THE POTENTIAL OF CONCENTRATED SOLAR POWER TECHNOLOGIES AND SUSTAINABILITY IMPACT IN ARID REGIONS

by

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

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DEDICATION

To: Souls of my mother and my Father

To: My Wife and my Children

To: My Brothers and my sisters

To: My mother and father-in-law

To: All my Friends.

I dedicate this work…

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ABSTRACT

In an era marked by escalating environmental issues, the convergence of sustainability and energy efficiency becomes a promising avenue for solutions. This research delves into this intersection, with specific emphasis on Iraq and the wider Middle East region. In these arid environments ensuring food security, managing water scarcity, and addressing energy demands are pressing priorities. The current work examines three crucial domains that present innovative approaches to address these challenges. The practice of indoor vertical farming has the potential to address future concerns regarding food insecurity by simultaneously decreasing land utilization and reducing reliance on the environment. Nevertheless, the substantial challenges lie in its elevated energy consumption and consequential environmental impact. This research examines the feasibility of utilizing Concentrating Solar Power (CSP) to power vertical farming in the arid regions of Iraq, taking advantage of the ample solar resources available. The study employs the system advisor model (SAM) to analyze the potential relocation of a commercial CSP plant from Seville, Spain, to six different locations in Iraq. The evaluation takes into consideration various factors, including implementation costs, energy production, and water usage. It is worth noting that the zones of Haditha and Ar Rutba demonstrate the highest annual energy output, exceeding that of Seville's original plant. In addition, the practice of vertical farming, particularly when focusing on Romaine lettuce as a representative crop, showcases the possibility of achieving significantly greater yields in arid regions when compared to traditional farming methods.

The subsequent points outline the significant findings of this research segment:

- Vertical farming is a sustainable solution for agriculture, maximizing space and water efficiency.
- CSP can address the high energy consumption of vertical farming.
- Six locations in west Iraq are suitable for CSP plants due to favorable conditions.
- Techno-economic analysis showed that Iraq's CSP outperforms Spain's in some locations.
- Vertical farming in Iraq can significantly increase lettuce yields, but it has higher energy requirements.
- The study can aid in reducing food insecurity and dependence on fossil fuels in arid regions.

The findings highlight the significance of CSP technologies in promoting sustainable agriculture in Iraq and provide valuable insights for policymakers and stakeholders who are interested in cost-effective and energy-efficient solutions.

It is crucial to reduce the reliance on fossil fuels in the agricultural sector. This research additionally examines the economic viability of incorporating solar energy photovoltaic (PV) into irrigation systems in the Middle East. Simulation models were used for four different locations, demonstrating that Egypt and the United Arab Emirates are particularly suitable for solar-powered irrigation. In Egypt, there is a quick return on investment, indicating its profitability, while access to solar power greatly benefits the United Arab Emirates. The integration of solar energy into irrigation networks in Egypt proves both feasible and financially rewarding, potentially serving as a blueprint for sustainable practices throughout the region.

The most important findings from this section of the study are as follows:

- Solar water pumping systems are environmentally friendly, emitting no emissions.
- They can mitigate fossil fuel dependence, conserve water, and reduce energy costs.
- Egypt, UAE, and other Middle Eastern countries are viable for solar water pumping.
- Egypt shows high efficiency and profitability for solar water pumping.
- Solar water pumping is strongly recommended in regions with abundant solar radiation.

Iraq is facing an energy crisis and a growing disparity between power generation capacity and actual usage. The additional aim of this work is to propose energy-efficient measures that can be implemented at the energy sector to address Iraq's electricity demand challenges and mitigate high energy costs in the industrial sector. An audit and evaluation of the real power plant reveal five recommendations, which lead to significant annual savings in electrical energy consumption and cost reductions. These findings highlight the urgent need for effective management of energy efficiency within Iraq's industrial sector.

The following are some of the most important takeaways from this section of the research:

- Energy audits reveal significant energy-saving opportunities at Haditha HPP.
- Recommendations for energy-efficient practices have low implementation costs.
- Potential annual cost savings amount to $920,996.
- The study provides insights into achieving energy efficiency in Iraq's industrial sector.

These studies highlight the potential of sustainable practices and renewable energy sources to address key challenges in agriculture, irrigation, and industries in Iraq and the broader

Middle East region. They provide practical insights for stakeholders seeking effective and environmentally friendly solutions, emphasizing the importance of integrating renewable energy into various applications to promote sustainable and resilient communities.

