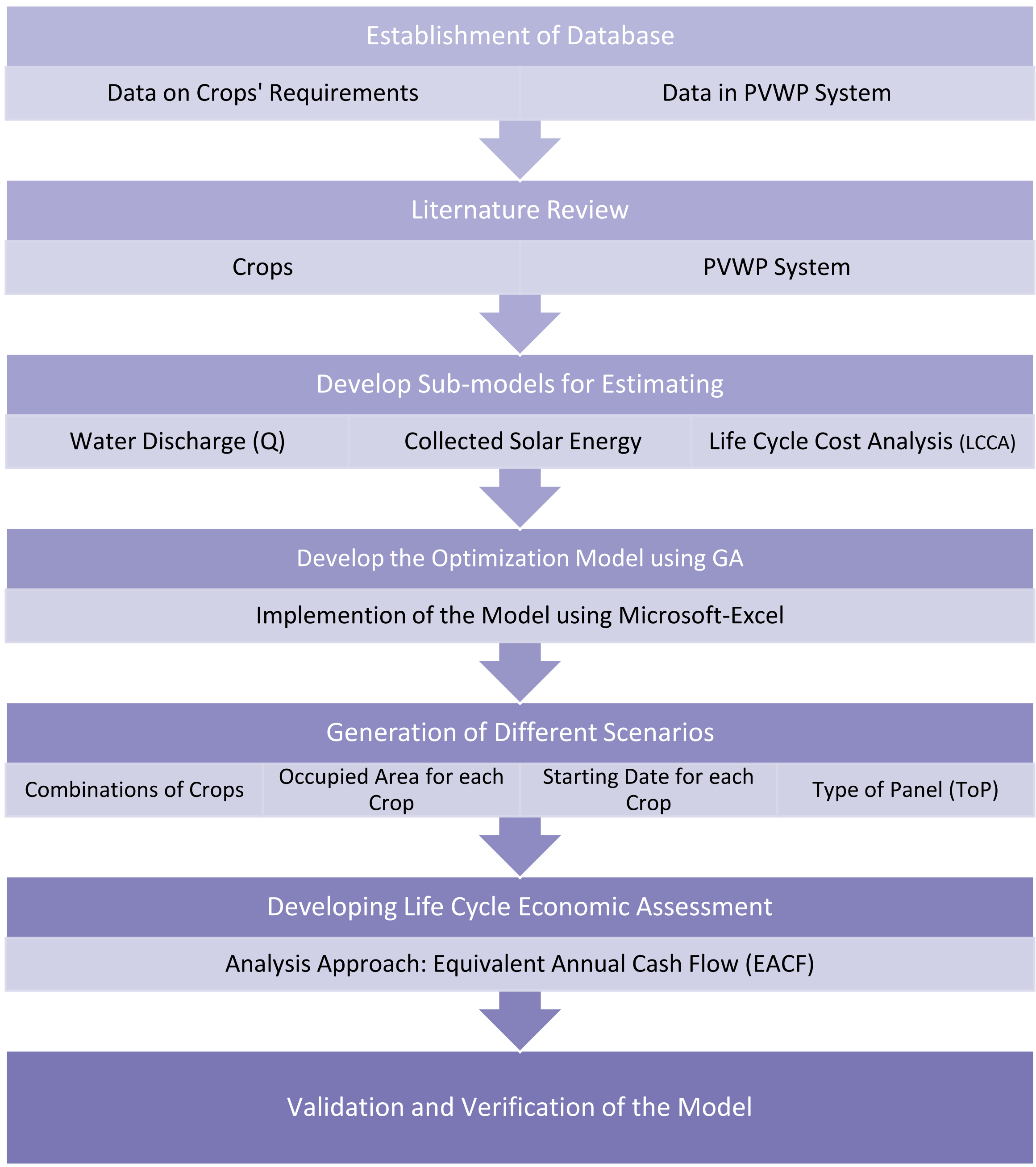

Figure 1: Research Methodology

The research starts by collecting data on crops and on PVWP system. The data on crops' requirements includes types of crops that can be planted inside greenhouses in Egypt, the starting limits and their corresponding duration, the number of seeds per specific area and their costs, the required number of workers and engineers for each crop and their salaries, the fertilizers, pesticides, and composites required and their cost, transportation costs, greenhouses' cost, and crops' prices. This is done through literature reviews and experts' interviews. The PVWP system data includes meteorological geographical information collected from National Aeronautics and Space Administration (NASA), types of panels (ToP) and motor-pumps available at the Egyptian market and their specifications. Then, a wide literature review has been conducted to understand the existing research concerning greenhouse crops and PVWP systems to identify the gaps in research regarding the selection of combination of crops grown inside greenhouses that have the maximum EACF and irrigated using an optimized PVWP system. Next, three secondary models are developed to be integrated in the main model as the following: the first model is developed to estimate the required water for irrigation for the combination of crops, the second model is developed to estimate the collected solar radiation on the tilted PV surface considering the effect of the ambient temperature and the third model is an economic model developed to analyze the life cycle cost (LCC) using EACF approach as each crop has different lifespan. After that, the main model is developed using GA as the number of possible scenarios are very large. For example, if the combination of crops is five, then the possible scenarios are equal to $21^5 \times 365^5 \times 6 = 1.58 \times 10^{20}$, i.e., 21 is the different types of crops, 5 is the number of selected crops, 365 is the possible starting dates, and 6 is the different types of panels. Hence, GA will be an appropriate technique to find the optimum solution. The model is implemented using *Microsoft-Excel* Add-in called *“Evolver 8.2”* (Palisade, 2021). Different generation scenarios are created to select the most optimum solution according to the model’s objective which is maximization of the return (EACF) by changing the combination of crops, the starting date for each crop, and the ToP. Next, the model is validated by comparing the outputs of the model for two different locations in Egypt (Luxor and Giza). Then, the model is verified in selecting the types of crops that matches the soil parameters, the maximum return on investment, and the minimum utilization for the water per economic return ratio compared to other methods. After that, the effect of changing the static head on the size of PVWP system and EACF is analyzed, in addition to the study of the effect of changing the crops’ costs and the crops’ prices on the EACF. Finally, a cost comparison between the PV generator and diesel generator is conducted to identify the cost of electricity produced from both methods.

1.5 Thesis Structure

This thesis is divided into six main chapters:

Chapter 1 – Introduction:

This chapter provides a background information about crops, greenhouses, and PVWP systems. It addresses the significance of the research objectives and methodology.

Chapter 2 – Literature Review:

This chapter includes a wide analysis of the previous research regarding the optimization for greenhouse farming, standalone water pumping system, and PV system for operating the water irrigation system. It also concentrates on the gap in the literature.

Chapter 3 – Model Development and Formulation:

In this chapter, the model development is broken-down to in-depth details to illustrate how the model is used to satisfy the objective of developing an optimization model for selecting combination of crops grown inside greenhouses and irrigated by PVWP system.

Chapter 4 – Verification and Validation of the Model:

This chapter includes verification and validation for the model. Verification is done by comparing the results of two locations in Egypt (Luxor and Giza). Concerning the validation, the model is applied through a case study and the results are compared to validate the model.

Chapter 5 – Results and Discussion:

This section includes the effect of changing the static head on the PVWP size and EACF. The effect of changing the costs of the crops and the prices of the crops on the EACF are also analyzed. In addition, the cost of electricity generated from PV system is compared to cost of electricity generated from diesel generator.

Chapter 6 – Conclusion and Recommendations:

This chapter states a summary for the work done, the research findings, limitations, and recommendations for future work.

CHAPTER 2 – LITERATURE REVIEW

This thesis investigates the development of a model for optimum return from a combination of crops inside greenhouses, therefore; this chapter provides a literature review of previous studies conducted on the following topics that includes greenhouse farming management, PVWP systems, and stand-alone PV systems for operating water pumping systems used for irrigation in Egypt. Current research gaps in the field of PVWP systems for irrigating greenhouses are summarized at the end of the chapter.

2.1 Greenhouse Farming Management

Optimizing greenhouse farming annual return is done by proper planning for greenhouse farming, resource allocation and optimizing the use of resources. Due to the complexity of the sector, most of the researchers use linear programming approach to determine the optimal crop combinations and feasibility of decision variables (Bhatia & Rana, 2020). Linear programming starts with a feasible solution and uses pivot operations to maintain the feasibility of the solution and identify the value of the objective function. Pap (2008) established a mathematical model of optimal agricultural production plan applied on a small farm located in west Vojvodina using linear programming model to maximize the total return by adopting crop rotation policy. The results indicates that applying rotation policy will aid to have higher revenues compared to the traditional crop practices (Pap, 2008). The Food and Agricultural Organization estimates that food production will need to be increased by 70% to feed the population in 2050 (International, 2009). This leads researchers to not only focus on crop yield but also on sustainable growth. Farmers usually face uncertainties problem involved in farmland revenues; therefore, Boyabatli et al. (2019) developed a dynamic model to select combination of crops under revenue uncertainty that can be cultivated in farmland (Boyabatlı et al., 2019).

Usually, crop planning is established based on maximizing the equivalent annual return. However, due to the involvement of other factors in the decision making such as environmental factors, a multi-objective model has been proposed by Raghava et al. (2012) especially in case with multiple water sources (surface and underground). Three cases for the availability of water resources have been studied. The first model was established under adequate availability of water resources, the second model was determined based on the crops allocation that were pre-decided under the availability of a limited supply of water which means that water needs to be optimally distributed among the combination of crops, and the third model was based on limited availability of water resources in which combination of crops can be selected freely. A multi-objective linear programing model was developed by formulating the three single objective functions for a multi-crop model to maximize the revenue and minimize the costs and water usage. The results showed that the optimization approach significantly improves the annual return with minimum crop allocation area (Raghava et al., 2012). In addition, Tsakiris and Spiliotis (2006) formulated a model to maximize the benefits by optimizing the irrigation pattern using multi-objective technique. The basis for classification was kept the same throughout the formulation to optimize the available resources and the net benefit was included as one of the constraints instead of making it part of the objective function. They concluded that the main advantage of the proposed methodology is that it avoids the subjectivity of assigning weights to the criteria of different natures as the two approaches were integrated and demonstrated using fuzzy set theory (Tsakiris & Spiliotis, 2006).

Sarker & Quaddus (2002) compared two versions of the crop planning problem which are single objective linear programming approach and multi-objective approach with conflicting objectives. Linear programing approach presents one optimal solution while multi-objective technique offers set of possible solutions as so provides a better vision for crop planning program and the user has to choose the appropriate solution (Sarker & Quaddus, 2002). This raises the importance of optimizing the net benefit in addition to the environmental factors such as water and energy to reach the optimum solution.

Visagie & Ghebretsadik (2005) proposed an integrated crop-livestock farming scenario in the optimization model for determining the optimum plan that increases the revenue of the farm. The results showed that crop rotation is very sensitive to risk and integrating livestock in formulation affects the land allocation and increases the production level of farming; however, it is one of the important factor that affects the gross margin and improves profitability and sustainability of the farm (Visagie & Ghebretsadik, 2005).

Optimizing the water use will aid to increase the annual return as well as optimize the resources used; therefore, Li & Guo (2014) developed a multi-objective water allocation model to optimize the economic, social and environmental benefits of an area. The results showed that the model provides a sustainable approach to allocate water resources in regions where there is lack of water resources and accordingly allocates the resources (Li & Guo, 2014). However, this requires accurate estimation for the required water for irrigation as well as the available water to be able to calculate the required energy to draw water from the water source. Studying the regional climate is essential for accurate calculations for the irrigation water requirements.

Regional climate and crop selection have a direct relationship on the required water demand and energy consumption inside the greenhouse (Hollingsworth et al., 2020). The impact of the climate variables on the plant growth and duration for yield of production during different seasons have to be studied to achieve good management practices for greenhouses (Abdrabbo et al., 2019). The major cultivation season especially for vegetable crops for greenhouses in Egypt is autumn (El-Gayar et al., 2019). Crops which are cultivated during autumn usually continue till winter or spring. Farmers tries to increase the duration of the crop, so they can have higher yield of production. However, the longer the duration of the crop, the higher amount of water for irrigation will be required.

Most of the previous models were developed using linear programing approach, however; Hosny et al. (2021) introduced a comprehensive database and multi-objective optimization model that aids the user to find efficient and economic methodology for the best utilization of land for either open field farming or greenhouse farming. However, the greenhouse farming depends on data that has to be entered by the user (Hosny et al., 2021). This means higher consumption of energy, i.e., higher cost of production. Therefore, developing a comprehensive database and having a balance between crop planning, used resources, the yield of production and energy consumption are essential to reach the maximum net benefit.

2.2 Standalone Water Pumping System for Irrigation

The main alternatives for water pumping system in case there is no grid are PV, diesel, and wind water pumping systems. PVWP system consists of three main components which are the PV modules, pump controller and electric water pump, i.e., motor and pump are connected as one unit, as shown in Figure 2 according to the Pacific Power Association (PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI) in 2019 (*Solar-Water-Pumping-Guidelines-V1*, 2019). Multiple configurations exist for the system layout and different technical components are available depending on their performance, reliability, and economic aspects (Lynn, 2010).

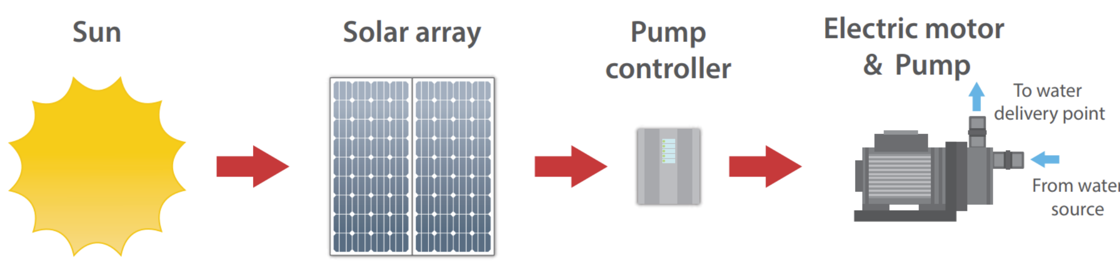

*Figure 2 : Typical PVWP System (*Solar-Water-Pumping-Guidelines-V1*, 2019)*

Several studies have identified that the PVWP system can be an attractive application for sustainable energy for irrigation. Hamidat et al. (2003) established a program to test the PVWP system performance used to irrigate regions in the Sahraa and it was concluded that PVWP systems are suitable for crop irrigation in small scale applications (Hamidat et al., 2003). Cuadros et al. (2004) illustrated how to design PVWP systems using drip irrigation method to have an effective irrigating water system for olive tree orchard in Spain (Cuadros et al., 2004). Several research on PVWP systems has focused mainly on system modelling and improvements in the system components (PV modules, controllers, inverters), performance of PVWP system under various operating heads and their effect on the environment (Fernández-Ramos et al., 2010; Kordzadeh, 2010; Matasane et al., 2014; Mozaffari Niapour et al., 2011). Glasnovic & Margeta (2007) proposed an optimization model for optimizing the PVWP size taking into consideration the required water for irrigation and the available water. They concluded that dynamic models gives more realistic results, however, the economic performance for the life cycle cost analysis (LCCA) was not covered (Glasnovic & Margeta, 2007). Kelley et al. (2010) studied the technical and economic feasibility for implementing PVWP system for irrigation and concluded that there are no barriers for applying PVWP system, however; the only barrier is the high price of the PV modules. Therefore, a LCCA is required to prove the compatibility of the PVWP system.

Many studies compared PVWP system to diesel generator irrigation system. Isaias et al. (2019) proved that the cost of the PV system over its useful life is much lower compared to diesel systems (Isaías et al., 2019). Another study was done states that the cost of the PV system represents around 64.2% of the cost of the diesel system (Shinde & Wandre, 2015). The PVWP systems overcome the problem of the fuel price fluctuations, availability, and environmental problem as PV generators don’t require fuel to operate (Tadesse et al., 2013). In addition, the PVWP system has lower LCCA compared to diesel generator used for irrigation due to the high operational and maintenance costs of diesel generators as well as the high costs associated with fuel transportation (Odeh et al., 2006); therefore, in remote areas, the diesel generator systems are not recommended. However, this might change from country to country according to the price of diesel fuel and the operation and maintenance costs where the diesel system is applied.

2.3 PV System for Operating Water Irrigation System

PV technology converts the sunlight energy into electricity through electromagnetic means. Collecting the sun energy is for free but it needs the appropriate equipment to have an optimized system. To have an optimized PV system, it is necessary to have an accurate data for solar irradiance. However, accurate data for solar irradiance are rarely found especially for remote areas where many PV systems are to be installed. To have the average hourly solar irradiance, which is required for solar energy calculation, not only expensive instruments such as pyranometers are required which is not the case in most of the developing countries like Egypt but also it requires regular calibrations that costs (10 - 15%) of the purchase price (Mohr et al., 1979). According to the official repository of the World Meteorological Organization for solar radiation data, only few data are stored in World Radiation Data Center (WRDC) (*Radiation Centres | World Meteorological Organization*, n.d.). Egypt has only 14 measuring stations. This raises the importance of developing an empirical model to calculate the hourly solar radiation on tilted PV surface.

There are various methods for optimizing stand-alone PV systems (Glasnovic & Margeta, 2009; Kelley et al., 2010; Kenna & Gillett, 1985; Qoaider & Steinbrecht, 2010). Previous studies analyzed the performance of PV system based on two important factors which are regional climates (i.e., the geographical factors and meteorological factors) and the available area characteristics (i.e., the on-site installation factors, and the available area) (Al-Badi et al., 2018; Glasnovic & Margeta, 2007; Kelley et al., 2010). Some studies have been done to maximize the performance of PV system by only considering the azimuth angle of the installed panels (ψ) which concluded that the southwest orientation is the best orientation for year round performance for the Northern hemisphere (Sánchez & Izard, 2015). Other studies have been done to maximize the average year round performance by optimizing the slope of the installed panels (β) which revealed that the optimal angle for the installed panels is the same as the latitude (Sharma et al., 2020). Gopinathan et al. (2007) developing a model to maximize the performance by introducing more than one factor. The solar irradiance was estimated based on the ψ (-90° to 90°) and the β (0° to 90°), and the results showed that the β changed as the ψ got away from south (0°) (Gopinathan et al., 2007). However, most of the previous studies ignore the effect of the ambient temperature on the PV performance.

2.4 Gap in the Literature

In Egypt, farmers typically exceed the maximum need for the irrigation of their crops as a safety factor which leads to over design for PVWP system, i.e., higher cost (Kudadze et al., 2019). Therefore, developing a model to correlate the water irrigation requirement to the available solar energy/m^2 is significantly required. Although optimizing the size of the PVWP system used for irrigation is covered in most of previous research (Glasnovic & Margeta, 2009; Kelley et al., 2010; Kenna & Gillett, 1985; Qoaider & Steinbrecht, 2010), there is still a gap in studying the way in which combination of crops and climate change affect the design of the PVWP system.

In addition, the average hourly solar radiation data is not available for most of locations in Egypt especially for remote areas where PV system is usually installed. To overcome this problem, an empirical model to estimate the solar irradiance according to monthly average global solar radiation data from NASA is greatly needed to be able to calculate the collected solar irradiance on PV surface. Most of the previous research performed that focus on optimizing the PVWP systems for irrigation lack dynamic matching between the characteristics of the PVWP system with the solar energy and environment (Fernández-Ramos et al., 2010; Kordzadeh, 2010; Matasane et al., 2014; Mozaffari Niapour et al., 2011). Therefore, developing an optimization model to select combination of crops that have the maximum equivalent annual return and irrigated by optimized PVWP system considering the solar radiation and environment is recommended.

Previous assessments for optimal PVWP systems in Egypt discarded some parameters such as groundwater availability and groundwater depth (Bhatia & Rana, 2020; Pap, 2008); therefore, different scenarios for different groundwater levels should be analyzed to have an overview of how PVWP systems size differ according to availability and depth of groundwater. Although PVWP system proves its efficiency over diesel generator system in most countries (Isaías et al., 2019). There is a lack of general comparison between the two system in Egypt; therefore, a cost comparison between PV system and diesel system was conducted to prove its competitiveness in Egypt.

CHAPTER 3 – MODEL DEVELOPMENT AND FORMULATION

This chapter details the formulation of the developed model in which the algorithm that optimizing the equivalent annual return of a piece of land by selecting a combination of crops and sizing PVWP system. The model targets the best utilization of the land by minimizing the size of PVWP system and the usage of water. As the user enters the necessary inputs, the model investigates the best combination of crops, starting date for each crop, occupied area for each crop and ToP. The purpose of the model is to find the maximum equivalent annual net cash flow (EACF) by having a dynamic simulation of PVWP system, solar irradiance, required water for irrigation, and crop yield response to season. In addition, the economic aspects of the PVWP systems are investigated. IIC and LCCA are used to compare different water pumping techniques and EACF is used to evaluate the net benefits gain, which will be further detailed in the upcoming sections.

3.1 Model Architecture

The developed model consists of five different modules: (1) inputs module, (2) database module (3) calculations module, (3) optimization module, and (5) output module. First, the user inputs all the required information for the project through the input module. Then, the database module is filtered according to the input data. Next, the calculation module uses the filtered database and the inserted inputs to calculate the required parameters for calculating crops net benefits and sizing the PVWP system. After that, the optimization modules will use these data to optimize the objective function which is maximizing the EACF by adjusting the model variables to generate the final results in the output module as illustrated in Figure 3.

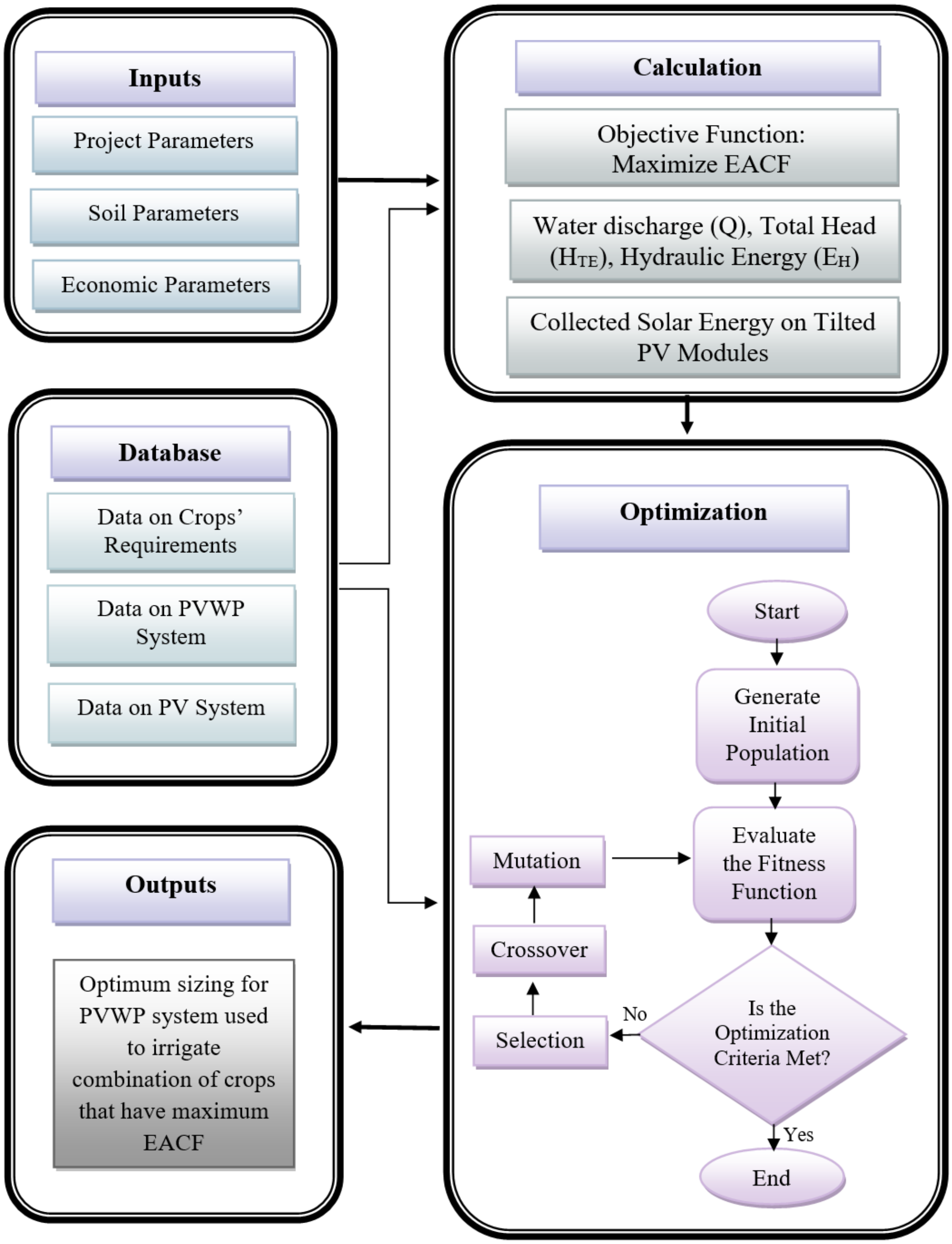

Figure 3 : Model Development Methodology

3.1.1 Inputs Module

The model allows the user to enter the required data which includes the following:

- Location
- Area (feddan)
- Budget (US$)
- Soil Salinity E_{ce} (dS / m)
- Electric conductivity E_{ciw} (dS / m)
- Irrigation method
- Cost of structure system / m^2 (US$)
- Cost of wiring / m^2 (US$)
- Annual Degradation for Electricity Output (%)

The model reads and uses the input data to optimize EACF and PVWP system for the combination of crops that have been selected by the model. The model has been developed using *Microsoft-Excel* and *Evolver 8.2* which is an *Excel* Add-in (Palisade, 2021). The model consists of several worksheets. To be able to insert the inputs, gets into the worksheet named “Model Inputs” and fill in the required data as indicated in Table 1. Inputs guide the user to include the correct data in the right place. The model has been developed to read the input data inserted by the user and share them among other worksheets to estimate the essential parameters for optimizing the model such as the reference evapotranspiration (ET_O) and the hourly average solar radiation (I).

Table 1 : Model Inputs

Insert Required Inputs	
Project Data	
Location	Giza
Land Area (feddan)	5
Maximum Budget Limit (B_L) (US$)	$100,000.00
Ece (dS/m)	1.3
Eciw (dS/m)	0.8
Irrigation Method	Surface Drip
Financial Parameters	
Future Value Discount Rate	7.00%
Cost per m^2 of supporting structure (US$)	22
Cost of Wiring per m^2 of land (US$)	5
Electrical Parameters	
Annual Output Degradation (linear):	0.60%

3.1.2 Database Module

The database module consists of three main parts: (1) data on crops' requirements, (2) data on PVWP system, and (3) data on PV system.

Data on Crops' Requirement:

The first part in the crops' requirement database contains data about the crops and trees that can be grown inside greenhouses in Egypt. The total duration for a pool of crops according to planting season are collected and summarized as shown in Appendix – (1 & 2) (Cooman et al., 2005; Retamales & Hancock, 2012; Shukla et al., 2014; Hosny et al., 2021). In addition, the crop coefficient (K_C) value for each crop during different growing stages is identified according to Cropwat that are freely distributed by the Food and Agricultural Organization (FAO) of the United States (Jamal, 2011). Also, the crops' costs are recognized according to the Egyptian market, they include the cost of making rows, seeds, fixed, temporary workers and engineers, composites, fertilizers, and pesticides as illustrated in Appendix - 3 (Hosny et al., 2021). The second part includes data about the greenhouses. There are three types of technology for greenhouses which are low, medium, and high (Groener et al., 2015). Table 2 represents total costs for different structures of greenhouses (Abdrabbo et al., 2019). In this study, the analysis was based on single span greenhouses using medium technology.

Table 2 : Greenhouse Types vs. Total Cost (Abdrabbo et al., 2019)

Greenhouse Type	Dimensions (m) (L – W- H)	Total Cost (EGP)	Cost / m^2 (EGP)
Single Span	40 x 8.5 x 3.30	36,000	100
Double Span	40 x 16 x 3.25	80,000	120
Double Span	30 x 16 x 3.30	75,000	130
Multi-Span	40 x 104 x 4	400,000	96
Wooden Greenhouse	6 x 140	200,000	22

Data on PVWP Systems:

There are different types of electrical motors that can be used to run pumps such as direct current (DC), and alternating current (AC) (Al-Badi et al., 2018; Qoaider & Steinbrecht, 2010). If DC motor is used, the PV array could be directly connected to the motor. DC motor needs continuous attention as its brushes need to be changed regularly. Usually, the motor and pump are built-in together for the submersible and floating pumps. In the surface pumping system, it is possible to choose the pump and motor separately and evaluate their performance (Meah et al., 2008). The selection of a proper pump in a solar water pumping system depends on required discharge (Q) and total head losses (H_{TE}) as shown in Figure 4 (EL-Shimy et al., 2017).

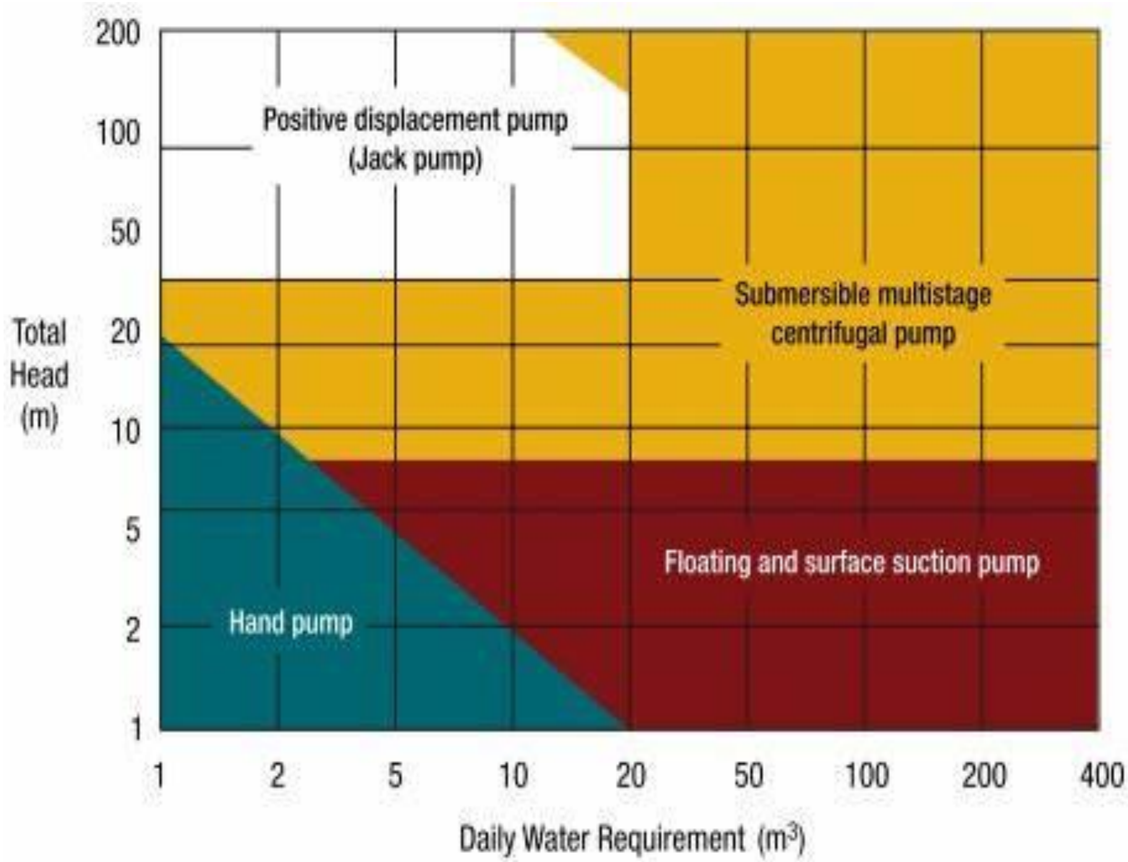

Figure 4 : Pump's Type vs. H_{TE} (m) and Q (m3) (EL-Shimy et al., 2017)

Concerning the pumps' performance, the efficiency of the pumps according to their types are presented in Table 3 (Bakelli et al., 2011). Usually, the pump controller system includes Maximum Power Point Tracker (MPPT) to assure that the solar array is delivering power at its maximum. AC powered pump has also inverter to convert the DC power to AC. The type of the inverter (single phase or three phase) is depending on the size of the motor (Kenna & Gillett, 1985). The type of the inverter is identified according to its application as indicated in Table 4 (Sinapis et al., 2015).

Table 3 : Pump's Type vs. Efficiency (Bakelli et al., 2011)

Head (m)	Pump's Type	Wire to Wire Efficiency (%)
0 – 5	Centrifugal	12 – 25
6 – 20	Centrifugal with Jet Submersible	10 - 20 20 – 30
21 - 100	Submersible Jack Pump	30 - 40 30 – 45
> 100	Jack Pump	35 – 50

Table 4 : Cost of Inverters according to Type (Sinapis et al., 2015)

Inverter Type	Sector	DC to AC Ratio
Single-Phase String Inverter	Residential PV (non-MLPE)	1.15
Microinverter	Residential PV (MLPE)	1.15
DC Power Optimizer String Inverter	Commercial PV (MLPE)	1.15
Three-Phase String Inverter	Commercial PV (non-MLPE)	1.15
Central Inverter	Utility-scale PV (fixed-tilt)	1.3 (oversized)
Central Inverter	Utility-scale PV (1-axis tracker)	1.3 (oversized)

Data on PV System:

In this study, the database of PV system involves two main parts. The first one covers the regional meteorological and geographical information for 27 governorates in Egypt collected from NASA. The global sunshine hours and solar radiation values for 27 locations covered almost all regions in Egypt are presented in "Database Module" and summarized in Figure 5. The yearly average value of sunshine hours and the global solar radiation in Egypt are calculated to be around 12 hours per day and 6.0 kWh m^{-2} day^{-1} respectively which give a great potential for applying PV system there.

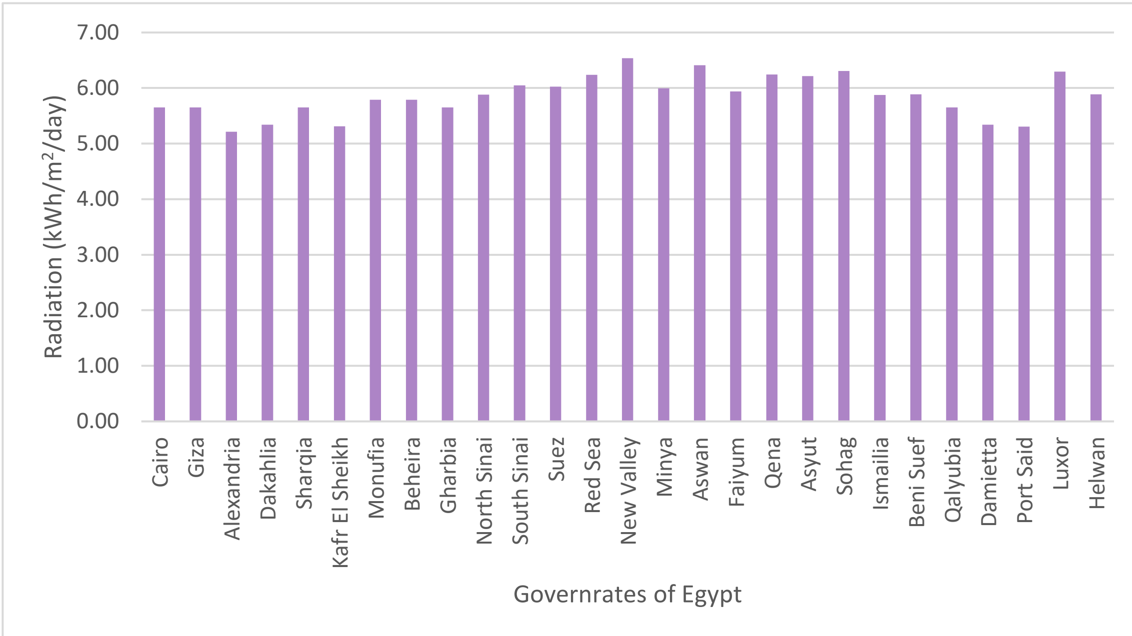

Figure 5 : Global Radiation Values

The second part deals with the specifications of the PV modules. They are categorized into six groups according to their type (monocrystalline or polycrystalline) and number of cells (36, 60, or 72) as indicated in Table 5. The physical information for the panels, i.e., capacity, efficiency, dimensions, losses, average cost, temp coefficient of power, PV transmittance, rated voltage, rated current open circuit voltage and short circuit current, were collected according to the Egyptian market.

Table 5 : PV Panels' Specification

Ref No	Type of Panel	No. of Cells	P_{max} (w)	η_r	Price (US$ / W_p)
1	Polycrystalline	36	160	15%	0.314
2	Monocrystalline	36	180	20%	0.326
3	Polycrystalline	60	275	15%	0.282
4	Monocrystalline	60	305	20%	0.295
5	Polycrystalline	72	340	15%	0.282
6	Monocrystalline	72	370	20%	0.295

3.1.3 Calculation Module

The calculation module consists of three sub-modules. The first one calculates the hydraulic energy (E_H) by identifying the required discharge (Q) for the combination of crops and the total head losses (H_{TE}). The second sub-module is for sizing the PV system that give the power output from the PV array based on location (Φ), slope (β), type of panels (ToP), azimuth of panels (Ψ) and ambient temperature (T_a) to generate the water irrigation system. The final one is to analyze the economic performance of PVWP system using EACF approach. Detailed steps for how the calculation models estimate the E_H, the nominal power capacity of PV system (P_{el}) required for sizing the PV system and the actual energy generated (E_A) required to operate the water irrigation system and assess the economic performance of the system are illustrated as the following:

(1) Hydraulic Energy (E_H): The hydraulic energy demand (E_H) is determined according to the plants water requirements, the irrigation method, and the total head losses according to equation 3.1(Glasnovic & Margeta, 2007; R. Sharma et al., 2020),

$$E_H = \frac{\rho g Q_d H_{TE}}{36 * 10^5 * \eta_F \eta_N} \qquad 3.1$$

where Q_d is the total water demand in (m^3 day^{-1}), E_H is the hydraulic energy (kWh), ρ is the density of water (1000 kg m^{-3}), g is the acceleration due to gravity (9.81 m s^{-2}), η_F is the efficiency of the irrigation system (fractional losses), η_N is the efficiency of the irrigation method (open channel, drip, trickle, flood).

The total water demand is the sum of crop evapotranspiration (ET_c), leaching requirement (LR), and irrigation applied in soil disinfection and pre-transplanted irrigation, i.e, 50 mm for soil disinfection done every (1-2) years and 20 mm for pre-transplanted (Bonachela et al., 2006; Corwin et al., 2012; Jamal, 2011). To be able to calculate the ET_c using equation 3.2, the K_C values and the reference evapotranspiration (ET_O) have to be determined (Rauff & A. Shittu, 2015). The K_C values are extracted from Cropwat and the ET_O is calculated according to Almeria radiation method using equation 3.3 (Melsen et al., 2011),

$$ET_c = K_c * ET_o \qquad 3.2$$

$$ET_o = \begin{cases} (0.288 + 0.0019n)R_o\tau & Julian\ days\ (n) \leq 220 \\ (1.339 - 0.00288n)R_o\tau & Julian\ days\ (n) > 220 \end{cases} \qquad 3.3$$

where R_O is the daily solar radiation outside the greenhouse (mm day^{-1}) and τ is the ratio between inside and outside radiation (transmissivity of greenhouse cover).

The leaching requirement (LR) is the amount of water needed to remove excessive salts that cause a crop yield decrement, and it was calculated using equation 3.4 (Corwin et al., 2012),

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}} \quad 3.4$$

where EC_{iw} is the electrical conductivity of the irrigation water applied, and EC_e is the soil salinity tolerated by crop as measured on soil saturation extract.