CHAPTER 1. INTRODUCTION

1.1 Motivation

The complex relationship between energy and food systems highlights the urgent requirement for a shift towards sustainability. It is worth noting that agri-food systems presently constitute a considerable share of global energy consumption, while also making a significant contribution to the emission of greenhouse gases. The attainment of the United Nations Sustainable Development Goals (SDGs) and the adherence to the principles outlined in the Paris Climate Agreement require a significant reorientation of these systems. The global energy landscape has undergone significant changes, characterized by a growing proportion of renewable energy sources. The pursuit of sustainability is especially relevant in the context of developing nations, particularly in the Middle East. The success of this undertaking relies on the implementation of energy-efficient, environmentally aware, and technologically sophisticated methodologies. Vertical farming, distinguished by its creative methodology, arises as a potentially effective resolution to a diverse range of worldwide predicaments, encompassing issues such as ensuring food security, mitigating water scarcity, and addressing climate change. Vertical farming offers many advantages, including a reduction in land utilization, thorough regulation of environmental factors, lessened water usage, and continuous crop production throughout the year. However, the energy-intensive features of vertical farming present a significant sustainability obstacle. These systems require a substantial energy supply for essential functions, such as providing lighting and controlling the climate. As a result, it is necessary to reassess the sources from which they obtain energy. The increasing adoption of renewable energy technologies presents an intriguing opportunity to explore the potential of utilizing concentrating solar power (CSP) for sustainable agriculture. CSP is distinguished by its ability to harness solar energy using mirrors and heat transfer fluids, enabling it to simultaneously produce electricity and heat. This research aims to fill existing knowledge gaps by conducting a comprehensive techno-economic assessment of the integration of Concentrated Solar Power (CSP) technology into vertical farming in arid regions, with a specific focus on Iraq. By doing so, the objective is to enhance the implementation of sustainable agricultural methods while utilizing renewable energy resources. Through the improvement of energy efficiency and utilization of renewable energy sources in vertical farming, it is possible to collectively tackle the obstacles presented by climate change, decrease energy expenses, and make substantial progress towards attaining global sustainability goals. The objective of this study is to provide significant perspectives that can serve as a guiding framework for policymakers and stakeholders in their efforts to navigate towards a more sustainable and energy-efficient future within the agricultural industry.

1.2 Background and Literature Review

In forthcoming years, advanced technology will utilize renewable energy to effectively address the increasing requirements of food production. This vision holds particular significance in arid regions such as Iraq, where the shortage of water and limitations on resources pose significant obstacles. The relationship between energy and food systems is deeply entwined. Renewable energy has the potential to play an important part in meeting the energy requirements of food systems in both developed and developing countries for electricity, heating, cooling, and transportation. Agri-food systems consume approximately 30% of the world's energy and contribute to one-third of its greenhouse gas emissions [1]. To supply the rising demand for energy and food in an equitable, environmentally sustainable, both systems must undergo significant changes. A coordinated approach to transforming energy and agri-food systems is essential to achieving the Sustainable Development Goals (SDGs) and fulfilling the Paris Climate Agreement [2].

The current use of energy in the food system is unsustainable for numerous reasons. One reason is that millions of people and small to medium-sized agri-food businesses do not have access to sustainable, reliable, and affordable energy. This lack of access hinders their ability to produce food, which can lead to significant losses [2]. Current agricultural production systems rely heavily on fossil fuels [3]. Projections suggest that in the coming decades, there will be a substantial and concurrent increase in the demand for water, energy, and food. This will lead to the depletion of natural resources and exacerbate the challenges posed by climate change [4]. The modernizing of agricultural systems through increased reliance on fossil fuels, as has been done in the past, is neither affordable nor sustainable. This is due to the impact of climate change and the effect of high and fluctuating fossil fuel prices on total production costs [3]. Therefore, it is essential to carefully consider the role of energy and its relationship with the production process when developing agricultural systems. Specifically, the agri-food value chain must gradually reduce its dependence on fossil fuels to produce more food using less and cleaner energy. To address these challenges, smart technologies in the agricultural systems must be adapted, which include improved access to state-of-the art production systems, larger use of renewable sources of energy, and the adoption of an integrated water-energy-agriculture nexus approach throughout the production processes. This is very crucial in developing countries that are unforgiving, such as Iraq with its arid climate nature, environment due to the nature of such countries in terms of increased demand due to growing population.

Due to food insecurity and rising food demand in Iraq and the region, more arable land must be utilized for farming and agricultural efforts must be intensified. As a technological advance, vertical farms are being designed and implemented to meet such demand around the globe [5]. Currently, such farms are largely used to cultivate and supply various types of goods to urban areas in China, South Korea, Japan, the United States, Singapore, and the United Arab Emirates. Vertical farming (VF) is a method of growing crops in vertically stacked layers, often in urban areas [6]. It uses controlled environmental conditions and nutrient solutions to produce food. Vertical farming can help to address a variety of social and environmental problems, such as food insecurity, water scarcity, and climate change. Vertical farming has several advantages over conventional farming techniques, including reduced land use, precise control over growing conditions, decreased water consumption, year-round crop production, and decreased transportation costs. Vertical farms can significantly reduce the amount of land required for crop production by growing crops in stacked layers. In addition, vertical farms are typically located indoors, allowing for precise regulation of temperature, humidity, and light. This expedites plant growth and increases crop yields. In addition, vertical farming systems can use up to 95% less water than conventional methods [7]. In addition, vertical farms can produce crops year-round, regardless of the external climate. By locating vertical farms in urban areas, farm-to-market transportation costs can be reduced. Vertical farms come in a variety of configurations, from two-level or tower systems to multi-story warehouses. Kalantari et al. [8] conducted a review of vertical farming technology. In their study, the authors focused on the period from 2009 to 2016 and reviewed existing and future vertical farming (VF) projects in Europe, Asia, and America. The study found that VF technology can help reduce poverty, increase food safety, and improve sustainability and human well-being. The study also found that VF can be integrated into urban areas, which can help to address the challenges of food insecurity, water scarcity, and climate change. Xin-Guang Zhu and Leo Marcelis [9] investigated the practice of cultivating crops using vertical farming techniques. These farms are indoor agricultural facilities that stack crops vertically in a highly controlled environment. Vertical farming offers several benefits, including higher water and nutrient efficiency, reduced use of pesticides and herbicides and decreased agricultural pollution. The authors suggest that combining vertical farming with photovoltaics-based electricity generation can help increase overall light energy use efficiency. Photovoltaics (PV) is a technology that converts sunlight into electricity. By combining vertical farming with PV, the authors believe that it is possible to create a more sustainable and efficient agricultural system.