Moving to the total head loss, the typical head consists of static head (H_{ST}), kinetic head (H_{DT}) and pressure head (H_F). Accordint to Ghoneim (2006), the static head is the elevation head from the water surface level to the point of discharge, the kinetic head represents the kinetic energy of the fluid ($H_{DT} = V^2/\,2g$), where V is the velocity and g is the acceleration (9.81 m sec^{-2}). In addition, there is a fraction loss that can be reduced by enlarging the pipe diameter, eliminating bends and reducing the flow rate (Ghoneim, 2006). Therefore, the total head from borehole T_{TE}, can be expressed by equation 3.5 (Glasnovic & Margeta, 2007), where increment i assumes the values i = 1 to N (N is the total number of time stages, decades), $H_{TE(i)}$ the total head lift (m).

$$H_{TE(i)} = H_{ST(i)} + H_{DT(i)} + H_{F(i)} \quad 3.5$$

Friction losses are calculated according to equation 3.6 (Diogo & Vilela, 2014), where f is Darcy friction factor, l is the pipe length (m). Darcy friction factor can be identified from moody chart as indicated in Figure 6. The minor fractional losses are assumed to be

10% according to PV project analysis in 2005 (RETScreen International Clean Energy Decision Support Centre (Canada) et al., 2005).

$$H_{F(i)} = \frac{8flQ^2}{\pi^2 g d^5} \quad 3.6$$

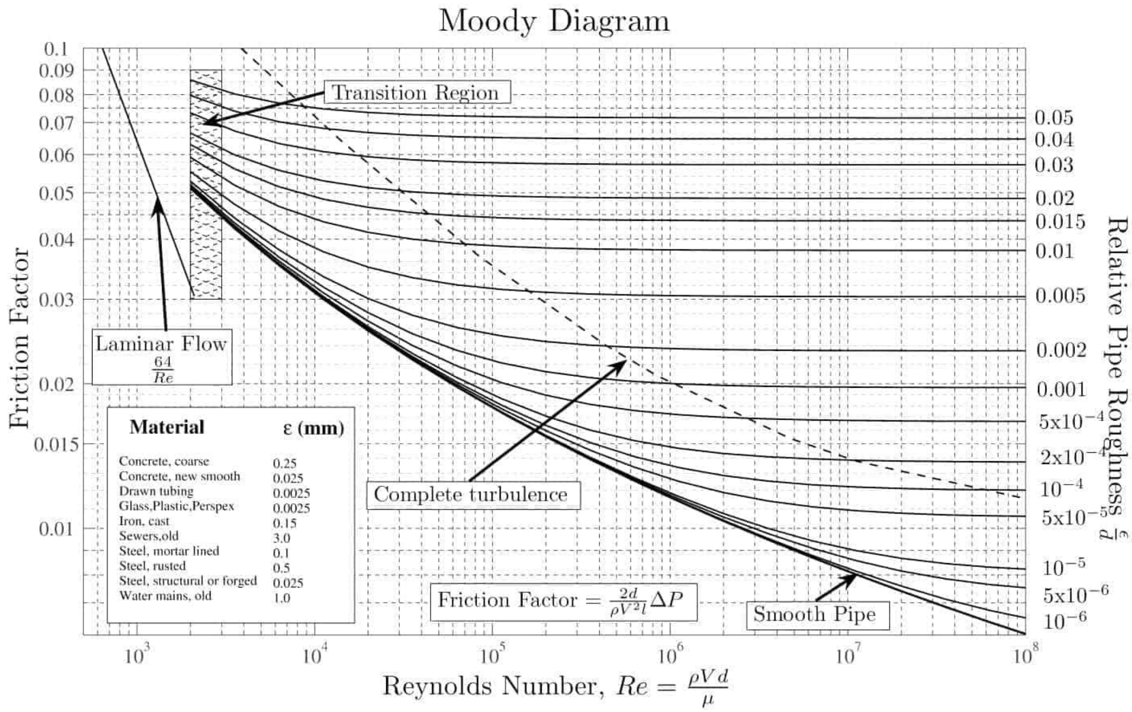

Figure 6 : Moody's Chart

(2) Nominal Power Capacity of PV system (P_{el}): The nominal capacity or peak power of PV (P_{el}) generator under standard conditions is given by equation 3.7 (EL-Shimy, 2013; Glasnovic & Margeta, 2007) considering the effect of the ambient temperature (T_a),

$$P_{el} = \frac{1000}{\left[1 - \alpha_P\left(T_C - T_{C,STM}\right)\right]\eta_S} * \frac{E_H}{I_T} \quad 3.7$$

where P_{el} is the nominal capacity (W), α_P is the temperature coefficient of PV module (/˚C), T_C is the cell temperature (˚C), $T_{C,STM}$ is the cell temperature at standard test conditions (˚C), η_S is the efficiency of the subsystem (inverter, motor, pump), I_T is the daily solar irradiation on PV surface (kWh m^{-2}).

To calculate the daily solar irradiance in PV surface, an empirical model is greatly needed especially for areas where there is no available data for the solar irradiance. The model is established to estimate the hourly horizontal solar radiation from the average daily solar radiation. El Shimy (2013) proved that CR model (Collares-Pereira & Rabl, 1979) has a higher correlation than LJ model (Liu & Jordan, 1960) (EL-Shimy, 2013). Therefore, the ratio between the hourly solar radiation and the daily solar radiation was calculated using CR model as identified in equation 3.8 (Collares-Pereira & Rabl, 1979; EL-Shimy, 2013),

$$\frac{I}{H} = a + b\cos\omega \frac{\left(\frac{\pi}{24}\right)(\cos\omega - \cos\ \omega_s)}{\sin\omega_s - \left(\frac{2\pi\omega_s}{360}\right)\cos\omega_s} \qquad 3.8$$

where I is the mean hourly solar radiation, H is the mean daily solar radiation, ω is the hour angle and ω_s is the sunset hour angle. The coefficients of the CR model are defined as the following:

$$\mathrm{a} = 0.409 + 0.5016\sin(\omega_S - 60°)$$

$$\mathrm{b} = 0.6609 - 0.4767\sin(\omega_S - 60°)$$

Next, Erb's correlation equation is used to calculate the diffuse fraction using equation 3.9 (Erbs et al., 1982). Then, the direct hourly solar radiation (I_b) is calculated by subtracting the diffused hourly solar radiation (I_d) from the total hourly solar radiation (I). After that, the HDKR model is used to estimate the collected solar radiation on tilted surface (I_T) using equation 3.10 (Duffie & Beckman, 2013). Figure 7 represents a sample that was developed by the model for total, diffused, and direct solar radiation on horizontal surface and the estimated collected solar radiation on a tilted PV surface (β = 25°) at Aswan that lies at latitude 24.09011 on July 17.

$$\frac{I_d}{I} = \begin{cases} 1.0 - 0.09k_T & k_T \leq 0.22 \\ 0.9511 - 0.1604k_T + 4.388k_T^2 - 16.638k_T^3 + 12.336k_T^4 & 0.22 < k_T \leq 0.8 \\ 0.165 & k_T > 0.8 \end{cases} \qquad 3.9$$

$$I_T = (I_b + I_d A_i)R_b + \frac{I_d(1 - A_i)(1 + \cos\beta)}{2} \times \left[1 + f\,\sin^3(\frac{\beta}{2})\right] + I\rho_g(1 - \cos\beta)/2 \qquad 3.10$$

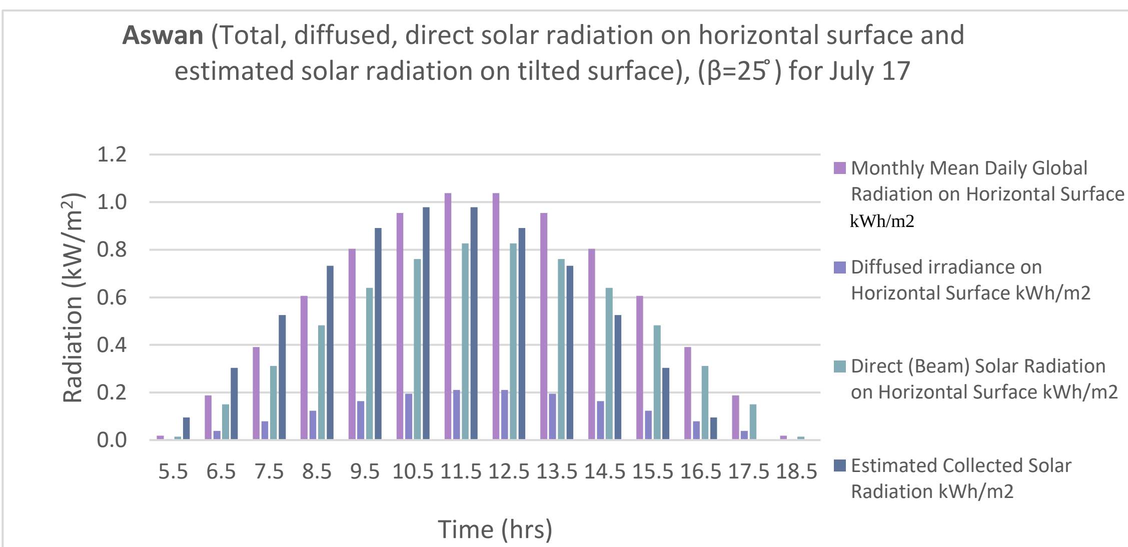

Figure 7 : Total, diffused, direct solar radiation on Hor surface & I_T

According to Photovoltaic Project Analysis, the ambient temperature is considered using equation 3.11, as it affects the power capacity of the PV as indicated before in equation 3.7,

$$T_c = \frac{T_a + (219 + 832K_t)C_f(T_{cn} - 20)}{800} \qquad 3.11$$

where T_a is the ambient air temperature (˚C), K_t is the monthly average clearance index, C_f is a correction factor to account for the effect of off-optimal tilt angle of the PV generator on the temperature of the PV modules and is calculated using equation 3.12 (RETScreen International Clean Energy Decision Support Centre (Canada) et al., 2005) and T_{cn} is the nominal operating cell temperature (˚C).

$$C_f = 1 - 1.17 * 10^{-4}(\beta^* - \beta) \qquad 3.12$$

The optimum tilt angle (β*) of the PV generator is defined by equation 3.13, where Φ is the latitude and δ is the declination angle and it is calculated using equation 3.14, and n is the Julian day (EL-Shimy, 2013; RETScreen International Clean Energy Decision Support Centre (Canada) et al., 2005).

$$\beta^* = \phi - \delta \qquad 3.13$$

$$\delta = 23.45\, sin\left(2\pi(\frac{184 + n}{365})\right) \quad 3.14$$

Actual Energy Generated (E_A): The actual daily energy output of the PVWP system E_A (kW) is determined from equation 3.15 (EL-Shimy, 2013),

$$E_A = S\eta_{PV} I_T \quad 3.15$$

where η_{PV} is the efficiency of the PV under operating condition, S is the overall solar area ($m*A_{PV}$) and A_{PV} is the area of the selected PV modules (m^2). The number of required PV panels is defined by equation 3.16 (EL-Shimy, 2013), where P_{max} is the rating power of PV module at standard conditions (W).

$$m = \frac{P_{el}}{P_{max}} \quad 3.16$$

After that, the η_{PV} is determined by using equation 3.17 (Awan et al., 2020), where η_{PV}, and η_r are the efficiencies of PV generation and reference PV module respectively. Finally, the actual daily energy output of the PV (E_A) can be calculated using equation 3.15.

$$\eta_{PV} = \eta_r\left[1 + \alpha_P(T_c - T_{c,STC})\right] \quad 3.17$$

(3) Life Cycle Economic Assessment: The IIC is estimated based on the component prices, structure costs, wiring costs, and engineering and installation costs. The LCC is estimated using equation 3.18 (Odeh et al., 2006), where $C_{O\&M}$ is present worth of the operation and maintenance costs, and C_F is the fuel costs. The operational and maintenance costs are considered as 1% of IIC of PV system / year (Qoaider & Steinbrecht, 2010).

$$LCC = IIC + C_{O\&M} + C_F \qquad 3.18$$

Crops revenue, excess electricity generated in case the PV system is connected to the grid, and reduction of CO_2 emissions are the potential revenues that can be generated through the operation of a PVWP irrigation system. The reduction of CO_2 emission can be through using of PV system instead of diesel to power the water irrigation system, the excess electricity produced from PV system as a renewable energy source, and soil carbon sequestration because of cultivating land. In this research, the profitability of PVWP system is analyzed using the NPV and EACF as economic indicators and can be calculated using equations (3.19 – 3.21) (Sánchez-Carbajal & Rodrigo, 2019), where i is the discount rate, n is the period of the LCCA, R_t is the net cash flow at time t, t is the time of cash flow and $A_{t,i}$ is the present value of the annuity value. EACF approach is used to solve the problem of having different life spans.

Therefore, life cycle economic model is developed to conduct LCCA based on EACF, some assumptions need to be established as follows: the analysis approach, the real discount rate, the analysis period, and the significant cost of ownership.

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \qquad 3.19$$

$$EACF = \frac{NPV}{A_{t,i}} \qquad 3.20$$

$$A_{t,i} = \frac{1 - \frac{1}{(1+i)^t}}{i} \qquad 3.21$$

3.1.4 Optimization Module

The model is developed on *Microsoft-Excel* using *Evolver*. *Evolver* is an *Excel Add-in* that applies GA technique to reach the near optimum solution. GA is an evolutionary algorithm that require the use of computer intelligence and higher processing power to reach the near optimum solution. These computer intelligence techniques can be evolutionary algorithms, artificial neural networks, or fuzzy logic. Regarding this aspect, several research conducted, it was found that many of the proposed techniques using evolutionary algorithms selected the genetic algorithm method to select the combination of crops that have the maximum equivalent annual return and have an optimized PVWP system (Li & Guo, 2014; Glasnovic & Margeta, 2007; Hosny et al., 2018; Hosny et al., 2021). GA is defined as heuristic technique that search randomly based on Charles Darwin's theory of natural selection (Akhoondzadeh & Azizi, 2019). GA has the ability to deal with complex problems and parallelism, and also can deal with different optimization types whether the fitness function is stationary or change with time like in case of crops' selection, linear or non-linear, continuous or discrete (Lambora et al., 2019). The reason behind that is that the population can explore the search space in many directions simultaneously and different parameters, strings, can be manipulated concurrently.

The Add-in makes several runs by changing the adjustable variables, then the GA keeps running different likelihoods in an iterative mode till the stopping criteria is met, then the optimum solution is reached. The stopping criteria will be defined by the user as number of trials, run time, maximum progress (%) that happens for last specific number of trials, formula if true, or/and stop if error occurs.

In this research, the model adjustable variables are defined as the combination of crops, the starting data for each crop, the occupied area for each crop and ToP. Every adjustable parameter has a defined lower and upper limit. The constraints are set as the allowable budget and the available land area to meet the objective function which is maximizing the EACF. Concerning the occupied area for crops, it was found that there should be a minimum assigned area for each crop to worth the investments. Therefore, another constraint is added that the minimum occupation area for any crop should be one feddan. In addition, overestimation for the PVWP system size will lead to over increase the IIC and consequently minimizing the EACF. On the other hand, underestimation for the PVWP system means to have improper Q which will have negative effects on the quality and the quantity of the crops and on the EACF . Therefore, other constraints are set as the following: the actual energy at any instant is higher than the required energy to ensure that the system is sufficient and minimizing the difference between the actual and the required energy to prove system efficiency.

3.1.5 Output Module

The output module provides the user with the maximum EACF, in addition, identifying the combination of crops, the starting date for each crop, occupied area for each crop and ToP to be used to meet the objective function. In addition to other economic parameters such as NPV, IIC, estimated quantity for water used per year, and percentage for the maximum utilization of the land.

3.2 Model Development

The development of the current model depends on integrating two models with some modifications to find the best utilization of the land where the model selects the combination of crops inside greenhouses that have the maximum EACF and optimizes the PVWP system.

The first model was developed by Hosny et al. (2022) targeted the selection of crops that have the highest life cycle return and minimize the the water used achieving the highest return per m^3 of water. However, they did not include data about greenhouses. They used GA technique with the aid of *Evolver, Microsoft-Excel Add-in,* to reach their optimum solution (Hosny et al., 2022).

The second model was developed by Glasnovic and Margeta (2007) aimed to minimize the maximum nominal power capacity of PV generator required to generate the PVWP system. However, they did not analyze the cost-effectiveness of the PVWP system based on systematic and dynamic quality. Systematic quality means that the hydraulic energy is correlated to the available solar irradiance and dynamic quality means that the system considers the change in the water static level, water quantity in the borehole that can vary from one month to another, and the demand of the hydraulic energy in all months not only the critical month. The computer programmer language MATLAB, Version 6.1 was used to reach the required objective (Glasnovic & Margeta, 2007).

The model utilizes the combination of crops, starting date for each crop, assigned area for each crop and the ToP to find the best utilization of the land. The model allows the user to insert the required inputs in the worksheet named "Model Inputs" as illustrated before in Table 1. This model is used to generate the optimum scenario that will be compared to two different locations in Egypt (Luxor and Giza) to verify the model. The models will be compared in terms of maximum EACF, critical period, the average daily water requirements, and size of the PVWP system. After that, the developed model will be compared to a case study to validate its output and to determine whether the integrated dynamic model developed is worth being used for identifying the best utilization of the land using sustainable source of energy or not. The model formulation is described in Figure 8.

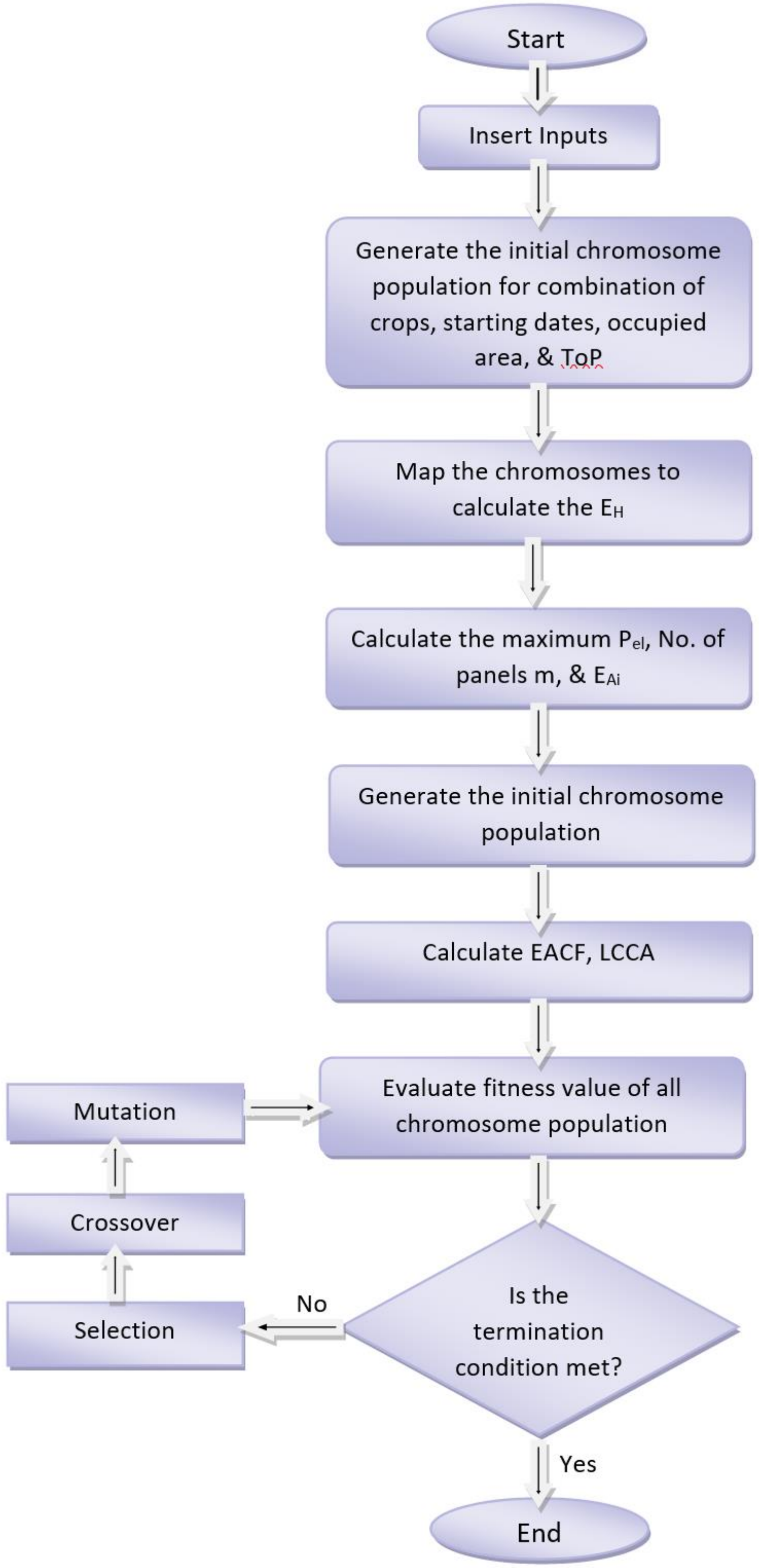

Figure 8: Model formulation Flow Diagram

The model allows the user to insert the inputs in two ways either list of choices that the user has to choose from them or empty cells that have to be filled as shown in Figure 9. List of choices are used for data that has names in order not to fall in the problem of mistyping as the worksheets are interrelated to each other and read the entered inputs and transfer them to other worksheets with the aid of VLOOKUP function.

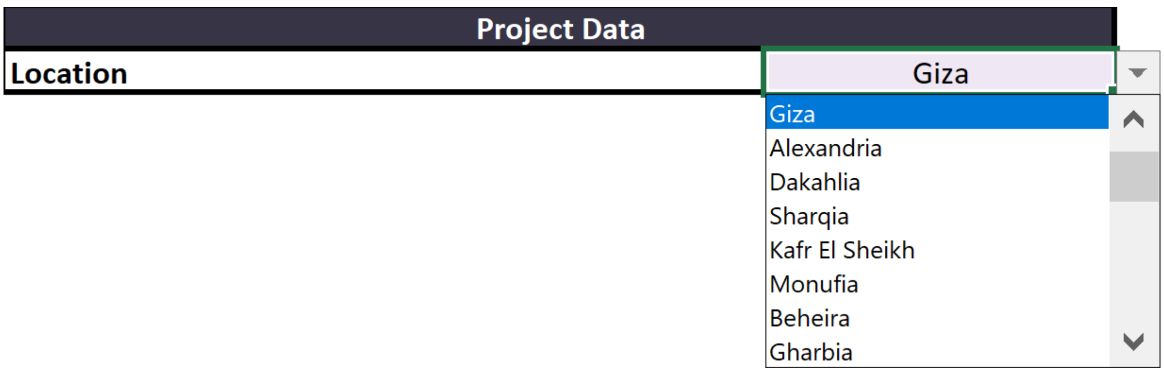

Figure 9: List of Options

In addition, the database module is done in a flexible way that can be edited or changed by the user if needed. The calculation module reads the inputs data entered and integrated it with the database module and reflects them again into several worksheets named "Empirical Model HSR", "Hydraulic Energy", "Annual Energy Gen", "LCCA", and "Cost Effectiveness" to find the required data as the following:

- The "Empirical Model HSR" is used to calculate the solar irradiance and estimate the collected solar radiation on the tilted PV surface.
- The "Hydraulic Energy" is used to calculate the required hydraulic energy based on ETc, LR, and H_{TE}.
- The "Annual Energy Gen" calculates the nominal power capacity (P_{el}), size of the PV system, and the actual energy generated (E_A).
- The "LCCA" worksheet calculates the LCC based on EACF approach.

- The “Cost Effectiveness” worksheet compares the cost of PV generator to diesel generator.

All these worksheets are interconnected to each other and to the main worksheet named “Calculation Model” using VLOOKUP function. “Calculation Model” combines all the necessary information required to run the model. It also contains the logic of the model and its identified parameters. The pool of crops is listed, and each type has a reference number. Then, the total duration of the crop according to the season is identified and adjusted with its starting limits as shown in Table 6.

Table 6: Adjusting Upper Limit for Starting Dates for Crops

A	B	C	D	E	F	G	H	I	J
Reference No	**Selected Crops**	**Crop Name**	**Duration Months**	**Lower Limit**	**Upper Limit**	**Check Point**	**Lower Limit**	**Adjusted Upper Limit**	**Start Adjusted**
1	0	**Tomato I**	11	7	10	0	7	10	7.9
2	0	**Tomato II**	10	9	12	0	9	12	11.2
6	0	**Sweet Pepper II**	10	9	12	0	9	12	10.1
7	1	**Sweet Pepper III**	10	1	3	0	1	3	1.3
8	0	**Sweet Pepper IV**	9	3	5	0	3	5	3.3
9	0	**Chili-Pepper I**	11	7	10	0	7	10	8.2
12	0	**Chili-Pepper IV**	9	3	5	0	3	5	3.3
13	2	**Cucumber I**	7	8	10	0	8	10	9.4
14	0	**Cucumber II**	8	9	11	0	9	11	9.7
18	0	**Cantaloupe II**	6	0	3	0	0	3	2.1
19	3	**Watermelon (grafting)**	6	11	2	1	11	14	1.9
20	0	**Watermelon (non-grafting)**	6	11	2	1	11	14	0.9
21	4	**Squash (Zucchini)**	5.5	11	2	1	11	14	11.1

Check point is done to make sure that the upper limit of the starting date of planting has higher value than the lower limit or not. Check point is done using IF function below:

=IF([Upper Limit]>[Lower Limit]=0,1)

If the check point contains “1”, this mean that the upper limit needs to be modified. The “Adjusted Upper Limit” is done applying the following IF function:

=IF([Check Point]=1,12+[Upper Limit],[Upper Limit])

where 12 represents the number of months in a year. The “Start Adjusted” represents the modified starting date using IF function as below, where the “Start Month” is the month selected by the optimization model as the starting date for cultivating the crop.

=IF([Start Month]>12,[Start Month]-12,[Start Month])

According to the start date for the selected crops, the duration for each crop, and the occupied area for each crop named “No of Feddan”, the cultivation schedule is created to identify the months where the crops are taking place and to identify the percentage of land utilization at each month as shown in Table 7.

Table 7 : Schedule for Optimized Combination of Crops

A	B	C	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
Reference No	**Selected Crops**	**Crop Name**	**End Month**	**END Adjusted**	**Crop Schedule**											
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	0	**Tomato I**	5.91	5.91	0	0	0	0	0	0	0	0	0	0	0	0
2	0	**Tomato II**	8.25	8.25	0	0	0	0	0	0	0	0	0	0	0	0
6	0	**Sweet Pepper II**	7.10	7.10	0	0	0	0	0	0	0	0	0	0	0	0
7	1	**Sweet Pepper III**	10.29	10.29	1	1	1	1	1	1	1	1	1	1	0	0
8	0	**Sweet Pepper IV**	1.00	1.00	0	0	0	0	0	0	0	0	0	0	0	0
9	0	**Chili-Pepper I**	6.19	6.19	0	0	0	0	0	0	0	0	0	0	0	0
12	0	**Chili-Pepper IV**	1.00	1.00	0	0	0	0	0	0	0	0	0	0	0	0
13	2	**Cucumber I**	3.37	3.37	1	1	1	0	0	0	0	0	1	1	1	1
14	0	**Cucumber II**	4.66	4.66	0	0	0	0	0	0	0	0	0	0	0	0
18	0	**Cantaloupe II**	7.14	7.14	0	0	0	0	0	0	0	0	0	0	0	0
19	3	**Watermelon (grafting)**	6.85	18.85	0	1	1	1	1	1	0	0	0	0	0	0
20	0	**Watermelon (non-grafting)**	5.85	17.85	0	0	0	0	0	0	0	0	0	0	0	0
21	4	**Squash (Zucchini)**	3.59	15.59	1	1	1	0	0	0	0	0	0	0	1	1
27	0	**Eggplant (Long)**	8.80	20.80	0	0	0	0	0	0	0	0	0	0	0	0
28	0	**Pinapple**	9.35	21.35	0	0	0	0	0	0	0	0	0	0	0	0
29	5	**Mango**	10.57	22.57	1	1	1	1	1	1	1	1	1	1	1	1
30	0	**Black Currant**	2.39	14.39	0	0	0	0	0	0	0	0	0	0	0	0
31	0	**Grape**	3.33	15.33	0	0	0	0	0	0	0	0	0	0	0	0
32	0	**Banana**	4.11	16.11	0	0	0	0	0	0	0	0	0	0	0	0
37	0	**Breadnut**	10.35	22.35	0	0	0	0	0	0	0	0	0	0	0	0
					4	5	5	3	3	3	2	2	3	3	3	3
Land Utilization (%)					80%	100%	100%	60%	60%	60%	40%	40%	60%	60%	60%	60%

To be able to create timetable the following IF function is applied.

=IF(OR([Month]=ROUND([Start Adjusted],0),AND([Month]>ROUND([Start Adjusted],0),[Month]<[End Month]),AND(ROUND([Start Adjusted],0)>[End Month],OR([Month]<[End Month],[Month]>ROUND([Start Month],0))),[Month]=[End

Month],AND([Check Point]=1,[Month]>[Start Adjusted],[Month]<[End Adjusted],[End Adjusted]<[Start Month],[Month]=[End Adjusted]),[No of Feddan],0)

where “End Month” is defined as:

=IF(([Duration]+[Start Adjusted])>12,IF(([Duration]+[Start Adjusted]-13)=0,1, ([Duration]+[Start Adjusted]-13)),IF(([Duration]+[Start Adjusted])=12,12, ([Duration]+[Start Adjusted]-1)))

The cost and the revenue for each crop is integrated in the model in “Database Module”; therefore, the cost and revenue corresponding to the selected combination of crops are presented using VLOOKUP and MATCH functions, as the following:

=VLOOKUP([Crop],[Database Module],MATCH(year,[Database Module],0),0)

The size of the PV generator required for water irrigation system is identified according to the required hydraulic energy, available solar irradiance, and ToP selected. The E_H is calculated in the calculation sheet named “Hydraulic Energy” and the available solar irradiance is presented in the calculating sheet named “Empirical Model HSR”. Six different ToP are presented in this study according to the Egyptian market. They are coded from 1 to 6 as presented in Table 8. The size of the PV system is calculated in the worksheet presented as “Annual Energy Gen” and is read by the main worksheet “Calculation Model” to be used in the optimization model by adjusting the model variables.

Table 8 : Coding for Type of PV Module

Product name	No of Cells	Product No
Polycrystalline	36	1
Monocrystalline	36	2
Polycrystalline	60	3
Monocrystalline	60	4
Polycrystalline	72	5
Monocrystalline	72	6

The objective function which is maximizing the EACF is calculated adding the EACF of the combination of crops to the EACF of the PVWP system. Then, the optimization model is generated using GA to run for one objective function which is maximizing the EACF. The optimization parameters that are set for GA is shown in Figure 10.

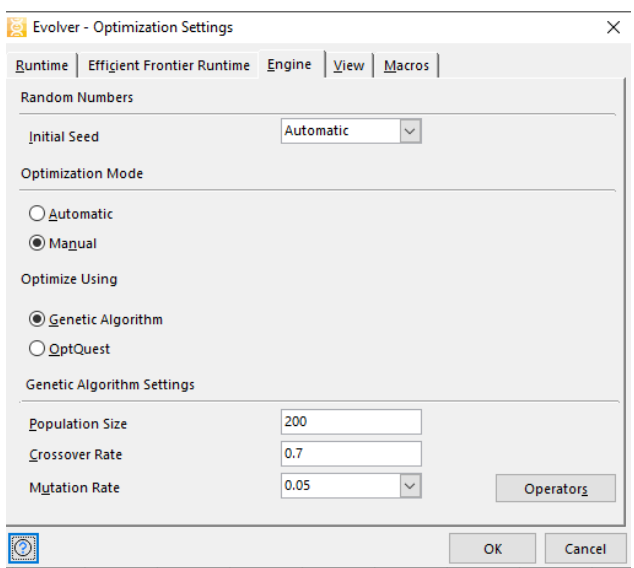

Figure 10 : Optimization Setting Parameters

The use of control parameters for the GA optimization is more effective to reach the near optimum solution and avoid locating at local optima (Katoch et al., 2020). There is no specific values that can fit all optimization problems, however; previous studies confirmed that identifying the population size is very important as overestimating will increase the computation time and underestimation will lead to poor solution (Das & Pratihar, 2018; Katoch et al., 2020). Usually, the population size ranges between 50 to 100, the mutation and crossover rates are set as 0.001 and 0.6 respectively (Espinoza et al., 2003). On the other hand, Ghaheri et al. (2015) concluded that the population size is identified according to the problem complexity, and it was tested on population size 100, 300, 400 and 600. The results shows that the larger the population size, the better the results (Ghaheri et al., 2015). It was concluded that there is no specific methodology that can be followed to reach the optimal solution, however; if the population size is large, the crossover rate should be high and if the population size is small, the mutation rate should be high to provide diversity and increase the efficiency of GA (Katoch et al., 2020). The model will keep running till the stopping criteria is met, then the optimum solution is reached. The stopping criteria is defined by the user as number of trials (100,000) as shown in Figure 11.

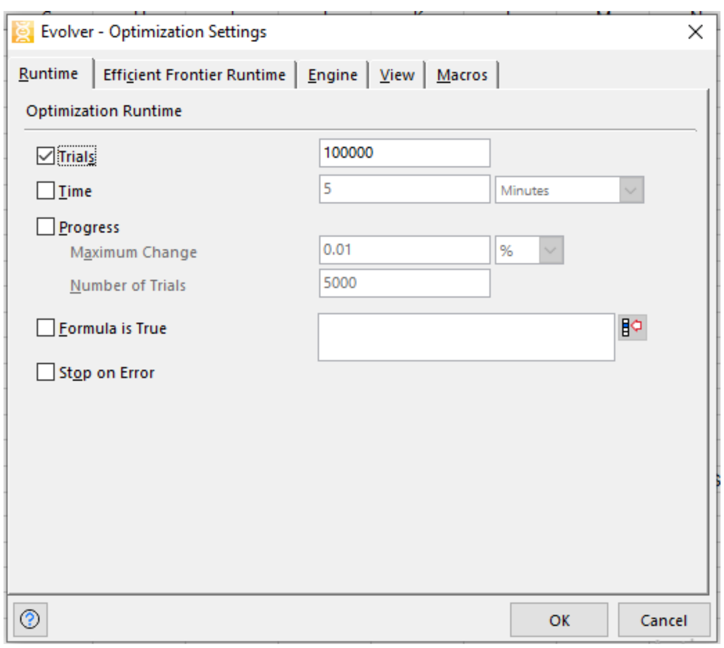

Figure 11 : Stopping Criteria as Inserted in Evolver

Objective:

- Maximize EACF

Variables:

- Combination of crops
- Starting date for each crop
- Occupied area for each crop
- ToP

Constraints:

- Available area
- Allowable budget
- Occupied area >= 1 feddan
- $E_{Ai} - E_{Hi} >= 0$
- $Max (E_{Ai}) - Max (E_{Hi}) \cong 0$

CHAPTER 4 – VERIFICATION AND VALIDATION OF THE MODEL

To outline to what extent the developed optimization model describes the system and for the purpose of determining appropriate results, verification of the model is essential. To verify the developed optimization model, two locations in Egypt, i.e., Luxor and Giza, having different climatic and environmental conditions have been selected. Considering all system parameters are variable, it is required to determine their reference values upon which certain variables change. Then, their effect on calculation of EACF and other parameters are observed.

4.1 Verification of the Model

4.1.1 Area in the Luxor Region

(1) Reference Parameters

The reference parameters for Luxor region have been selected as the following:

PV Pumping System

- Nominal efficiency of motor-pump unit= 43%
- Nominal efficiency of inverter= 90%

Climate Region

- Location: Luxor
- Latitude: 25.70231

Borehole

- Irrigation well of typical values
- Water conductivity (EC_{iw}) = 0.8 dS m^{-1}
- Static level = 50 m
- Velocity = 0.9 m sec^{-1}
- Diameter = 0.12 m
- Length of Pipe = 60 m
- Head lift from the ground surface: $H_{OT} = 0$
- Maximum discharge capacity: Q_{max}= 72 m^3 hr^{-1}

Irrigation Area

- Total Area: 5 feddans
- Type of soil: Clay soil
- Soil salinity (EC_e) = 1.1 dS m^{-1}

Irrigation Method

- Irrigation method: surface drip
- Efficiency of drip method $\eta_N = 90\%$

Financial Parameters

- Allowable budget = 100,000 US$
- Future discount rate = 8.75%

This study selects the irrigation period to be twice a week in summer and once a week in winter, which is in practice more realistic, in view of water and energy consumption as there is no significant change in the moisture of the active soil from which crops intake water.

(2) Input Data for Developed Model

The user should enter the input data required for the developed model such as location (Luxor), total available (feddan), E_{ci}, E_{ciw}, irrigation method, and financial parameters such as cost / m^2 for PV supporting structure and cost / m^2 of wiring shown in Table 9.

Table 9 : Input Data required for Luxor Region

Project Data	
Location	Luxor
Land Area (feddan)	5
Maximum Budget Limit (B_L) (US$)	$100,000.00
Ece (dS/m)	1.1
Eciw (dS/m)	0.8
Irrigation Method	Surface Drip
Financial Parameters	
Future Value Discount Rate	8.75%
Cost per m^2 of supporting structure (US$)	22
Cost of Wiring per m^2 of land (US$)	5

(3) Database for Developed Model

The database is filtered based on the input parameters. It includes data about the average daily solar radiation and the ambient air temperature (T_a). The geographical and meteorological information were collected from NASA. Upon filtering the database, the ET_o is calculated based according to Almeria radiation method using equation 3.3 (Melsen et al., 2011) and the collected solar radiation on the tilted PV modules (I_T) will be estimated based on the HDKR model (Duffie & Beckman, 2013). Figure 12 represents the monthly mean daily daylight hours and monthly mean daily temperature for Luxor that is generated by the developed model according to collected data from NASA. It is characterized by long daily daylight hours (more than 10 hrs) all over the year.

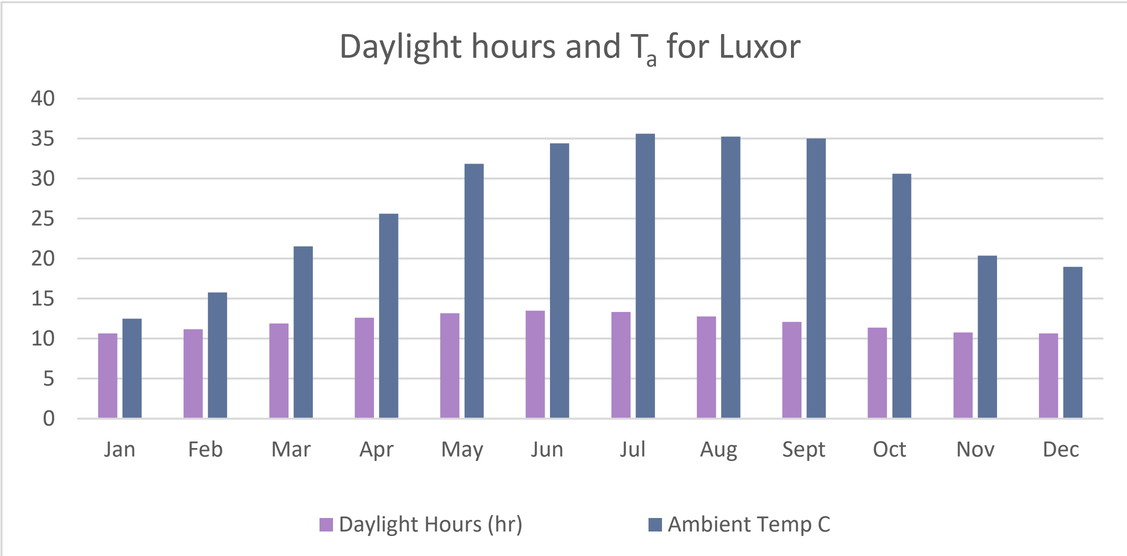

Figure 12: Average Daylight hr & Average Ambient Temp for Luxor

(4) Optimization Results for Reference Parameters for Luxor

The optimization results of the combination of crops, area for each crop, starting date for each crop and ToP are shown in Table 10 which represents the log of progress steps in the optimization process of the developed optimization model. The EACF was maximized to 318,620 US$ when the combination of crops was Tomato I, Tomato IV, Sweet Pepper II, and Mango, and the corresponding area for each crop was 2, 1, 1 and 1 feddan respectively as illustrated in Table 11. The maximum EACF satisfied by selecting 3 different types of crops that required 50,803 W_p as optimal nominal electric power of PV generator. Tomato crop is planted in two different seasons as indicated in Table 12. To satisfy the required nominal power, 134 panels of type 6 were required.

Table 10 : Log of Progress Steps in the Optimization Process for Luxor

Trial	Result	Adjustable Cells																						
		D23	L48	L49	L50	L51	L52	L53	L54 - L82	L83	L84	K48	K49	K50	K51	K52	K53	K54 - K82	K83	K84	B24	B26	B28	B30	B32
1	13,598	6	0	2	0	2	0	0	.. ..	0	0	7.9	9.2	3.0	4.0	7.9	9.0	.. ..	10.0	10.0	1	2	4	3	5
2197	57,570	6	0	2	0	2	0	0	.. ..	0	0	7.9	9.0	3.0	4.0	7.9	9.0	.. ..	10.0	10.0	1	2	4	3	5
11730	89,524	6	0	1	0	2	0	0	.. ..	0	0	7.9	9.0	3.0	4.0	7.9	9.0	.. ..	10.0	10.6	1	2	4	3	5
19108	215, 312	6	0	1	0	2	0	0	.. ..	0	0	7.9	9.0	3.0	4.0	7.9	9.0	.. ..	10.0	10.6	1	2	4	3	5
27840	270,002	6	0	1	0	2	0	0	.. ..	0	0	7.9	9.0	3.0	4.0	7.9	9.0	.. ..	10.0	10.6	1	2	4	3	5
35238	318,620	6	2	0	0	1	0	1	.. ..	0	0	8.5	9.0	2.0	4.0	9.8	12.0	.. ..	15.5	15.2	1	2	4	3	5

- Result stands for the equivalent annual cash flow in US$ (EACF)
- D23 stands for the Type of panels (ToP)
- K48 – K84 stands for the starting date for each crop
- L48 - L84 stands for the different types of crops and the number presented identify the area for each crop

Table 11 : Optimization Results of PVWP System for Luxor

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tomato I	2	2	2	2	2	2	0	0	2	2	2	2
Tomato IV	1	0	0	1	1	1	1	1	1	1	1	1
Sweet Pepper II	1	1	1	1	1	1	1	1	1	0	0	1
Mango	1	1	1	1	1	1	1	1	1	1	1	1
Land	**100**	**80**	**80**	**100**	**100**	**100**	**80**	**80**	**100**	**80**	**80**	**100**

The difference between the daily energy produced and the daily required hydraulic energy is as shown in Figure 12. The positive values for the energy indicate that the system is sufficient as $E_{Ai} - E_{Hi} >= 0$. To have an efficient system the max (E_{Ai}) – max (E_{Hi}) ≈ 0, it was observed that the critical period occurs on day 72 as the difference between max E_{Ai} – max E_{Hi} is 3.88 kWh as indicated in Figure 13.