The practice of vertical farming is not without its fair share of difficulties. One challenge is energy dependency. Vertical farms are highly dependent on energy sources and require a significant amount of energy to keep growing conditions at an optimal level [10]. Vertical farms have a significantly higher average energy use at 15 kWh/kg/year of produce [11]. Compared to outdoor traditional farming, which averages 0.3 kWh/kg/year [12]. This energy consumption is primarily driven by the need for intensive lighting, climate control, and heating and cooling technologies. Additionally, air circulation and ventilation systems are needed to ensure the growing environment is free from pathogens and contaminants [13]. The high energy consumption of vertical farming has important implications for the sustainability and economic viability of these operations, particularly in areas with high electricity prices. Reducing energy consumption and increasing the use of renewable energy sources is essential for the long-term sustainability of vertical farming [14]. Renewable energy, especially Concentrating Solar Power (CSP), can be utilized in a variety of ways to improve the sustainability and effectiveness of vertical farming techniques. Solar technologies, such as photovoltaic (PV) and CSP systems, can be incorporated into vertical farm structures to produce electricity for LED grow lights, equipment, and climate control systems. Solar-powered desalination units can convert salty water into fresh water for irrigation, thereby decreasing reliance on conventional energy sources for water purification. Heating, ventilation, and air conditioning systems are also powered by renewable energy sources, with solar thermal systems providing heat and PV panels operating fans and pumps to maintain optimal growing conditions. CSP with energy storage enables off-grid vertical farming in remote areas and provides reliable and sustainable power sources. By utilizing only renewable energy, vertical farms can significantly reduce their carbon footprint, aligning with environmentally sustainable farming practices, particularly in regions such as Iraq where food and energy security pose unique challenges.

Gorjian et al. [15] showed in their review work that integrating renewable energy technologies into farms can improve reliability and efficiency, reduce fossil fuel consumption and carbon emissions. A set of key indicators should be used to simplify the integration of renewable energy in agricultural cycles. Access to electricity in remote areas can also create new businesses. Hassanien et al. [16] examined the modern solar energy technologies in indoor agricultural systems, focusing on climate control technologies such as cooling and heating, with lighting and irrigation systems. The use of solar air heaters and solar thermal collectors is discussed as the most efficient options, with solar PV schemes and solar thermal systems being the most suitable for remote and arid regions. These systems can reduce energy use, greenhouse energy input, and electricity production in high-irradiation areas. The benefits of using solar energy in agriculture, according to the authors, include environmental friendliness, low maintenance, eliminating the cost of fuel, and a growth in overall land productivity. Overall, the authors indicate that the use of solar energy in greenhouses has the potential to reduce energy consumption and provide more sustainable agricultural solutions. Saving energy is one of the most crucial aspects in controlled-environment agricultural systems. Xu et al. [17] proposed a new type of solar heat collection and release system that uses a hollow polycarbonate sheet indoor collector to improve greenhouse solar heat utilization. The authors stated that the new system has a larger effective heat-absorbing area than other water-circulating solar heat utilization systems, which can improve thermal and energy-saving performance. These results demonstrate a high system's energy conservation which was used in controlled-environment agriculture.

Yano and Cossu [18] conducted a review discussing the use of renewable energy in greenhouses, specifically the application of photovoltaic (PV) systems for electricity generation and shading. The review highlights the importance of balancing PV and crop production in order to achieve energy-sustainable greenhouse crop production. The authors stated that in regions of lower latitude with plentiful solar insolation, photovoltaic systems are suitable for powering greenhouses. In arid areas with sand accumulation, however, cleaning solar PV surfaces may be necessary. For automating ventilation and irrigation in low-latitude greenhouses in isolated and remote areas, stand-alone PV power systems would be useful. Kumar et al. [19] conducted an in-depth assessment to evaluate the potential benefits of solar power for greenhouse cultivation and to discuss new and feasible solar technologies that could be implemented. Due to their high efficiency and ability to generate electrical and thermal energy, semi-transparent photovoltaic, solar thermal collectors (STC), and photovoltaic/thermal (PV/T) modules are gaining popularity for controlled environment (greenhouse) applications. By utilizing these solar methods in greenhouses for cultivation, crop yield and quality could be enhanced while maintaining an output of energy that is both sustainable and green. The authors concluded that STC are ideal for greenhouse applications due to their high efficiency and low price.

Vertical farming systems' high energy consumption has led to discussions about using renewable energy like solar and wind to make urban agriculture more sustainable. Recent papers have examined solar energy and energy consumption in urban agriculture, as well as vertical farm subsystems like lighting and temperature control. The literature on solar-based vertical farming is lacking. Studies focused on off-grid solar PV systems with batteries to power irrigation systems and other loads in agricultural farms. This study examines the suitability of Concentrating Solar Power (CSP) technology as a potential energy solution for sustainable farming in arid land, specifically Iraq, where solar energy resources are abundant. The purpose of this investigation is to address the issue of energy consumption in Vertical Farming (VF) through the evaluation of CSP technologies. CSP uses mirrors to focus sunlight onto a small area which is then converted to heat via heat transfer fluid, generating renewable energy without relying on non-renewable sources like coal or oil. This technology has shown great potential not only in reducing greenhouse gas emissions but also lowering the overall cost of energy production by utilizing free resources available from nature [20]. One of the primary benefits of CSP technology is its ability to produce both electricity and heat at the same time, besides the added value of thermal energy storage [21], [22]. This makes it an excellent choice for powering vertical farms, which require both types of energy to maintain crop growth conditions.

The primary objective of this study is to assess the viability of concentrated Solar Power (CSP) technology for the implementation of sustainable vertical farming practices in Iraq. This research will examine the techno-economic factors associated with the implementation of concentrated solar power (CSP) systems. The objective is to provide insights into the potential for achieving agricultural sustainability and energy independence in arid regions. The study considers different locations for the implementation of CSP technologies in the west part of Iraq due to the high potential of solar energy resources, water resources and the proximity to both road and national electric network. As far as the authors are aware, no studies have been conducted in Iraq to compare various CSP technologies and identify optimal locations for techno-economic evaluation aiming to supply sustainable agricultural systems in arid land within Iraq. Iraq suffers significant shortages in electricity production, which is negatively affecting all aspects of the economy [23, 24, 25, 26]. It is estimated that the lack of energy supply is costing the country around US$40 billion per year [27]. The nation has a large population, but its agricultural land and water resources are limited. The lack of reliable and feasible power supply from the national grid and the high cost of alternative resources (mainly diesel generators) is a predicament facing the agriculture sector in Iraq. Approximately, 20 percent of Iraq's workforce are working in the agriculture sector, which is the second-largest contributor to the gross domestic product (GDP) right behind oil with 5 percent of the GDP [28]. Therefore, it is crucial to develop and tackle the issues facing the agriculture sector to support Iraq to reach a state of a more diversified economy. Moreover, this will aid in generating employment while advancing private sector involvement in the economy.

Today, some countries face severe challenges to meet the basic level of life. The global set a series of standards to level the difference between countries. The agriculture practices today may impact water supply in rural or urban regions. Demographics, natural resource scarcity, climate change, and food waste are four major development factors that put pressure on the old agricultural model to meet demands in the future [29-33]. These factors all exacerbate the issues of hunger and food scarcity, especially considering the United Nations Sustainable Development Program's warning that 800 million people worldwide suffer from hunger [34]. The most crucial approach for sustainable development in the agricultural sector is water management [35-36]. On the other hand, for a nation that is situated in dry and semi-arid areas and whose long-term annual rainfall average is about one-third of the global average rainfall, lowering water consumption in the agriculture sector is one of the key priorities. Arid regions play an important role in extending the green areas around the country [37-39]. Arid regions are described by lower water availability, drought tolerance of plants, low electricity supply, shortage of rich soil, etc. Meanwhile, in recent years, the prices of fossil fuels have increased as the price of solar photovoltaics goes down steadily [40], which indicates the importance of using Photovoltaics solar power (PV) in water pumping and irrigation to expand green areas in arid regions. Arid regions encourage countries to apply the definition of sustainable farming. The foundation of a sustainable agriculture system is the wise use of recyclable and/or renewable resources. To ensure that natural resources are continuously replenished, a sustainable agricultural system safeguards the integrity of natural systems. As part of sustainable agricultural systems, healthy agricultural soils should be repopulated, and the quality of groundwater and surface water should be preserved or improved. As the cornerstone of a sustainable agricultural system, this ethic seeks to protect the land community's capacity for self-renewal [41,42]. In the present energy crisis, solar-powered irrigation systems are seen to be a viable option for farmers [43]. The application of solar technology in irrigation systems was the subject of various research [44-45]. Mehmood et al. [46] highlighted that the energy crisis impacted on the agriculture sector. Mehmood declared the importance of replacing the fossil fuel used in water pumping with PV technology, as water pumping is a significant energy-intensive farming practice. Mehmood et al. performed an economic evaluation for the utilization of PV technology (mono-Si) in water pumping using RET Screen international software. The results stimulate the effectiveness of PV technology to mitigate the emission of around 1.2-1.4 tons of carbon dioxide as well as electric power saving between 7-8 MWH annually [47]. Optimized the PV pumping system based on technical and economic evaluations to supply a suitable amount of water to a village in Kuala Lumpur, Malaysia. The system consists of PV panels, a DC-DC converter, DC motor coupled with a centrifugal pump, and a storage tank. The PV panels consist of 5 PV arrays connected in series and 4 arrays connected in parallel with the 52 m^3 maximum capacity of the storage tank. Mushen et al. declared that the proposed system meets the water demands with only 55.015 m^3 water shortage throughout the year. Due to the high consumption of fossil fuel, Raza et al. [48] proposed a system that utilized PV energy for the high-efficiency irrigation system. According to Raza et al., the proposed technology can offer a clean, innovative approach for effective irrigation systems in arid regions. The results show that the system saves around 4.84 USD million per annum of diesel. The levelized cost of electricity was about 0.1219 USD/KWh, which is less than the diesel cost by 66%. After a systematic questionnaire, the farmers highly recommend the proposed system for development in arid regions as the system fulfills the water and electricity demands in irrigation, and they feel valued, and their work has a positive impact on the environment. Therefore, using renewable and sustainable energy has great social and economic impacts and achieves social justice within the country's borders. In Egypt, the most promising technique for irrigation in arid regions is canals from the Nile River. These canals suffer from water evaporation, and Egypt loses a significant amount of water to reach the target area. Therefore [49]. Take advantage of using PV panels over irrigation canals to prohibit water evaporation as well as utilize the generated power in electricity to feed the main grid with additional power and supply the irrigation with proper power for water pumping. Concluded that the canal-top PV system has less impact on LCOE and decreases the rate of evaporation, which means a greater amount of water reaches arid regions, which is reflected in a broader green land in Egypt. [49] compare two systems of conventional irrigation systems and complete PV systems in Farafra's new reclaimed lands in Egypt. Adly et al. used the MATLAB Simulink for the simulation of the two systems and their performance. Adly and his team declared that the PV irrigation system costs about 36% of the diesel conventional system.