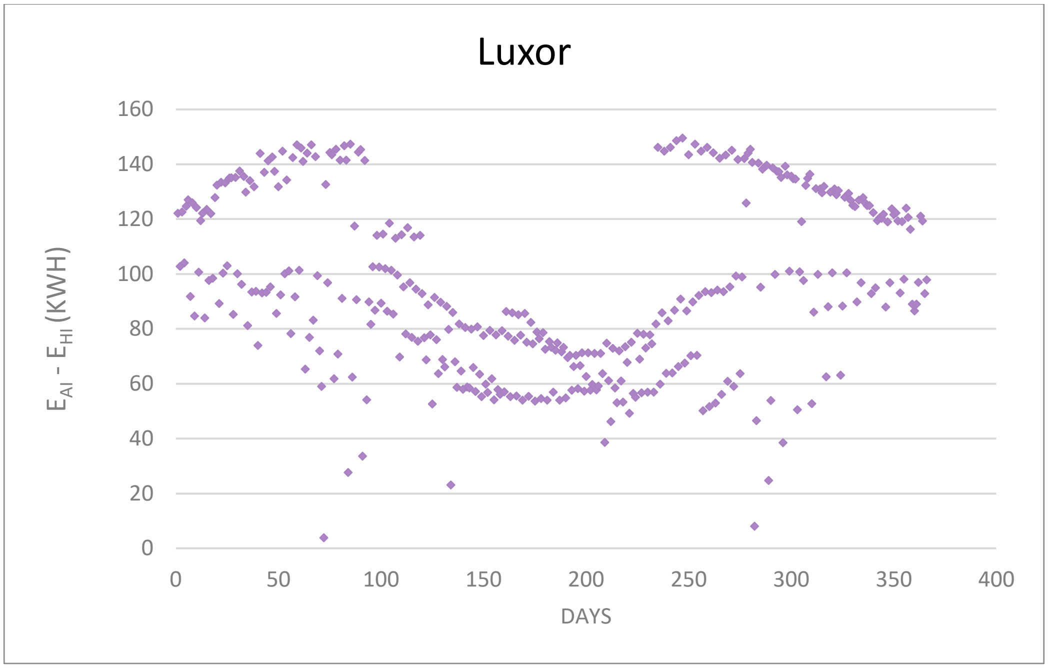

Figure 13 : Daily Energy Losses for Luxor (kWh)

4.1.2 Location in the Giza Area

(1) Reference Parameters

The same reference parameters have been selected as for the area in Luxor location except for the climate parameters and the soil type. Giza is located at latitude of 30.00951 resulted in different meteorological data than Luxor area. The type of soil is assumed to be sand.

Figure 14 represents the monthly mean daily daylight hours and monthly mean daily temperature for Giza that is produced by the developed model using data from NASA. It is characterized by long daily daylight ranges from 10 hr and in some months reaches more than 13 hr.

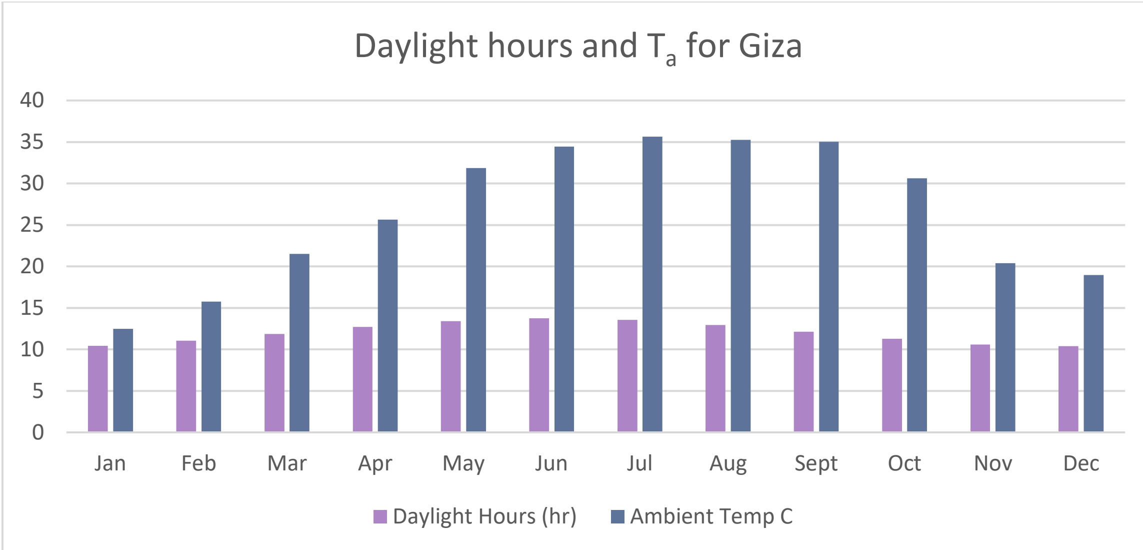

Figure 14 : Average Daylight hours and Average Ambient Temp for Giza

(2) Optimization Results for Reference Parameters for Giza

The optimization results of the combination of crops, area for each crop, starting date for each crop, occupied area for each crop and ToP are shown in Table 12 which represents the log of progress steps in the optimization process of the developed optimization model. The EACF was maximized to 397,064 US$ when the combination of crops was Sweet Pepper, Green Beans II, and mango and the corresponding area for each crop was 3, 1, and 1 feddan respectively as illustrated in Table 14. Sweet Pepper has three different planting dates as indicated in Table 13. The nominal maximum power required to satisfy the requirements of the irrigation system is 72,486 W_p. To satisfy the required nominal power, 191 panels of type 6 were required.

Table 12 Log of Progress Steps in the Optimization Process for Giza

Trial	Result	Adjustable Cells																								
		D23	L49	L50	L51	L52	L53	L54	L55	L56	L57 - L82	L83	L84	L85	K49	K50	K51	K52	K53	K54	K55	K56	K57 - K82	K83	K84	K85
1	275,806	6	0	0	0	0	0	1	1	0	.. ..	0	0	0	8.5	9.0	2.0	3.0	10.0	10.5	1.9	3.2	.. ..	19.1	15.5	15.2
86	356,657	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	10.0	10.5	1.9	3.2	.. ..	19.1	15.5	15.2
149	377,051	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	9.8	10.5	1.9	3.2	.. ..	19.1	15.5	15.2
1544	377,492	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	9.8	10.5	1.9	3.2	.. ..	19.1	15.5	15.2
3917	389,428	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	9.8	12.0	1.9	3.2	.. ..	19.1	15.5	15.2
6665	389,536	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	9.8	12.0	1.9	3.0	.. ..	19.1	15.5	15.2
25991	390,509	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	9.8	12.0	1.9	3.0	.. ..	18.9	15.5	15.2
48675	397,064	6	0	0	0	0	0	1	1	1	.. ..	0	0	0	8.5	9.0	2.0	3.0	9.8	12.0	1.9	3.0	.. ..	18.8	15.5	15.2

- Result stands for the equivalent annual cash flow in US$ (EACF)
- D23 stands for the Type of panels (ToP)
- K48 – K84 stands for the starting date for each crop
- L48 - L84 stands for the different types of crops and the number presented identify the area for each crop

Table 13 : Optimization Results of PVWP System for Giza

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sweet Pepper II	1	1	1	1	1	1	1	1	1	0	0	1
Sweet Pepper III	0	1	1	1	1	1	1	1	1	1	0	0
Sweet Pepper IV	0	0	1	1	1	1	1	1	1	1	1	1
Green Bean II	1	1	1	1	1	0	0	0	0	0	1	1
Mango	1	1	1	1	1	1	1	1	1	1	1	1
Land	**60**	**80**	**100**	**100**	**100**	**80**	**80**	**80**	**80**	**80**	**60**	**80**

The difference between the daily energy produced and the daily required hydraulic energy is as shown in Figure 15. The positive values for the energy indicate that the system is sufficient as E_{Ai} - E_{Hi} >= 0. To have an efficient system the max (E_{Ai}) – max (E_{Hi}) ≈ 0, it was observed that the critical period occurs on day 209 as the difference between E_{Ai} - E_{Hi} is 7.77 kWh as indicated in Figure 14.

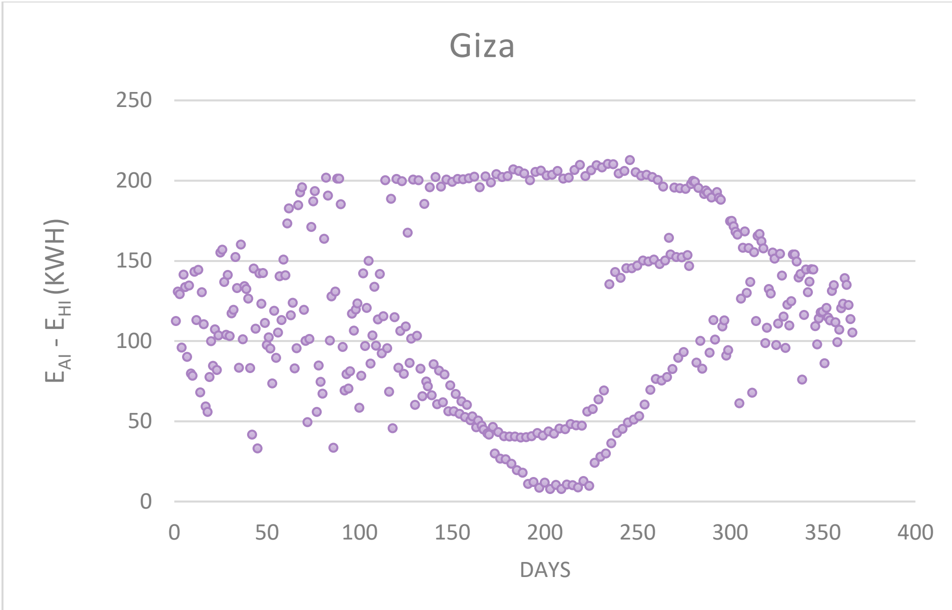

Figure 15 : Daily Energy Losses for Giza (kWh)

The LCCA indicated that it worth to invest in Giza than in Luxor as it has higher NPV, higher estimated revenue for the first year, and higher return per every 1m^3 of water within the allowable budget compared to Luxor as indicated in Table 14.

Table 14 : LCCA for Luxor and Giza Optimizations

Parameter	**Luxor**	**Giza**	**Unit**
Expected NPV	51,332,642	63,970,535	EGP
Estimated Initial Investment Cost	3,443,628	4,656,531	EGP
Estimated First year Revenue	5,079,064	6,329,510	EGP
Estimated Water Quantity Used / year	198,527	199,117	m^3
Average Daily Water Quantity	543.9	545.5	m^3
Max Land Utilization	100	100	%
Return / Water Quantity	258.6	321.3	EGP / m^3

Although the average daily water requirements for both locations are almost the same, there is a big difference in the number of required panels. The required number of panels are 134 for Luxor and 191 for Giza although same ToP is used in both locations. This can be justified as Luxor has higher estimated solar irradiance than Giza as indicated in Figure 16 considering the effect of the T_a on the performance of the PV modules.

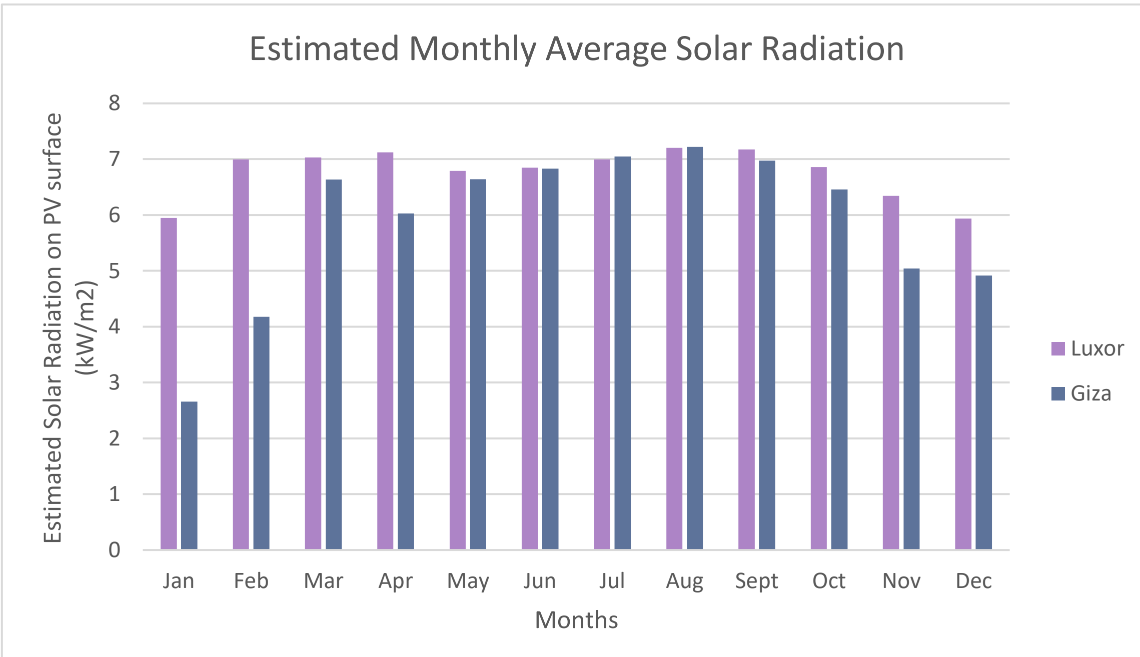

Figure 16 : Estimated Monthly Average Solar Radiation PV Surface (kW/m2)

Although the same reference parameters were used for both locations except for climate values and soil type, noticeable difference in the EACF are obtained. This can be justified as Luxor has lower net benefit form crops because of the transportation costs. In addition, soil salinity for Luxor (1.1 dS m^{-1}) has lower value compared to Giza (1.3 dS m^{-1}) resulted in higher leaching requirement for Luxor. The higher solar irradiance in Luxor also leads to higher ET_o which means higher ET_C. Therefore, the total water requirements for Luxor will be greater compared to Giza. By variation of different elements in the optimization output, it can be concluded that the model response to any change in the reference parameters.

4.2 Case Study and Model Validation

After verifying the ability of the model to deliver results, the model's ability to generate accurate results needed to be validated. The validation is conducted by testing the developed model on the same case study that was presented in the research conducted by Hosny et al. (2022). Results of the developed model are compared with the results of the case study for validation.

(1) Project Information and Model Inputs

The agricultural land is located in the Qata district, in Giza, Egypt. The total area is 20 feddan. The soil type is sandy soil with ESP 10% and soil depth 1000 cm. The owner of the land cultivated cucumber and peas in successive cycles without the use of greenhouses as indicated in Table 15. Input data was collected as shown in Table 16 according to Hosny et al., (2022).

Table 15 : Current Cultivation Practice in Giza Land (Hosny et al., 2022)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Peas	30	30	30	30	30	0	0	0	0	0	0	0
Cucumber	0	0	0	0	0	0	30	30	30	30	0	0
Land Utilization (%)	**100**	**100**	**100**	**100**	**100**	**0**	**100**	**100**	**100**	**100**	**0**	**0**

Table 16 : Input Data for the Current Cultivation Practice (Hosny et al., 2022)

Parameter	Value	Unit
Study Period	20	years
Total Area	30	feddan
Cost of Utilizing Land / feddan	75,000	EGP
Cost of Water / m^3	1.5	EGP
Cost of Electricity / kWh	0.65	EGP

(A) Current Cultivation Practice:

According to Hosny et al., (2022), the output financial parameters for the current cultivation practice for the land were confirmed by the landowner that these values are within the acceptable predictable ranges as indicated in Table 17. According to the financial cycle of the land, it is obvious that the landowner was targeting a short-term profitability. The IIC of crops was around 0.5 million EGP although the allowable budget for utilizing this specific land plot was 1.5 million EGP. The reason behind that is that such chosen crops have a fast turnover and require a low IIC.

Table 17 : Management Parameters for the Current Practice (Hosny et al., 2022)

Parameter	Value	Unit
Future Discount Rate	8.75	%
Inflation Rate	5.1	%
Expected NPV	4,706,351	EGP
Estimated Initial Investment Cost (IIC)	511,887	EGP
Estimated First year Revenue	258,341	EGP
Estimated Water Quantity Used / year	146,112	m^3
Average Daily Water Quantity	400	m^3
Max Land Utilization	100	%
Return / Water Quantity	32.2	EGP / m^3

(B) Optimized Cultivation Practice according to Economic Land Utilization Optimization Model (ELUOM):

An optimization was done for better return and better water management using ELUOM developed by Hosny et al., (2022). On contrary with the landowner point of view, they were targeting long-term turnover and utilizing almost all the available budget. The results were to use the land for planting two crops that are considered as long-term crops (Lemon Trees and Bananas) and two crops that have short-term turnover (Sweet Potatoes and Beets). Although the cultivation practice according to ELUOM resulted in a lower land utilization percentage as 97% as summarized in Tables 18, it is expected to have higher return and better water management, as indicated in Table 19, compared to the current cultivation practice for the agricultural land (Hosny el al., 2022).

Table 18 : Cultivation Practice for ELUOM (Hosny et al., 2022)

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sweet Potatoes	0	0	0	0	0	0	10	10	10	10	0	0
Beet	10	10	0	0	0	0	0	0	0	0	0	10
Lemon Trees	10	10	10	10	10	10	10	10	10	10	10	10
Bananas	9	9	9	9	9	9	9	9	9	9	9	9
Land Utilization (%)	**97**	**97**	**63**	**63**	**63**	**63**	**97**	**97**	**97**	**97**	**63**	**97**

Table 19 : Management Practice for ELUOM (Hosny et al., 2022)

Parameter	Value	Unit
Expected NPV	18,505,969	EGP
Estimated Initial Investment Cost (IIC)	1,498,280	EGP
Estimated First year Revenue	920,290	EGP
Estimated Water Quantity Used / year	151,996	m^3
Average Daily Water Quantity	415.5	m^3
Max Land Utilization	97	%
Return / Water Quantity	121.8	EGP / m^3

(C) Recommended Cultivation Practice inside Greenhouses

Using the same target methodology of ELUOM optimization, this optimization is done based on long-term turnover. However, the optimization is done to analyze the effect of planting inside greenhouses using PVWP system for irrigation. This means that the cost the greenhouses and the PV system will be added to the cost of the project. On the other hand, the cost of the electricity, lower irrigation water requirements and higher productivity rates will be considered as benefits. In addition, the types of crops, planting season, and duration for cultivation inside greenhouses differ from the cultivation in an open field. The model suggests better alternative compared to both the current and optimized cultivation practice using ELUOM in terms of economic and environmental aspects. The optimization results of the combination of crops, area for each crop, starting date for each crop and ToP are shown in Table 20 which represents the log of progress steps in the optimization process of the developed optimization model. The EACF was maximized to 4,435,703 EGP when the combination of crops was Sweet Pepper II, Sweet Pepper IV, Squash (Zucchini), and Mango, and the corresponding area for each crop was

2, 4, 4 and 1 feddan respectively as illustrated in Table 21. The maximum utilization of the land is 36%.

Table 20 : Log of Progress Steps in the Optimization Process for Case Study in Giza

Trial	Result	Adjustable Cells																						
		D23	L49	L50	L51	L52	L53	L54	L55	L56	L57 - L83	L84	L85	K49	K50	K51	K52	K53	K54	K55	K56	K57 - K84	K84	K85
1	225,498	6	0	0	0	0	3	2	0	3	.. ..	0	0	8.5	9.0	2.0	3.0	8.5	10.5	2.0	3.0	.. ..	15.5	15.2
2637	226,877	1	0	0	0	0	3	2	0	3	.. ..	0	0	8.5	9.0	2.0	3.0	8.5	10.5	2.0	3.0	.. ..	15.5	15.2
9936	227,123	1	0	0	0	0	3	2	0	3	.. ..	0	0	8.5	9.0	2.0	3.0	10.0	10.5	2.0	3.0	.. ..	15.5	15.2
13819	227,129	1	0	0	0	0	3	2	0	3	.. ..	0	0	8.5	9.0	2.0	3.0	10.0	10.5	2.0	3.0	.. ..	15.5	15.2
14120	227,137	1	0	0	0	0	3	2	0	3	.. ..	0	0	8.5	9.0	2.0	3.0	10.0	10.5	2.0	3.0	.. ..	15.5	15.2
34247	282,298	1	0	0	0	0	0	2	0	4	.. ..	0	0	8.5	9.0	2.0	3.0	10.0	10.5	2.0	3.0	.. ..	15.5	15.2
36469	282,349	1	0	0	0	0	0	2	0	4	.. ..	0	0	8.5	9.0	2.0	3.0	10.0	10.5	1.9	3.2	.. ..	15.5	15.2

Table 21 : Recommended Cultivation Practice for the Developed Model

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sweet Pepper II	2	2	2	2	2	2	2	0	0	0	2	2
Sweet Pepper IV	0	0	4	4	4	4	4	4	4	4	4	4
Squash (Zucchini)	4	4	4	0	0	0	0	0	0	0	4	4
Mango	1	1	1	1	1	1	1	1	1	1	1	1
Land Utilization (%)	**24**	**24**	**36**	**24**	**24**	**24**	**24**	**17**	**17**	**17**	**36**	**36**

Table 22 shows and validates that the crops selected can be cultivated well in sandy soil and inside greenhouses. The results of the recommended management practice done by the developed optimization model are summarized in Table 23.