The aim of the part of the study is to figure out the financial and environmental benefits of using solar energy for agricultural water pumping. The research applies to the PV solar water pump in Egypt, United Arab Emirates, Qatar, and Saudi Arabia. The Study focuses on using arid regions in four countries to lessen the consumption of fossil fuels in the irrigation sector. The simulation system was evaluated by using the PVSYST simulation system. All economic aspects were held by the quantification of the PVSYST program and the system's performance was measured by using the PVSYST program. Rice, wheat, and cotton are the three main crops projected in the plantation of irrigated hectares. The study quantifies the yield of each hectare by using the current price of crops to determine the internal rate of return of the simulated system.

Energy usage across the world is growing rapidly today. Such growth has resulted in cause for concern in terms of the effects towards energy supplies, exhaustion of resources, and the current and aftereffects on the environment. The environmental concerns involve aspects such as climate-change and global warming. Further, the growing and if not, highest concerns can be witnessed across developing countries. These countries have and continue to witness increasing growth in energy demands and consumption, with little to no effective resources or capacity in place [50,51]. As such, this is expected to impact the several different aspects of the average individual's life. It is without a doubt that energy consumption will continue to rise, and considering all these aspects mentioned above, the implementation and adoption of energy efficient measures through certain practices is not only becoming recommended but now required for the betterment of the future. Such actions must be considered essential for both local and global energy policy makers.

The commercial sector, alongside industrial and governmental, is currently under economic and environmental pressure. The focus on developing a dynamic economy and the ever-increasing attention to the global environment is now a necessity that cannot be overlooked. For example, the large pressure towards reducing pollution through air, water and coal are causing economies to deploy a transitional shift and thus implement efficient operational methods and capital cost investment decisions. Energy management continues to be an important tool to assist governments and organizations to meet such critical demands for both short-term and long-term outlook. [52] Adopting energy management assists in improving environmental quality and results in a reduction of load and power consumption within power plants. Such practices can result in savings both across energy and money that is spent. Within Iraq's case, such practices are recommended to improve outdated energy infrastructure and practices that cause high energy consumption in both residential and industrial facilities. Implementing such efficient practices can result in lower operational costs and provide the capability of the Republic of Iraq to meet its energy demands. This would be particularly helpful during summer times in the country, when energy consumption is at its highest.

Energy availability and resources result in a significant impact on the economy and progression of any country. Currently, the Republic of Iraq suffers from a severe shortage of power supplies [53]. For the past few decades, it has been subject to several wars and domestic calamities causing loss of economical and infrastructural development. After the 2003 occupation, governments who came to power have spent billions of dollars to revive the capacity of electricity generation. This was done to ensure that consumers can receive fixed electricity [54]. However, despite the increased spending in this aspect (close to $80 billion), the country still faces load shedding and unannounced power outages for long periods of time. As a result, the average Iraqi citizen is now reliant on small sized generators (capacity up till 1MW) to provide themselves with electricity. These generators are mostly built locally and consume either gasoline or diesel, thus having detrimental environmental effects. In 2003, the average annual electricity generation capacity in Iraq was at 4000 MW. Today, this increased by 15,000MW, resulting in a total production level of more than 19,000 MW in 2019. However, at peak times (i.e. summer), the electricity demand in Iraq is estimated to be at 28 GW [54]. As such, these figures indicate that it is imperative for the Republic of Iraq to adopt efficient energy consumption measures to meet such high demand. Unfortunately, no energy efficiency standards are in place or being developed. The high level of bureaucracy and governmental regulations are causing restrictions towards development of such measures, mostly due to political instability. As one can imagine, the presence of green based infrastructure does not exist in Iraq, which is a growing concern.

The aspect of energy efficiency within buildings is a well-researched topic that has caused a spark of innovation for countries to adopt. However, in the case of both developed and developing countries such as Iraq, the problem persists. In 2004, regulatory and voluntary approaches to enhance building energy efficiency was reviewed [55], and it was observed that the potential energy cost saving factor alone is insufficient motivation towards investing into improvement measures, unless an energy price shock occurs. A policy that involves regulatory and voluntary instruments and bodies was advised to be put into place to achieve energy efficiency within buildings. The term 'energy efficiency' within both residential and industrial sectors directly relates towards three stages in the design stage. First, building envelope, second, the type of processes and equipment, and third building occupants. [56] discusses the effects of the building envelope on energy needed for cooling and heating and found a major link between the different factors. Further, [57] studies building envelopes that can reduce cooling loads in Iraq through a roof pond. [58] discusses and concludes that around 60%-70% of heat gain should be eliminated within building interiors throughout countries such as Iraq and Saudi Arabia. This is bound to provide energy efficiency. [59] reports that energy consumption of buildings within developed countries comprises between 20%–40% of total energy use.

These figures are witnessed across the industry and transportation sectors which are above standards in the United States of America and European Union. It has also been stated that availability of comprehensive building energy information is essential to allow for suitable analysis and effectively plan energy policies. It was concluded that a public-private initiative to promote energy efficiency, innovative technologies for energy production, limiting energy consumption and raising public social awareness are essential to create a sustainable energy future. [60], discusses how utilizing thermal insulation reduces cooling loads significantly in a hot-dry climate. Further, it is important to take into consideration climatic conditions while assessing energy related issues at the local scale in a predefined location [56].

Applying energy efficiency practices to the industrial sector is very limited in the developing countries. Plant operational energy audit and optimization are regularly carried out to reduce specific energy consumption and optimize the output [61,62] demonstrated that energy audit is a very effective energy management approach [63] studied the possibility of implementing energy efficient approaches on an industrial project, which is a cement production plant. This plant is characterized by its high energy and cost-effective approach. The factory operates for an extended number of hours (8784 hours per year) and produces about 640,809 tons of industrial clinker. The researchers worked on measuring and preparing the data needed for analysis and for developing an effective energy management plan. During the study, thermal energy was analyzed and checked in the heat treatment systems of the cement plant where the most fuel is consumed in this unit and the combustion heat generates the largest part of the thermal energy needed for manufacturing up to 95.48% of cement. Data and measurements showed significant waste of energy lost in exhaust gases up to 27.9%, when compared to the total amount of heat input. So, the researchers reanalyzed this system and studied the heat recovery methods of exhaust gases to improve unit performance in terms of energy consumption. The researchers' proposals enabled savings in energy and thermal power of 42.88 MW/year and high financial benefits due to the best use of energy conservation methods. This shows how effective those energy saving approaches can be when they're specifically designed for the plant.

In Iraq, the use of mechanical and electrical systems, such as cooling and heating units, in buildings is necessary to ensure a suitable indoor environment for occupants, especially during the summer. Use of such auxiliary systems has led to an increase in building energy consumption. A recent study states that the Iraqi infrastructure has very poor energy performance with no insulation, single glazing, and inefficient heating, ventilation, and air conditioning (HVAC) systems [64]. Most of the research conducted in Iraq was aimed at enhancing energy efficiency of residential buildings.one study [65] implemented a novel control technique in order to reduce the energy consumed by the HVAC system within buildings in Iraq. The weather in Basra, a southern city of Iraq, was considered as a case study to test the proposed system. The output controller signals were adopted to obtain the energy consumption for three different control objectives and strategies, which were evaluated with respect to typical and modified HVAC systems. Based on the results of the performed simulations, the author concluded that when using the indoor controllers as a variable objective for the HVAC system, the controller performs better and provides more energy savings, while still obtaining the desired level of indoor thermal comfort.

Another study [66] tackled another aspect to minimize energy consumption. The authors investigated the effectiveness of applying high reflective roofs to reduce the cooling loads of Iraqi houses and in turn electricity demand. The analysis results show energy conservation equal to 73% for the whole year by using high reflective roofing. When applied at a large scale, high reflective roofs can contribute to a change of albedo in the cities, helping to minimize Iraq's electricity power consumption and hence reduce the frequency of blackouts. All the research works were targeting the enhancement of energy consumption in residential and commercial buildings. Applying different approaches shows a great potential in cutting energy usage in these buildings in Iraq. However, industrial energy efficiency practices apparently have never been employed at any level in the industrial sector within Iraq. The main contribution of this study is to address the lack of energy efficiency practices in the Iraqi industrial sector. This approach can help governmental and private entities identify energy efficiency improvement opportunities to minimize energy waste due to the outdated energy practices.

The three studies presented in this dissertation are interconnected through their focus on sustainable practices and renewable energy solutions to address pressing challenges in Iraq and the wider Middle East region. The connections between these studies can be summarized as follows:

Energy-Efficient Agriculture: The first study explores the potential of indoor vertical farming as a sustainable solution to address food insecurity in arid regions, such as Iraq. It identifies a challenge in the elevated energy consumption of vertical farming and proposes Concentrating Solar Power (CSP) to address this energy demand sustainably.

Integration of Renewable Energy in Agriculture: The second study delves into the economic viability of incorporating solar energy, specifically photovoltaic (PV), into irrigation systems in the Middle East, including Egypt and the United Arab Emirates. It focuses on solar water pumping systems as an environmentally friendly alternative to traditional fossil fuel-dependent irrigation methods.

Energy Efficiency in the Industrial Sector: The third study addresses Iraq's energy crisis and the disparity between power generation capacity and actual usage in the industrial sector. It proposes energy-efficient measures based on an audit of a real power plant, aiming to reduce energy consumption and mitigate high energy costs.

Connections and Overarching Themes: Renewable Energy Integration: All three studies emphasize the integration of renewable energy sources (CSP, PV) to meet energy demands in different sectors, promoting a shift away from fossil fuel dependence.

Geographical Considerations: The studies collectively analyze various locations in Iraq and the wider Middle East, considering specific conditions and resources unique to each region.

Sustainability: The common goal across the studies is to promote sustainable practices, whether in agriculture, irrigation, or industrial processes. This involves reducing environmental impact, conserving resources, and mitigating dependence on non-renewable energy sources.