Table 22 : Velidation for Selected Crops

Type of Crop	Proof	Reference
Sweet Pepper	Abdrabbo et al., proves that Sweet Pepper is one of high value crops that can be cultivated inside greenhouse and Ezzo et al., confirms that Sweet Pepper can grow well in Sandy Soil.	(Abdrabbo et al., 2019; Ezzo et al., 2010)
Squash (Zucchini)	Abdrabbo et al., proves that Zucchini is one of high value crops that can be cultivated inside greenhouse and Shaheen and Fattah confirm that Zucchini can grow well in Sandy Soil.	(Abdrabbo et al., 2019; Shaheen & Fattah, 2021)
Mango	Abdrabbo et al., proves that Mango is one of high value crops that can be cultivated inside greenhouse and Taha confirms that Sweet Pepper can grow well in Sandy Soil.	(Abdrabbo et al., 2019; Taha, 2020)

Table 23 : Recommended Cultivation Management Practice for Developed Model

Parameter	Value	Unit
Expected NPV	45,488,956	EGP
Estimated Initial Investment Cost (IIC)	1,436,837	EGP
Estimated First year Revenue	4,500,866	EGP
Estimated Water Quantity Used / year	114,889	m^3
Average Daily Water Quantity	314.8	m^3
Max Land Utilization	55%	%
Return / Water Quantity	395.9	EGP / m^3

(D) *Results and Discussion of Current and Suggested by ELUOM Vs. Recommended Cultivation Practice*

The optimization model has guided to a noticeable increase in the expected return while maintaining the allowable budget and managing the water consumption that is presented as return per 1 m^3 of water. The land area utilization percentage ranges between 17 – 36% as presented in Table 22. Comparing the NPV to IIC, it was found that 9.19 EGP, 12.35 EGP, and 31.66 EGP generated in profit for every 1 EGP invested in IIC representing current practice, ELUOM optimization, and the proposed optimization respectively. In addition, optimized recommended solution gives a much higher value of return per 1 m^3 of water which is 320% more efficient than ELUOM optimization and 1200% better than the current practice as indicated in Table 24. In conclusion, the developed model is validated in selecting the types of crops and is effective in improving the agricultural return and minimizing the water and energy consumption. In addition to, the positive impact on the environment for using PV system representing a clean and sustainable source of energy.

Table 24 : Current, ELUOM, and Recommended Optimization Practice

Parameter	**Current Practice Values**	**ELUOM Results**	**Proposed Model Results**	**Unit**
Expected NPV	4,706,351	18,505,969	45,488,956	EGP
Estimated Initial Investment Cost	511,887	1,498,280	1,436,837	EGP
Estimated First year Revenue	258,341	920,290	4,500,866	EGP
Estimated Water Quantity Used / year	146,112	151,996	114,889	m^3
Average Daily Water Quantity	400	415.5	314.8	m^3
Max Land Utilization	100	97	36	%
Return / Water Quantity	32.2	121.8	395.9	EGP / m^3

CHAPTER 5 – DISCUSSION AND ANALYSIS

This chapter presents how the optimization results will be affected by changing the objective function to minimize the total energy losses without scarifying the net profit gained from the optimization model in section 4.1, i.e., maximum EACF. It also includes technical and economic feasibility of PVWP system in comparison with diesel generator. In addition, studying the effect of having different water sources (surface, deep borehole, very deep borehole) on sizing the PVWP system. Furthermore, considering the likelihood of having change in the prices or the costs of the crops on the maximum EACF. The analysis of this chapter uses the Giza optimization model used to verify the module in section 4.1.2 as the basic scenario to compare with.

5.1 Best Utilization for Energy

After optimizing the Giza model in section 4.1.2, it was noticed that although the project had a reasonable EACF (397,064 US$) as shown in Table 13, it had a high percentage of energy loss that reaches 68% compared to total actual energy produced. Therefore, another optimization run is done to decrease the percentage of energy losses. The model reference parameters don't change except adding another constraint which is the new EACF shouldn't be lower than the old one (397,064 US$). The model is defined as the following:

Objective:

- Minimize total energy losses: $\sum_{i=1}^{365}(E_{Ai} - E_{Hi})$

where E_{Ai} is the actual energy generated and E_{Hi} is the hydraulic energy required

Variables:

- Combination of crops
- Starting date for each crop
- Occupied area for each crop
- ToP

Constraints:

- Available area
- Allowable budget
- $E_{Ai} – E_{Hi} >= 0$
- $\text{Max}(E_{Ai}) – \text{Max}(E_{Hi}) \cong 0$
- EACF >= 397,064 (Maximum EACF without reducing energy losses)

The optimization results show that the total energy losses decreased from 43,267 kWh to 40,795 kWh which represents about 1% reduction in the total losses using the same adjustable parameters by reallocating for crops in the irrigation schedule. This leads to decrease the maximum discharge from 952.88 m^3/day on day 215 to 905.59 m^3/day on day 182 as indicated in Figure 17.

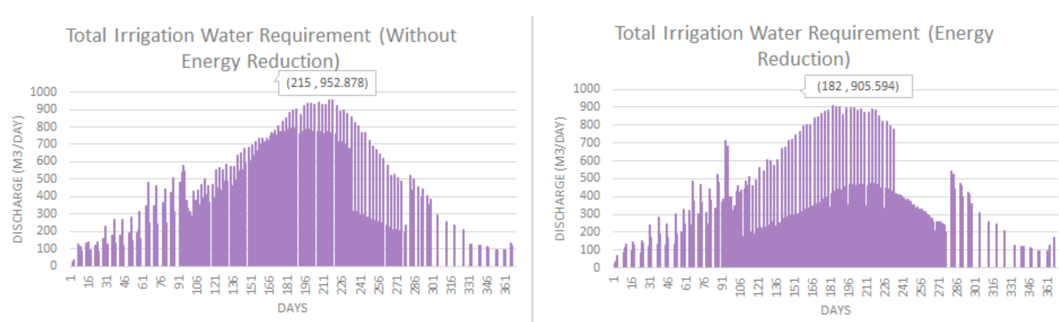

Figure 17 : Optimized Water Discharge by Re-allocating Crops

This reduction will affect the size of the PVWP system and the economic assessment of the project as well as illustrated in Table 25. Although the percentage of total energy loss decreases, the total water requirement per year increases as 35% which may not be a suitable solution in case of applying the system in remote areas where there is always shortage in water.

Table 25 : Comparison between Max EACF and Min Energy Loss

Objective Function:	**Max EACF**	**Min** $\sum_{i=1}^{365}(E_{Ai} - E_{Hi})$	**Unit**
Maximum Nominal Power Capacity	72,486	69,365	W_p
ToP	6	6	
Required Number of Panels	191	183	
Expected NPV	63,970,535	64,140,350	EGP
Estimated Initial Investment Cost	4,656,531	4,488,869	EGP
Estimated First year Revenue (EACF)	6,329,510	6,346,312	EGP
Estimated Water Quantity Used / year	199,117	270,072	m3
Average Daily Water Quantity	545.5	739.9	m3
Max Land Utilization	100	100	%
Return / Water Quantity	321.3	237.5	EGP / m^3

In conclusion, optimizing for energy reduction leads to better LCCA as it has lower IIC, higher NPV and higher EACF. However, it has a negative effect on the water usage as the total water requirement for irrigation increases and this is due to reallocation of crops in the irrigation schedule which may be inappropriate solution in case of water shortage problem. In addition, the reduction of the energy losses is insignificant compared to the total energy produced as it is only decrease from 68% to 67%. Therefore, it is greatly needed to make a cost comparison between PV system and other systems such as diesel generator to verify whether to apply PVWP system or not.

5.2 Cost Comparison between PV and Diesel Generator

The electricity generation costs, and the performance of the designed PV generator are compared with those of an equivalent diesel generator to assure its competitiveness. Concerning the PV generator, the total investment costs of PV system are summarized in Table 26.

Table 26: Total Investment Costs of the PV system

Breakdown Elements	**%**	**US$**
PV Array	84.03%	210,195
Cost of Inverter	7.06%	17,672
Cost of Wiring	0.75%	1,870
Engineering and Planning Costs	8.16%	20,412
Total Cost of PV System	**100.00%**	**250,150**

The total cost of the PV array includes the total cost of the PV modules (201,967 US$) and the supporting structure cost (8,282 US$). The total cost of the inverters represents around 7% of the cost of the total PV system. The engineering and planning costs are calculated according to Qoaider and Steinbrecht (2010) which include overall planning and coordination cost, origin product shipment and support cost, destination percipience and transport cost and installation and supervision cost (Qoaider & Steinbrecht, 2010). Figure 18 illuminates graphically the cost share pf the PV system and as shown, the PV array has the largest share of the investment costs. The annual operation and maintenance costs of PV system were considered as 1% of the total investment costs (Kim et al., 2016). The interest rate was assumed to be 8.75% based on the rate declaimed by the Central Bank of Egypt in 2021.

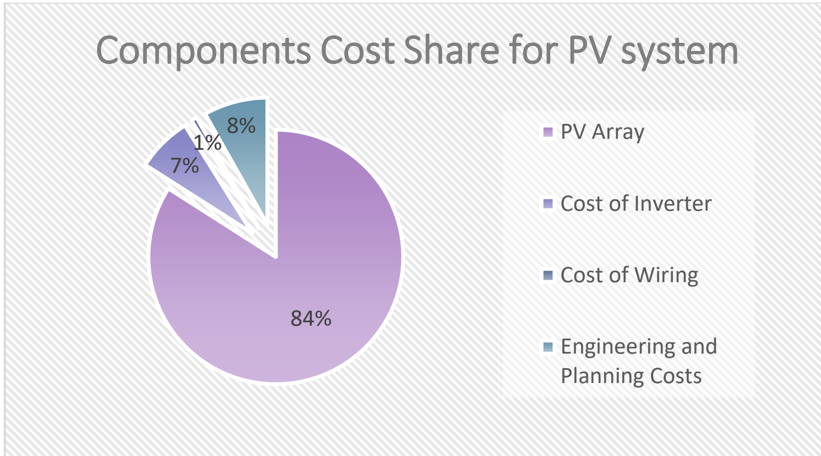

Figure 18 : Components Cost Share of PV System

Annuity method was conducted to calculate the costs of generated unit of electricity according to equation 5.1 (Qoaider & Steinbrecht, 2010), where C is the annuity and C_{cap} is the investment costs.

$$C = C_{cap} * \frac{i * (1+i)^n}{(1+i)^n - 1} \qquad 5.1$$

The results of the annuity analysis are presented in Table 27, if annual net energy used is 80% of the total energy produced.

Table 27 : Annuity and Energy Costs

System Lifetime (years)	25
Interest Rate (%)	8.75%
Annual Operation and Maintenance Cost (US$)	2,501
Annuity (US$)	24,953
Total System Cost for 25 years (US$)	565,476
Annual Net Energy Yield Used for total Area (kW)	50,620
Cost of Energy Unit (US$/kWh)	0.49

In case of full usage, the cost of energy will be decreased to 0.39 US$ kWh^{-1}. On the other hand, if the percentage of the total energy used is 32% as in the previous case, the price of energy will highly increase to 1.25 US$ kWh^{-1}. Table 28 presents the energy costs associated to different percentages for the total energy loss.

Table 28 : Cost of Energy vs Total percentage of Energy Losses

Percentage of Losses (%)	0	10	20	30	40	50	60	70	80
Cost of Energy Unit (US$/kWh)	0.39	0.44	0.49	0.56	0.66	0.79	0.99	1.31	1.97

Figure 19 represents the electricity cost share of PV system. The PV system is mainly dependent on the investment costs of the PV system that contribute to 73% to the final energy cost.

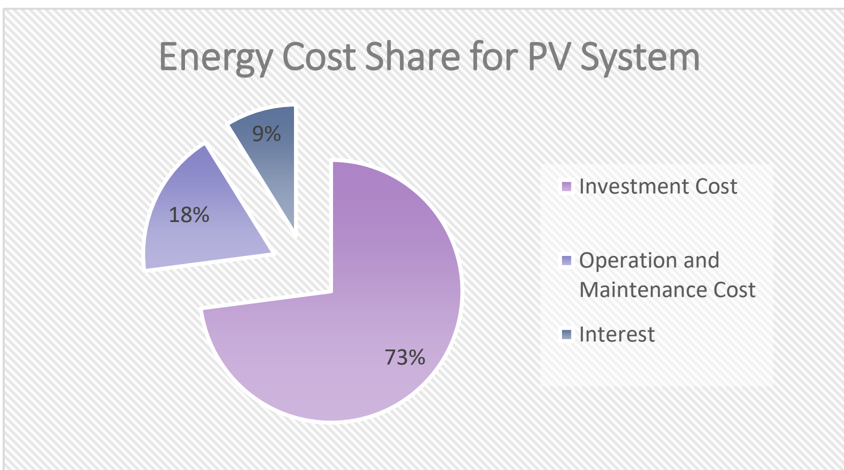

Figure 19 : Electricity Cost Share through PV System

Moving to the diesel generator, the diesel fuel price in Egypt at the time of study (2021) was 0.42 US$ lit^{-1} (*Egypt Diesel Prices, 2021*). However, there is a gradual removal for the subsidies till it reaches the real market diesel price. Consequently, calculations were based on the real market value of diesel. The average yearly diesel price of 2021 according to the United States was 0.56 US$ lit^{-1} (*U.S. Diesel Fuel Retail Price Annually*, *2020*). In addition, the price of diesel will be higher in case the required location was far from the center, i.e., remote area such as Sahraa desert, as transportation cost will be added to diesel price. The diesel generator unlike the PV generator, its maintenance costs are based on the number of working hours for diesel generator. As the operating hours increase, the operation and maintenance costs increase. The average lifespan for diesel generator is 15,000 hrs. According to Giza, the operating hours were 2,504 ,8(hrs)*313(days), per year. Therefore, the lifespan of the diesel generator will be 6 years. This means that throughout the lifespan (25 years), 4 diesel generators are required. The total investment costs are presented in Table 29. The operation and maintenance costs was considered as 0.035 US$ kWh^{-1} (Qoaider & Steinbrecht, 2010) which resulted in annual operation and maintenance cost equals to 4,356 US$ as indicated in Table 30.

Table 29 : Total Investment Costs for Diesel Generator

Breakdown Elements	**%**	**US$**
Total Costs of Generators	79.95%	64,000
Engineering and Planning Costs	20.05%	16,054
Total Cost of the System	**100.00%**	**80,054**

The annuity analysis method is used for financing the project over the 25 years with the same interest rate used in PV generator which was 8.75% and the results for the annuity analysis was shown in Table 31. The diesel generator electricity cost is calculated as 0.53 US$ kWh^{-1}. It is found that the cost of electricity produced by diesel generator is 1.4 times more than the cost of electricity produced by PV generator (0.39 US$ / kWh).

Table 30 : Annuity and Energy Costs for Diesel Generator

Annual Electricity Generation (kWh)	108,903
Annual Operation and Maintenance Cost (US$)	4,356
Annual Fuel Consumption per kWh (lit)	0.40
Total Annual Fuel Consumption (lit)	43,561
Total Annual Fuel Cost (US$)	25,701
Annuity (US$)	33,687
Total System Cost for 25 years (US$)	3,258,328
Annual Net Energy Yield Used for total Area (kW)	63,274
Cost of Energy Unit (US$/kWh)	0.53

The energy cost shares of the diesel generator are presented in Figure 20. The cost of the electricity produced through diesel generator mainly depends on the fuel cost (82%) as indicated in Figure 20 which makes the system sensitive for fuel price changes unlike the PV generator which depends on the installation costs which are fixed from the start of the project, and this makes the PV system less risky.

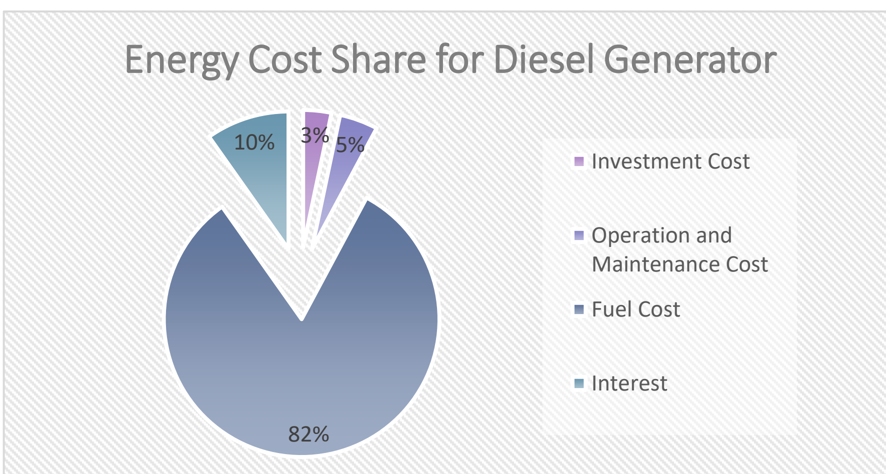

Figure 20 : Energy Costs Share for Diesel Generator

To conclude, PV system can be applied in case the percentage of the total energy losses is less than 30% as indicated in Table 28. If percentage of losses exceed this amount, the diesel generator will be a better economical choice. However, the cost of the energy produced from diesel generator is very sensitive to the cost of fuel which changes overtime, and this makes it a higher risk option comparing to the PV generator. In addition to the negative environmental impacts associated with using diesel generator.

5.3 Sensitivity Analysis

The effect of having different water sources, i.e., different total head losses, on the PVWP size and EACF is examined. In addition, studying the effect of having increase in the costs of the crops or decrease in the crops' prices on the EACF.

5.3.1 Different Water Sources

To study the effect of having different water sources, three different scenarios representing surface, deep borehole, and very deep borehole are analyzed. Static head is assumed for the three scenarios as indicated in Table 31 and consequently the total head loss is calculated for each case.

Table 31 : Three different scenarios for Water Source

Scenario	**I**	**II (Basic)**	**III**
Static Head H_{ST} (m)	1.00	50.00	150.00
Total Head Loss H_{TE} (m)	1.99	55.57	165.27

The optimized case scenario is done based on scenario II. Then, the effect of changing the static head is applied and resulted in the following results as shown in Table 32.

Table 32 : Sensitivity Analysis for Changing Static Head

Parameters	Scenario I	Scenario II	Scenario III
EACF (US$)	430,028	397,064	329,885
PV Generator Size (W_P)	2,591	72,486	214,876
No of Panels	7	191	566
Maximum E_{Hi} (kWh)	7.10	198.58	588.66
IIC (US$)	51,105	292,114	783,273
NPV (US$)	4,346,165	4,013,007	3,334,050

It is noticeable that the water source directly affects the economic performance of the PVWP system. The required number of panels drops to 7 in case the water is available on the surface and highly increases to 566 in case of very deep borehole. Consequently, the IIC is significantly affected that might be a problem in case of limited allowable budget. The EACF is increased by 8.3% in case of surface water and decreased by 16.9% in case if very deep-water source compared to the basic scenario II. As indicated before, the PVWP system has a huge percentage of energy losses due to fluctuating needs of the irrigation water requirements and solar irradiance. However, it could be turned into benefits in case there is a grid connection and consequently the NPV and EACF will be positively affected. The required pumping energy for each scenario is shown in Figure 21. The critical period is between Mid-July to Mid-August for scenarios II and III.