Economic Viability: Each study includes an economic analysis, addressing the financial feasibility of implementing renewable energy solutions. This reflects a broader theme of seeking cost-effective and financially rewarding approaches to sustainability.

Potential Synergies: The findings collectively suggest potential synergies between these approaches. For instance, the surplus energy generated from CSP in arid regions could be utilized for solar water pumping systems or other industrial applications, creating a holistic and interconnected approach to sustainable development.

In summary, these studies collectively contribute to a comprehensive understanding of how renewable energy and sustainable practices can be integrated into various sectors to address environmental challenges and promote resilience in Iraq and the broader Middle East region.

CHAPTER 2. EXPLORING THE POTENTIAL OF CONCENTRATING SOLAR POWER TECHNOLOGIES FOR VERTICAL FARMING IN ARID REGIONS: THE CASE OF WESTERN IRAQ

This chapter is published by:

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Abstract:

Indoor vertical farming can address future food insecurity by reducing land use and environmental dependence, positively mitigating the environmental impacts associated with conventional agriculture. However, its high energy consumption and environmental impact raise concerns. This paper explores the use of Concentrating Solar Power (CSP) to power vertical farming in Iraq's arid regions, using abundant solar resources to reduce environmental impact and energy costs. The study evaluates the feasibility and benefits of integrating CSP technologies into sustainable agricultural practices, considering factors like implementation costs, energy production, and water usage. The study utilized the system advisor model (SAM) to carry out the techno-economic assessment by relocating existing commercial CSP plant in Seville, Spain to six Iraqi locations, following a comprehensive technical site assessment. The energy production level, capacity factor (CF), and levelized cost of electricity (LCOE) of the initial Spanish plant were lower than five of the six selected locations. Haditha and Ar Rutba cities have the highest annual energy output, 123 GWh and 122 GWh, respectively, surpassing Seville's original plant output, which at 110 GWh performed less than Iraq locations. Next, comparisons are made between conventional farming and vertical farming (VF) cultivation. The study focuses on Romaine lettuce

as the benchmark crop due to its prevalence in vertical farms and its suitability for arid climates. VF shows the potential to achieve yields between 41 to 68 kg/m2/y, 63 to 104 times higher than conventional farming in Western Iraq. VF's year-round cultivation with artificial lighting results in 83 times greater energy demands, requiring 25 kWh/kg/y. The findings emphasize the potential of CSP technologies to support sustainable agriculture in Iraq's arid regions.

The primary aim of this study is to assess the viability and advantages of incorporating Concentrating Solar Power (CSP) technologies into sustainable agricultural methods, specifically vertical farming, within arid regions of Iraq. The study endeavors to tackle a multitude of pivotal research inquiries and goals in accordance with the information provided.

Objective 1: This study aims to explore the viability of utilizing Concentrating Solar Power (CSP) technologies for the purpose of supplying energy to vertical farming systems in the arid regions of Iraq.

Objective 2: Evaluate the environmental and economic viability of integrating Concentrated Solar Power (CSP) technologies into sustainable agricultural practices.

Objective 3: Assess the technical and economic aspects associated with the relocation of a current commercial Concentrated Solar Power (CSP) plant situated in Seville, Spain, to six specific locations in Iraq.

Objective 4: Conduct a comparative analysis of the energy production levels, capacity factors (CF), and levelized costs of electricity (LCOE) between the relocated concentrated solar power (CSP) plant in Iraq and its original counterpart in Spain.

Objective 4: Examine the energy requirements and outputs associated with vertical farming (VF) practices, with a specific focus on the cultivation of Romaine lettuce as the benchmark crop in the region of Western Iraq.

Objective 6: Explore the potential of Concentrated Solar Power (CSP) technologies in facilitating year-round and sustainable agriculture in the arid regions of Iraq. This investigation will focus on addressing key factors such as energy consumption, water usage, and crop yield.

Objective 7: Evaluate the environmental and economic advantages of concentrated solar power (CSP)-enabled vertical farming in comparison to conventional farming methods within the specified region.

The primary purpose of these objectives is to investigate the feasibility and potential benefits of employing Concentrated Solar Power (CSP) technologies to facilitate environmentally friendly agricultural practices, particularly vertical farming, in the arid regions of Iraq. This study undertakes a comprehensive evaluation of the integration by considering technical, economic, and environmental considerations.

2.1 Solar Power Concentration Systems

Concentrated Solar Power (CSP) systems use multiple mirrors to focus sunlight onto a collector, which then transfers the solar energy to a heat transfer fluid for various applications such as electricity generation, water desalination, and industrial heating [29]. CSP systems can also be paired through thermal energy storage (TES) for use during cloudy or nighttime conditions. CSP technology is classified into four main designs depending on how they collect solar energy: Parabolic Trough (PT), Fresnel Reflector (FR), Solar Power Tower (SPT), and Solar Dish (SD)

[30] [31], see Figure 1 [32]. PT systems utilize rows of curved mirror reflectors to concentrate solar irradiance onto absorber tubes. These tubes, coated with selective materials, collect heat. Heat transfer fluid (HTF), such as synthetic or mineral oil, water, or molten salt, conveys this heat to exchangers, where water is heated and turned into superheated steam. This steam drives turbines for electricity generation. PT technology is dominant in the concentrated solar power (CSP) market, constituting 78% of operational and under-construction plants. FR technology involves reflecting and concentrating sunlight onto stationary linear receivers mounted above mirrors. This approach offers simplicity and cost-efficiency. Early FR systems used direct saturated steam without HTF and exchangers. Recent large-scale FR plants generate superheated steam up to 500°C.