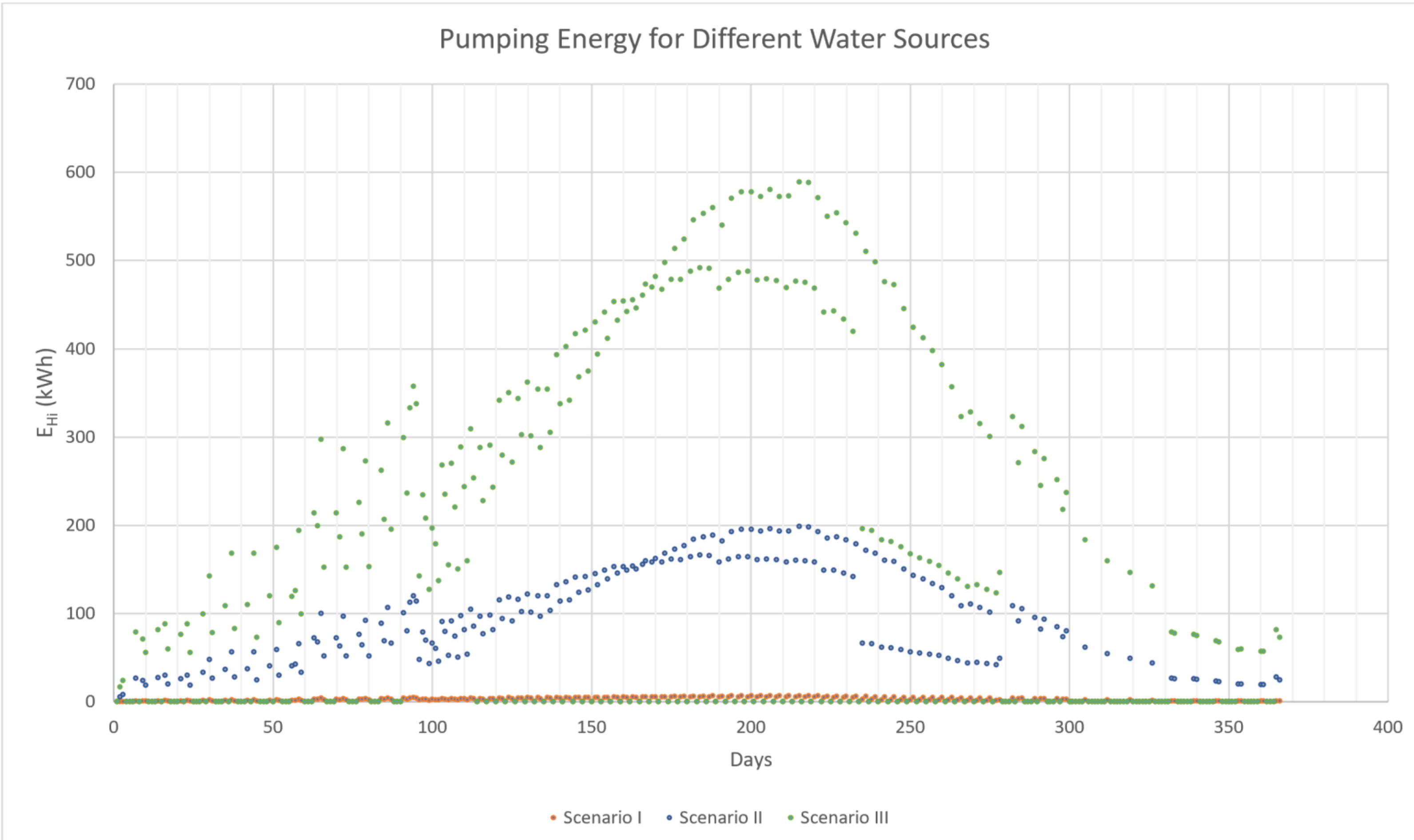

Figure 21: Daily Pumping Energy for 3 Scenarios

This concludes that the source of water has a significant effect on the PVWP system as well as the LCCA; therefore, it has to be carefully considered in any project.

5.3.2 Crops Costs Change

In order to study the effect of crop costs on the EACF, 10% increase in the cost is assumed. As illustrated in Table 33, the IIC is increased by increasing the crop costs while the EACF and NPV are reduced. The 10% increase in crops costs leads to decrease in the EACF and NPV by 1.19% and increase in the IIC by 1.44%.

Table 33 : Effect of Cost Change

Parameter	**Basic Case**	**10% Increase in Cost**	**Change %**
EACF (US$)	397,064	392,346	-1.19%
IIC (US$)	292,114	296,310	1.44%
NPV (US$)	4,013,007	3,965,326	-1.19%

5.3.3 Crops Price Change

The price of crops is directly affected by the quality of the products. Therefore, it is important to study the effect of having lower price because of having less quality products. The price change is assumed to be decrease by 10%. This leads to lower EACF and NPV as indicated in Table 34. The percentage of change will differ from one location to another as the transportation cost will have an effect on the final cost.

Table 34 : Effect of Price Change

Parameter	**Basic Case**	**10% Decrease in Price**	**Change %**
EACF (US$)	397,064	381,821	-3.84%
IIC (US$)	292,114	292,114	0
NPV (US$)	4,013,007	3,858,954	-3.84%

CHAPTER 6 – CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1 Conclusion

The proposed model presented in this research introduced a new approach to the problem by considering almost all the relevant factors affecting both the PV system and the irrigation system such as location, PVWP system, local climate, soil type, water source, total head losses, pool of different crops, and irrigation system. Accurate estimation for the irrigation water requirements and solar irradiance were carried out. In addition, the PV energy output was calculated taking into consideration the slope of installed panels (β), modules' azimuth (Ψ), and the effect of the ambient temperature (T_a) on the performance of the PV modules as well. The model was developed based on GA technique with aid of *Evolver 8.2* which is a *Microsoft-Excel Add-in*. Then, the model was verified by comparing the model outputs for two locations in Egypt (Luxor and Giza) and it was proved that the model describes the subject system very well as several useful outcomes achieved. The developed model was validated in selecting the types of crops that matched the soil parameters and the climate conditions. Not only that but also the selected combination of crops gave a higher return on investment and minimum utilization for water per economic return ratio compared to other methods.

The model was run to maximize the equivalent annual cash flow (EACF) by considering the net benefit from the combination of the crops and the PVWP system costs. Accordingly, the ToP, combinations of crops, starting date for each crop and occupied area for each crop were adjusted to meet the objective function. This model is characterized by having a flexible database module that can be edited by the user if needed. Next, the model outputs were generated including maximum EACF, economic analysis, and optimized PVWP system size. It was also observed that the total irrigation water requirements and the available solar irradiance have significant effects on the EACF through comparing the optimization results for the two locations (Luxor and Giza). Although Luxor is characterized by high solar irradiance which gives it an advantage over other locations in optimizing the PV system size, it was noticed that higher percentage of water for irrigation is required because of higher ET_o value resulted from the high solar irradiance. Giza provided better economic analysis than Luxor as it had higher EACF (397,064 US$) compared to Luxor (318,620 US$) and higher return per 1 m^3 of water (20.15 US$) compared to Luxor (16.26 US$). In both locations, the PVWP system was considered as sufficient system as the E_{Ai} - E_{Hi} >0. However, the percentage of the total energy losses in both locations exceeded 50% which highlight the importance of optimizing the percentage of the total energy losses.

Optimizing the energy losses was done on Giza area and results showed that EACF improved significantly but the percentage of the total energy losses were slightly enhanced only by 1%. This led to consider other option such as using diesel generator instead of PV system. Results indicated that diesel generator is a better option as long as the percentage of total energy losses exceed 30%; however, it is a risky option as 83% of its cost depends on fuel price. Therefore, further investigation on applying other options for energy storage systems is greatly needed.

In addition, the effect of having different water sources have been studied. Three different scenarios were analyzed representing surface (H_{ST} = 1 m), deep boreholes (H_{ST} = 50m), and very deep borehole (H_{ST} = 150m). It was noticed that as the static head increases, the total head loss increases, and the required hydraulic energy dramatically increase. The required E_H (kW) was 7.10, 198.58, and 588.66 for surface water, deep borehole, and very deep borehole respectively. This was reflected in sizing the PWVP system and the IIC. The required number of panels were 7 for surface water, 191 for deep borehole, and 566 for very deep borehole. There was also a noticeable increase in the IIC as it was 51,105 US$ in case of surface water, 292,114 US$ in case of deep-water source and 783.273 US$ in case if very deep-water source.

Finally, the effect of changing the cost of crops and the selling price were analyzed. It was concluded that decreasing the selling price by 10% led to drop in the EACF by 3.84% while increasing the crops cost by 10% lead to drop in the EACF by only 1.19% and increase in the IIC cost by 1.44%. To sum up, the optimization model presented in this research is an example for how technology and sustainability can be integrated into agricultural sector to help farmers and investigators to find efficient and economic practice for the best utilization of land for greenhouse farming while bridging the gap of overestimation for irrigation water and consequently oversizing for PVWP system.

6.2 Recommendations for Future Work

This study develops an optimization model for aiding the agricultural sector in identifying the best utilization of the land using sustainable energy. This study provides an overview on greenhouse crops that can be cultivated in Egypt, estimation for irrigation water requirements, design, optimize and assess the technical and economic feasibility of PV system. This section identifies some limitations that needed further exploration.

First, this research concentrates on the off-grid system, however; there is a possibility of interfacing the PVWP system to the grid. Therefore, it is recommended to study the feasibility of integrating PVWP system to the grid system.

In addition, this study focusses on the economic and technical assessment of PVWP system without paying attention to the environmental impacts. Thus, life cycle environmental analysis is greatly needed to be analyzed.

Moreover, the minor losses inside the pipes are assumed as 10% (RETScreen International Clean Energy Decision Support Centre (Canada) et al., 2005) due to the lack of details about design of the pipe network. Hence, investigating on studying the minor losses may lead to better results.

Integrating energy storage system to the PVWP system may lead to better results concerning the percentage of the total energy losses and consequently the PVWP system size. Therefore, it is recommended to study different scenarios for energy storage such as water tanks with different capacities or batteries and evaluate their economic performance.

More efforts are also required to study the probability for each crop to be affected by environmental conditions. This could give better realistic results as there are some crops that highly affected by temperature, for example, and this may lead to lose all the crop yield.

REFERENCES

Abdrabbo, M., Negm, A., Fath, H., & Javadi, A. (2019). *GREENHOUSE MANAGEMENT AND BEST PRACTICE IN EGYPT*. *11*, 369–381.

Abou-Hadid, A. F., Medany, M. A., & El-Beltagy, A. S. (1993). Productivity and pre-economical studies on the use of drip irrigated low tunnels [for tomatoes] in Egypt. *Egyptian Journal of Horticulture (Egypt)*. https://scholar.google.com/scholar_lookup?title=Productivity+and+pre-economical+studies+on+the+use+of+drip+irrigated+low+tunnels+%5Bfor+tomatoes%5D+in+Egypt&author=Abou-Hadid%2C+A.F.+%28Ain-Shams+Univ.%2C+Cairo+%28Egypt%29.+Faculty+of+Agriculture%29&publication_year=1993

Abu-Aligah, M. (2011). Design of photovoltaic water pumping system and compare it with diesel powered pump. *Jordan Journal of Mechanical and Industrial Engineering*, *5*, 273–280.

Akhoondzadeh, M., & Azizi, K. (2019, November 3). *Genetic Algorithm (GA)*.

Al-Badi, A., Yousef, H., Al Mahmoudi, T., Al-Shammaki, M., Al-Abri, A., & Al-Hinai, A. (2018). Sizing and modelling of photovoltaic water pumping system. *International Journal of Sustainable Energy*, *37*(5), 415–427. https://doi.org/10.1080/14786451.2016.1276906

Aliyu, M., Hassan, G., Said, S. A., Siddiqui, M. U., Alawami, A. T., & Elamin, I. M. (2018). A review of solar-powered water pumping systems. *Renewable and*

Sustainable Energy Reviews, *87*, 61–76. https://doi.org/10.1016/j.rser.2018.02.010

Argaw, N., Foster, R., & Ellis, A. (2003). *Renewable Energy for Water Pumping Applications In Rural Villages; Period of Performance: April 1, 2001--September 1, 2001*. https://doi.org/10.2172/15004054

Awan, A., Alghassab, M., Zubair, M., Bhatti, A., Uzair, M., & Abbas, G. (2020). Comparative Analysis of Ground-Mounted vs. Rooftop Photovoltaic Systems Optimized for Interrow Distance between Parallel Arrays. *Energies*, *13*, 3639. https://doi.org/10.3390/en13143639

Bakelli, Y., Hadj Arab, A., & Azoui, B. (2011). Optimal sizing of photovoltaic pumping system with water tank storage using LPSP concept. *Solar Energy*, *85*(2), 288–294. https://doi.org/10.1016/j.solener.2010.11.023

Bekhet, H., & Azlina, A. (2010). Energy use in agriculture sector: Input-Output analyses. *International Business Research*, *3*, 111–120. https://doi.org/10.5539/ibr.v3n3p111

Bhatia, M., & Rana, A. (2020). A Mathematical Approach to Optimize Crop Allocation – A Linear Programming Model. *International Journal of Design & Nature and Ecodynamics*, *15*(2), 245–252. https://doi.org/10.18280/ijdne.150215

Bonachela, S., González, A. M., & Fernández, M. D. (2006). Irrigation scheduling of plastic greenhouse vegetable crops based on historical weather data. *Irrigation Science*, *25*(1), 53. https://doi.org/10.1007/s00271-006-0034-z

Boyabatlı, O., Nasiry, J., & Zhou, Y. (Helen). (2019). Crop Planning in Sustainable Agriculture: Dynamic Farmland Allocation in the Presence of Crop Rotation Benefits. *Management Science*, mnsc.2018.3044. https://doi.org/10.1287/mnsc.2018.3044

Chandel, S. S., Naik, M. N., & Chandel, R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. *Renewable and Sustainable Energy Reviews*, *49*, 1084–1099.

Collares-Pereira, M., & Rabl, A. (1979). The average distribution of solar radiation-correlations between diffuse and hemispherical and between daily and hourly insolation values. *Solar Energy*, *22*(2), 155–164. https://doi.org/10.1016/0038-092X(79)90100-2

Comsan, M. N. H. (2010). *Solar Energy Perspectives In Egypt*. https://www.osti.gov/etdeweb/biblio/21502997

Cooman, A., Medina, A., Schrevens, E., & Tenorio, J. (2005). Simulation of Greenhouse Management for the Cultivation of Tomato in the High Altitude Tropics. *Acta Horticulturae*, *691*. https://doi.org/10.17660/ActaHortic.2005.691.6

Corwin, D., Rhoades, J., & Simunek, J., Jirka. (2012). Leaching Requirement: Steady-State Versus Transient Models. In *Agricultural Salinity Assessment and Management: Second Edition* (pp. 801–824). https://doi.org/10.1061/9780784411698.ch26

Cossu, M., Cossu, A., Deligios, P. A., Ledda, L., Li, Z., Fatnassi, H., Poncet, C., & Yano, A. (2018). Assessment and comparison of the solar radiation distribution inside the main commercial photovoltaic greenhouse types in Europe. *Renewable and Sustainable Energy Reviews*, *94*, 822–834. https://doi.org/10.1016/j.rser.2018.06.001

Cuadros, F., Opez-Rodr, F., Iguez, Marcos, A., & Coello, J. (2004). A procedure to size solar-powered irrigation (photoirrigation) schemes. *Solar Energy - SOLAR ENERG*, *76*. https://doi.org/10.1016/j.solener.2003.08.040

Das, A. K., & Pratihar, D. K. (2018). A Direction-Based Exponential Mutation Operator for Real-Coded Genetic Algorithm. *2018 Fifth International Conference on Emerging Applications of Information Technology (EAIT)*, 1–4. https://doi.org/10.1109/EAIT.2018.8470407

Diogo, A. F., & Vilela, F. A. (2014). Head losses and friction factors of steady turbulent flows in plastic pipes. *Urban Water Journal*, *11*(5), 414–425. https://doi.org/10.1080/1573062X.2013.768682

Duffie, J. A., & Beckman, W. A. (2013). *Solar Engineering of Thermal Processes*. John Wiley & Sons, Incorporated. http://ebookcentral.proquest.com/lib/aucegypt/detail.action?docID=1162079

Egypt diesel prices. (2021). GlobalPetrolPrices.Com. Retrieved December 25, 2021, from https://www.globalpetrolprices.com/Egypt/diesel_prices/

El-Gayar, S., Negm, A., & Abdrabbo, M. (2019). Greenhouse Operation and Management in Egypt. In A. M. Negm (Ed.), *Conventional Water Resources and Agriculture in Egypt* (pp. 489–560). Springer International Publishing. https://doi.org/10.1007/698_2017_230

EL-Shimy, M. (2013). Sizing optimisation of stand-alone photovoltaic generators for irrigation water pumping systems. *International Journal of Sustainable Energy*, *32*(5), 333–350. https://doi.org/10.1080/14786451.2012.697463

EL-Shimy, M., Noor, M., & Abdo, T. (2017). *Viability and Emission Analysis of Various Energy Supply Options for Irrigation Water Pumping Systems* (pp. 309–393). https://doi.org/10.6084/m9.figshare.6169493

Erbs, D. G., Klein, S. A., & Duffie, J. A. (1982). Estimation of the diffuse radiation fraction for hourly, daily and monthly-average global radiation. *Solar Energy*, *28*(4), 293–302. https://doi.org/10.1016/0038-092X(82)90302-4

Espinoza, F. P., Minsker, B., & Goldberg, D. (2003). Performance Evaluation and Population Reduction for a Self Adaptive Hybrid Genetic Algorithm (SAHGA). *GECCO*. https://doi.org/10.1007/3-540-45105-6_104

Ezzo, M., Glala, A. A., Habib, H., & Helaly, A. (2010). Response of Sweet Pepper Grown in Sandy and Clay Soil Lysimeters to Water Regimes. *J. Agric. & Environ. Sci*, *8*.

Fernández-Ramos, J., Narvarte-Fernández, L., & Poza-Saura, F. (2010). Improvement of photovoltaic pumping systems based on standard frequency converters by means of programmable logic controllers. *Solar Energy*, *84*(1), 101–109. https://doi.org/10.1016/j.solener.2009.10.013

Ghaheri, A., Shoar, S., Naderan, M., & Hoseini, S. S. (2015). The Applications of Genetic Algorithms in Medicine. *Oman Medical Journal*, *30*(6), 406–416. https://doi.org/10.5001/omj.2015.82

Ghoneim, A. A. (2006). Design optimization of photovoltaic powered water pumping systems. *Energy Conversion and Management*, *47*(11), 1449–1463. https://doi.org/10.1016/j.enconman.2005.08.015

Glasnovic, Z., & Margeta, J. (2007). A model for optimal sizing of photovoltaic irrigation water pumping systems. *Solar Energy*, *81*(7), 904–916. https://doi.org/10.1016/j.solener.2006.11.003

Glasnovic, Z., & Margeta, J. (2009). Optimal sizing of photovoltaic-hydro power plant. *Progress in Photovoltaics: Research and Applications*, *17*(8), 542–553. https://doi.org/10.1002/pip.906

Gopinathan, K. K., Maliehe, N. B., & Mpholo, M. I. (2007). A study on the intercepted insolation as a function of slope and azimuth of the surface. *Energy*, *32*(3), 213–220. https://doi.org/10.1016/j.energy.2006.04.009

Groener, B., Knopp, N., Korgan, K., Perry, R., Romero, J., Smith, K., Stainback, A., Strzelczyk, A., & Henriques, J. (2015). Preliminary Design of a Low-cost Greenhouse with Open Source Control Systems. *Procedia Engineering*, *107*, 470–479. https://doi.org/10.1016/j.proeng.2015.06.105

Hamidat, A., Benyoucef, B., & Hartani, T. (2003). Small-scale irrigation with photovoltaic water pumping system in Sahara regions. *Renewable Energy*, *28*(7), 1081–1096. https://doi.org/10.1016/S0960-1481(02)00058-7

Hollingsworth, J. A., Ravishankar, E., O’Connor, B., Johnson, J. X., & DeCarolis, J. F. (2020). Environmental and economic impacts of solar-powered integrated greenhouses. *Journal of Industrial Ecology*, *24*(1), 234–247. https://doi.org/10.1111/jiec.12934

Hong, T., Koo, C., Kwak, T., & Park, H. S. (2014). An economic and environmental assessment for selecting the optimum new renewable energy system for educational facility. *Renewable and Sustainable Energy Reviews*, *29*, 286–300. https://doi.org/10.1016/j.rser.2013.08.061

Hosny, O. A., Dorra, E. M., Tarabieh, K. A., Nassar, K. A., Zahran, S., Amer, M., & Ibrahim, A. (2018). Development of an automated optimizer for sustainable urban landscape design. *Automation in Construction*, *94*, 93–103. https://doi.org/10.1016/j.autcon.2018.05.031

Hosny, O., El Eslamboly, A., Elkhayam, D., Tarabieh, K., Abotaleb, I., Amer, M., Farouk, M., et al. 2021. "Developing a Comprehensive Relational Database for Optimizing Land Utilization for Sustainable Farming." In *CSCE 2021 Annual Conference*. Springer International Publishing.

Hosny, O., El Eslamboly, A., Elkhayam, D., Tarabieh, K., Abotaleb, I., Amer, M., Farouk, M.,, Gad, H., Abd El Raouf, Y., Sherif, A., Hussien, Y. (2022). Designing an Automated Interface for Optimizing Integrated and Sustainable Farming.

International, C. A. B. (2009). How to feed the world in 2050. *How to Feed the World in 2050.* https://www.cabdirect.org/cabdirect/abstract/20093293526

Isaías, D. H. dos S., Cuamba, B. C., & Leão, A. J. (2019). A Review on Renewable Energy Systems for Irrigation in Arid and Semi-Arid Regions. *Journal of Power and Energy Engineering*, *7*(10), 21–58. https://doi.org/10.4236/jpee.2019.710002

Jamal, H. (2011). *Irrigation Water Requirement of Crops | Evaluation of Losses in Irrigation*. Retrieved January 23, 2022, from https://www.aboutcivil.org/water-requirements-of-crops.html

Katoch, S., Chauhan, S. S., & Kumar, V. (2020). A review on genetic algorithm: Past, present, and future. *Multimedia Tools and Applications*, 1–36. https://doi.org/10.1007/s11042-020-10139-6

Kelley, L. C., Gilbertson, E., Sheikh, A., Eppinger, S. D., & Dubowsky, S. (2010). On the feasibility of solar-powered irrigation. *Renewable and Sustainable Energy Reviews*, *14*(9), 2669–2682. https://doi.org/10.1016/j.rser.2010.07.061

Kenna, J., & Gillett, B. (1985). Solar water pumping: A handbook. *Solar Water Pumping: A Handbook.* https://www.cabdirect.org/cabdirect/abstract/19856757935

Khattab, N. M., Badr, M., El Shenawy, E., Sharawy, H. H., & Shalaby, M. (2016). *Feasibility of hybrid renewable energy water pumping system for a small farm in Egypt*. *11*, 7406–7414.

Kim, J., Hong, T., Jeong, J., Lee, M., Koo, C., Lee, M., Ji, C., & Jeong, J. (2016). An integrated multi-objective optimization model for determining the optimal solution in the solar thermal energy system. *Energy*, *102*, 416–426. https://doi.org/10.1016/j.energy.2016.02.104

Kordzadeh, A. (2010). The effects of nominal power of array and system head on the operation of photovoltaic water pumping set with array surface covered by a film of water. *Renewable Energy*, *35*(5), 1098–1102. https://doi.org/10.1016/j.renene.2009.10.024

Kudadze, S., Adams Jongare, I., & Adzawla, W. (2019). Farmers' Perception on Irrigation Farming and the Factors Influencing Access to and Size of Irrigable lands in Northern Region, Ghana. *Asian Food Science Journal*, 1–14. https://doi.org/10.9734/afsj/2019/v8i329994

Lambora, A., Gupta, K., & Chopra, K. (2019). Genetic Algorithm- A Literature Review. *2019 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COMITCon)*, 380–384. https://doi.org/10.1109/COMITCon.2019.8862255

Li, M., & Guo, P. (2014). A multi-objective optimal allocation model for irrigation water resources under multiple uncertainties. *Applied Mathematical Modelling*, *38*(19), 4897–4911. https://doi.org/10.1016/j.apm.2014.03.043

Liu, B. Y. H., & Jordan, R. C. (1960). The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. *Solar Energy*, *4*(3), 1–19. https://doi.org/10.1016/0038-092X(60)90062-1

Lynn, P. A. (2010). *Electricity from sunlight: An introduction to photovoltaics*. Wiley.

Matasane, C., Dwarika, C., & Naidoo, R. (2014). Modelling the Photovoltaic Pump Output Using Empirical Data from Local Conditions in the Vhembe District. *International Journal of Educational and Pedagogical Sciences*, *8*(11), 1724–1729.

Meah, K., Ula, S., & Barrett, S. (2008). Solar photovoltaic water pumping—Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *4*(12), 1162–1175. https://doi.org/10.1016/j.rser.2006.10.020

Melsen, L.A., Lanen, H.A.J., Wanders, N., Huijgevoort, M.H.J. van, & Weedon, G.P. (2011). Reference evapotranspiration with radiation-based and temperature-based method—Impact on hydrological drought using WATCH Forcing Data. In *EU-WATCH Technical Report* (Issue 39, p. 1null). WATCH. https://dspace.library.uu.nl/handle/1874/221990

Mohamed, S. A., & Abd El Sattar, M. (2019). A comparative study of P&O and INC maximum power point tracking techniques for grid-connected PV systems. *SN Applied Sciences*, *1*(2), 174. https://doi.org/10.1007/s42452-018-0134-4

Mohr, A. J., Dahlberg, D. A., & Dirmhirn, I. (1979). Experiences with tests and calibrations of pyranometers for a mesoscale solar-irradiance network. *Solar Energy*, *22*(3), 197–203. https://doi.org/10.1016/0038-092X(79)90133-6

Mozaffari Niapour, S. A. KH., Danyali, S., Sharifian, M. B. B., & Feyzi, M. R. (2011). Brushless DC motor drives supplied by PV power system based on Z-source inverter and FL-IC MPPT controller. *Energy Conversion and Management*, *52*(8), 3043–3059. https://doi.org/10.1016/j.enconman.2011.04.016

Odeh, I., Yohanis, Y. G., & Norton, B. (2006). Economic viability of photovoltaic water pumping systems. *Solar Energy*, *80*(7), 850–860. https://doi.org/10.1016/j.solener.2005.05.008

Padmanabhan, P., Cheema, A., & Paliyath, G. (2016). Solanaceous Fruits Including Tomato, Eggplant, and Peppers. In B. Caballero, P. M. Finglas, & F. Toldrá (Eds.), *Encyclopedia of Food and Health* (pp. 24–32). Academic Press. https://doi.org/10.1016/B978-0-12-384947-2.00696-6

Palisade. (2021). *Evolver—Sophisticated Optimization for Spreadsheets*. Palisade. Retrieved January 20, 2022, from https://www.palisade.com/evolver/default.asp

Pap, Z. (2008). *Crop rotation constraints in agricultural production planning*. 1–5. https://doi.org/10.1109/SISY.2008.4664951

Qoaider, L., & Steinbrecht, D. (2010). Photovoltaic systems: A cost competitive option to supply energy to off-grid agricultural communities in arid regions. *Applied Energy*, *87*(2), 427–435. https://doi.org/10.1016/j.apenergy.2009.06.012

Radiation Centres | World Meteorological Organization. (n.d.). Retrieved December 30, 2021, from https://community.wmo.int/activity-areas/imop/radiation-centres

Raghava, Y., Dr, R., Padi, T. R., & Prof, A. (2012). Multi Objective Crop Planning For Optimal Benefits. *International Journal of Engineering Research and Applications*, *2*, 279–287.

Rauff, K. O., & A. Shittu, S. (2015). Determination of Evapotranspiration and Water Use Efficiency in Crop Production. *Agricultural Sciences*, *06*(09), 1058–1067. https://doi.org/10.4236/as.2015.69101

Retamales, J. B., & Hancock, J. F. (2012). *Blueberries*. CABI.

RETScreen International Clean Energy Decision Support Centre (Canada), United Nations Environment Programme, United States, & CANMET Energy

Technology Centre (Canada) (Eds.). (2005). *Clean energy project analysis, RETScreen engineering & cases textbook* (3rd ed) [Electronic resource]. CANMET Energy Technology Centre. http://epe.lac-bac.gc.ca/100/200/301/nrcan-rncan/clean_energy_project-e/M154-13-2005E.pdf

Rezk, H., & El-Sayed, A. H. M. (2013). Sizing of a stand alone concentrated photovoltaic system in Egyptian site. *International Journal of Electrical Power & Energy Systems*, *45*(1), 325–330. https://doi.org/10.1016/j.ijepes.2012.09.001

Sánchez, E., & Izard, J. (2015). Performance of photovoltaics in non-optimal orientations: An experimental study. *Energy and Buildings*, *87*, 211–219. https://doi.org/10.1016/j.enbuild.2014.11.035

Sánchez-Carbajal, S., & Rodrigo, P. M. (2019). Optimum Array Spacing in Grid-Connected Photovoltaic Systems considering Technical and Economic Factors. *International Journal of Photoenergy*, *2019*, e1486749. https://doi.org/10.1155/2019/1486749

Sarker, R. A., & Quaddus, M. A. (2002). Modelling a nationwide crop planning problem using a multiple criteria decision making tool. *Computers & Industrial Engineering*, *42*(2), 541–553. https://doi.org/10.1016/S0360-8352(02)00022-0

Shaheen, A. E. A., & Fattah, A. K. A. (2021). Response of Zucchini Plants to Nano and Organic Fertilizers Application Grown in Sandy Soil. *Asian Journal of Soil Science and Plant Nutrition*, 11–22. https://doi.org/10.9734/ajsspn/2021/v7i430118

Sharma, M. K., Kumar, D., Dhundhara, S., Gaur, D., & Verma, Y. P. (2020). Optimal Tilt Angle Determination for PV Panels Using Real Time Data Acquisition. *Global Challenges*, *4*(8), 1900109. https://doi.org/10.1002/gch2.201900109

Sharma, R., Sharma, S., & Tiwari, S. (2020). Design optimization of solar PV water pumping system. *Materials Today: Proceedings*, *21*, 1673–1679. https://doi.org/10.1016/j.matpr.2019.11.322

Shinde, D., & Wandre, S. (2015). Solar photovoltaic water pumping system for irrigation: A review. *African Journal of Agricultural Research*, *10*, 2267–2273. https://doi.org/10.5897/AJAR2015.9879

Shukla, S., Shrestha, N., Jaber, F., Srivastava, S., Obreza, T., & Boman, B. (2014). Evapotranspiration and crop coefficient for watermelon grown under plastic mulched conditions in sub-tropical Florida. *Agricultural Water Management*, *132*, 1–9. https://doi.org/10.1016/j.agwat.2013.09.019

Sinapis, K., Litjens, G., van den Donker, M., Folkerts, W., & van Sark, W. (2015). Outdoor characterization and comparison of string and MLPE under clear and partially shaded conditions. *Energy Science & Engineering*, *3*(6), 510–519. https://doi.org/10.1002/ese3.97

Solar Pumping for Irrigation: Improving livelihoods and sustainability. (2016). /Publications/2016/Jun/Solar-Pumping-for-Irrigation-Improving-Livelihoods-and-Sustainability. Retrieved December 28, 2021, from https://www.irena.org/publications/2016/Jun/Solar-Pumping-for-Irrigation-Improving-livelihoods-and-sustainability

Solar PV – Renewables 2020 – Analysis. (2020). IEA. Retrieved December 21, 2021, from https://origin.iea.org/reports/renewables-2020/solar-pv

solar radiation—NASA Search Results. (n.d.). Retrieved December 21, 2021, from https://nasasearch.nasa.gov/search?query=solar++radiation&affiliate=nasa&utf8=%E2%9C%93%20(accessed%20Jun.%2024,%202021)

Solar-Water-Pumping-Guidelines-V1. (2019). Retrieved December 25, 2021, from http://www.seiapi.com/wp-content/uploads/2019/07/Solar-Water-Pumping-Guidelines-V1_compressed.pdf

Tadesse, A., Bosona, T., & Gebresenbet, G. (2013). Rural Water Supply Management and Sustainability: The Case of Adama Area, Ethiopia. *Journal of Water Resource and Protection*, *5*(2), 208–221. https://doi.org/10.4236/jwarp.2013.52022

Taha, A. (2020). *RESPONSE OF MANGO (Keitt var.) PRODUCTIVITY TO DEFICIT IRRIGATION IN SANDY SOIL pdf*.

Tsakiris, G., & Spiliotis, M. (2006). Cropping pattern planning under water supply from multiple sources. *Irrigation and Drainage Systems*, *20*(1), 57–68. https://doi.org/10.1007/s10795-006-5426-y

U.S. diesel fuel retail price annually. (2020). Statista. Retrieved December 25, 2021, from https://www.statista.com/statistics/1185300/diesel-fuel-retail-price-annual-average-us/

Visagie, S. E., & Ghebretsadik, A. H. (Eds.). (2005). Modelling risk in farm planning. *Agrekon*. https://doi.org/10.22004/ag.econ.31702

Wazed, S. M., Hughes, B. R., O'Connor, D., & Calautit, J. K. (2017). A review of sustainable solar irrigation systems for Sub-Saharan Africa. *Renewable and Sustainable Energy Reviews*, *81*. https://doi.org/10.1016/j.rser.2017.08.039

APPENDICES

Appendix - 1 : Crops Coefficient and Total Duration

Crop Name	Value of Crop Coefficient depends on Stage			Duration
	Initial Kc	Maximum Kc	Final Kc	Months
Tomato I	0.70	1.05	0.80	9
Tomato II	0.70	1.05	0.80	8
Tomato III	0.70	1.05	0.80	8
Tomato IV	0.70	1.05	0.80	7
Sweet Pepper I	0.70	1.05	0.85	9
Sweet Pepper II	0.70	1.05	0.85	8
Sweet Pepper III	0.70	1.05	0.85	8
Sweet Pepper IV	0.70	1.05	0.85	7
Chili-Pepper I	0.70	1.05	0.85	9
Chili-Pepper II	0.70	1.05	0.85	8
Chili-Pepper III	0.70	1.05	0.85	8
Chili-Pepper IV	0.70	1.05	0.85	7
Cucumber I	0.60	1.00	0.75	5
Cucumber II	0.60	1.00	0.75	6
Cucumber III	0.60	1.00	0.75	4
Cucumber IV	0.60	1.00	0.75	5
Cantaloupe I	0.50	0.85	0.60	4
Cantaloupe II	0.50	0.85	0.60	4
Watermelon (grafting)	0.40	1.00	0.75	4
Watermelon (non-grafting)	0.40	1.00	0.75	4
Squash (Zucchini)	0.50	0.95	0.75	3.5
Green Bean (Al Hamma) I	0.50	1.05	0.90	5
Green Bean (Al Hamma) II	0.50	1.05	0.90	4
Green Bean (Joya) I	0.50	1.05	0.90	5

Green Bean (Joya) II	0.50	1.05	0.90	4
Eggplant (Romy)	0.60	1.00	0.90	8
Eggplant (Long)	0.60	1.00	0.90	8
Pineapple	0.51	0.37	0.33	12
Mango	0.5	0.8	0.75	12
Blackberry	0.3	1.05	0.5	12
Grape	0.3	0.8	0.5	12
Banana	0.5	1.1	1	12
Strawberry	0.40	0.85	0.75	9
Chestnut	0.15	0.91	0.15	12
Raspberry	0.3	1.05	0.5	12
Blueberry	0.3	1.05	0.5	12
Breadnut	0.4	1.15	0.40	12

Appendix - 2 : Starting Limits for Crops

Crop Name	Can't start before	Can't start after
Tomato I	8	10
Tomato II	10	12
Tomato III	2	3
Tomato IV	4	5
Sweet Pepper I	8	10
Sweet Pepper II	10	12
Sweet Pepper III	2	3
Sweet Pepper IV	4	5
Chili-Pepper I	8	10
Chili-Pepper II	10	12
Chili-Pepper III	2	3
Chili-Pepper IV	4	5
Cucumber I	9	10
Cucumber II	10	11
Cucumber III	2	3
Cucumber IV	5	6
Cantaloupe I	8	10
Cantaloupe II	1	3
Watermelon (grafting)	12	2
Watermelon (non-grafting)	12	2
Squash (Zucchini)	12	2
Green Bean (Al Hamma) I	11	12
Green Bean (Al Hamma) II	12	1
Green Bean (Joya) I	11	12
Green Bean (Joya) II	12	1
Eggplant (Romy)	11	1

Eggplant (Long)	11	1
Pineapple	11	10
Mango	11	10
Strawberry	10	4
Chestnut	11	10
Raspberry	11	10
Blueberry	11	10
Breadnut	11	10

Appendix - 3 : Crops' Costs Breakdown (EGP)

Crop Name	Cost of making Rows (EGP)	Cost of Seeds (EGP)	Cost of Composite (EGP)	Cost of Fertilizing & pesticides (EGP)	Cost of Workers & Engineers (EGP)
Tomato I	1,500	20,800	5,600	19,500	64,800
Tomato II	1,500	20,800	5,600	19,500	57,600
Tomato III	1,500	20,800	5,600	19,500	57,600
Tomato IV	1,500	20,800	5,600	19,500	50,400
Sweet Pepper I	1,500	44,000	8,500	26,500	64,800
Sweet Pepper II	1,500	44,000	8,500	26,500	57,600
Sweet Pepper III	1500	44,000	8,500	26,500	57,600
Sweet Pepper IV	1,500	44,000	8,500	26,500	50,400
Chili-Pepper I	1,500	36,000	8,500	26,500	64,800
Chili-Pepper II	1,500	36,000	8,500	26,500	57,600
Chili-Pepper III	1,500	36,000	8,500	26,500	57,600
Chili-Pepper IV	1,500	36,000	8,500	26,500	50,400
Cucumber I	1,500	18,400	3,400	27,500	36,000
Cucumber II	1,500	18,400	3,400	27,500	43,200
Cucumber III	1,500	18,400	3,400	27,500	28,800
Cucumber IV	1,500	18,400	3,400	27,500	36,000
Cantaloupe I	1,500	12,420	2,250	28,000	28,800

Cantaloupe II	1,500	12,420	2,250	28,000	28,800
Watermelon (grafting)	1,500	14,000	2,250	28,000	28,800
Watermelon (non-grafting)	1,500	7,000	2,250	28,000	28,800
Squash (Zucchini)	3,000	32,500	16,500	11,000	25,200
Green Bean (Al Hamma) I	3,000	48,300	1,000	5,500	36,000
Green Bean (Al Hamma) II	3,000	48300	1,000	5,500	28,800
Green Bean (Joya) I	3,000	62,100	1,000	5,500	36,000
Green Bean (Joya) II	3,000	62,100	1,000	5,500	28,800
Eggplant (Romy)	1,500	22,400	5,600	19,500	57,600
Eggplant (Long)	1,500	22,400	5,600	19,500	57,600
Strawberry	3,000	432,000	8,000	25,500	97,200

Appendix - 4 : Trees' Cost (EGP)

Tree Name	Cost for Year 1 (EGP)	Cost for Year 2 (EGP)	Cost for Year 3 (EGP)	Cost for Year 4 (EGP)	Cost for Year 5 (EGP)
Pineapple	417,549	127,549	140,304	154,335	169,768
Mango	97,549	57,549	63,304	69,635	76,598
Black Currant	177,549	100,049	100,049	132,249	132,249
Grape	67,327	54,015	59,416	65,358	71,893
Banana	87,549	57,549	63,304	69,635	
Chestnut	169,609	56,022	58,703	55,989	74,613
Gooseberry	178,801	100,145	100,145	132,266	132,266
Red Currant	178,801	100,145	100,145	132,266	132,266
Breadnut	169,609	56,022	58,703	55,989	74,613

Appendix - 5 : Average Production (kg/plant) and Total No. of Plants / feddan

Crop Name	Average production/plant (kg)	Total No of plants/ feddan
Tomato I	18	8000
Tomato II	15	8000
Tomato III	15	8000
Tomato IV	12	8000
Sweet Pepper I	8	8000
Sweet Pepper II	7	8000
Sweet Pepper III	7	8000
Sweet Pepper IV	6	8000
Chili-Pepper I	6	8000
Chili-Pepper II	5	8000
Chili-Pepper III	5	8000
Chili-Pepper IV	4.5	8000
Cucumber I	5	8000
Cucumber II	6	8000
Cucumber III	4	8000
Cucumber IV	5	8000
Cantaloupe I	1.25	5400
Cantaloupe II	1	5400
Watermelon (grafting)	36	1400
Watermelon (non-grafting)	10	2000
Squash (Zucchini)	3	25000
Green Bean (Al Hamma) I	0.6	21000
Green Bean (Al Hamma) II	0.3	21000
Green Bean (Joya) I	0.55	27000
Green Bean (Joya) II	0.35	27000
Eggplant (Romy)	8	8000
Eggplant (Long)	7	8000
Strawberry	1.5	36000

Appendix - 6 : Lifespan in years for different Tree Types

Tree Name	Lifespan (years)
Pineapple	10
Mango	20
Black Currant	20
Grape	10
Banana	4
Chestnut	20
Gooseberry	20
Red Currant	20
Breadnut	15

Appendix - 7 : Egyptian Electricity Tariff

According to the Egyptian Ministry of Electricity				
Consumption Bracket		**New Tariff**	**Old Tariff**	**Hike**
From (kW)	**to (kW)**	**EGP**	**EGP**	~~**%**~~
0	**50**	0.38	0.3	27%
51	**100**	0.48	0.4	20%
101	**200**	0.65	0.5	30%
201	**350**	0.96	0.82	17%
351	**650**	1.18	1	18%
651	**1000**	1.40	1.18	19%
0	**1000**	1.18	1	18%
Above 1000		1.45	1.45	0%

Appendix - 8 : Technical Properties of PV Panels

No	Product	P_{max}	η_r	Price/W_p	T_{cn}	α_p	V_{MP}	I_{MP}	V_{oc}	I_{sc}
1	P36	165	15 %	0.314	44	-0.40%	18.75	8.80	22.36	9.36
2	M36	185	20%	0.326	44	-0.37%	19.86	9.19	23.59	9.74
3	P60	280	15%	0.282	44	-0.40%	31.10	8.76	38.70	9.31
4	M60	310	20%	0.295	44	-0.37%	33.16	9.20	39.30	9.73
5	P72	340	15%	0.282	44	-0.40%	37.60	8.84	46.81	9.38
6	M72	380	20%	0.295	44	-0.37%	39.83	9.23	47.25	9.74