SPT systems employ heliostats to direct sunlight onto a central receiver atop a tower. The receiver uses various heat-transfer media like water, molten salts, or air to create thermal energy for power generation. High-temperature gases can replace natural gas in gas turbines, benefiting from their efficiency. SD systems, albeit producing relatively less power (3–25 kW), use parabolic reflectors to concentrate light onto a receiver. This heats a fluid which powers a Stirling engine for electricity generation. These systems exhibit high solar-to-electric efficiency and scalability. A Dish Stirling system by Ripasso Energy demonstrated 34% efficiency. Notably, a prominent installation in Maricopa, Phoenix was transferred to China due to energy demands. CSP systems are best installed in regions of the sunbelt with clear skies and high Direct Normal Irradiance (DNI), which is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Due to lower installation costs and higher capacity factors (CF), the global weighted average levelized cost of energy (LCOE) for CSP has decreased significantly.

Here, the capacity factor (CF) represents the ratio of the total electricity generated in an CSP plant to its nominal capacity (name plate) over the course of one year, and the levelized cost of energy (LCOE) in USD/kWh is a measure of the average costs of a power-plant over its lifetime. Further reductions in LCOE are possible with favorable regulatory and institutional frameworks, low risks, strong local engineering capabilities, and excellent solar resources [33]. CSP technology has been deployed in several African and Middle Eastern countries, with current installed capacities exceeding 1.3 GW and an additional 1.1 GW in development [34]. The various CSP technologies and their underlying operating principles and key performance metrics are summarized in Table 1, more technical details, and operational principles about the CSP technologies can be retrieved from reference [35].

The distinct situations in Iraq make it a particularly suitable candidate for investigating the potential of CSP technology within the framework of sustainable vertical farming. The country is dealing with notable challenges, such as arid climatic conditions, growing food demand, and a dependence on conventional energy sources. The arid climate of Iraq, which is marked by ample sunlight, offers a promising prospect for the efficient utilization of CSP technology [36]. Moreover, Iraq suffers from the issue of power shortage, which has endured for several decades, presenting a significant and unyielding challenge [37]. In addition, the energy resources in the region, which come mainly from non-renewable sources, require a transition towards sustainable and self-sufficient energy alternatives. The objective of this study is to tackle the obstacles encountered by Iraq and examine the potential of CSP technology in offering a sustainable solution, thus making it a significant and applicable case study within the wider framework of global agricultural sustainability and the transition towards renewable energy.

Figure 1. Main CSP Technologies [32]

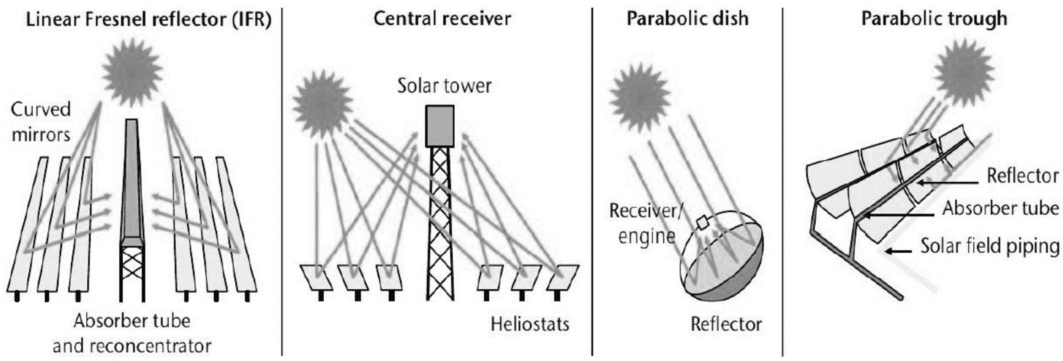


Table 1. Representative technical details of the four CSP Technologies [24] [25] [32] [35]

Parameter	PT	SPT	FR	SD
Typical Capacity (MWe)	1 – 250	1 – 400	1 – 125	0.01 – 10
Focusing	Line	Point	Line	Point
Tracking	Single axis	Two-axis	Single axis	Two-axis
Concentration ratio	50 – 90	> 1000	50 – 70	>1300
Maturity of technology	Commercially proven	Commercially proven	Pilot projects	Pilot projects
Operating temperatures (˚C)	393 (therminol), 550 (molten salt)	250 – 500 (water), 550 (molten salt), 680 (air)	250 – 400 (water)	250 – 700 (hydrog or helium)
Peak solar to electricity efficiency (%)	23 – 27	23 – 27	18 – 22	29 – 32
Annual solar to electricity efficiency (%)	10 – 16	20 – 35	8 – 12	16 – 29
Annual CF (%)	25 – 28 (no TES), 29 – 43 (7h TES)	55 (10h TES)	22 – 24	25 – 28
Land use (km²/MWe)	0.025	0.036	0.008	0.011
Hybridization	Yes and direct	Yes	Yes, direct (steam boiler)	Not planned
Cycle	Superheated steam Rankine – organic Rankine	Superheated steam Rankine steam – Brayton	Superheated steam Rankine – organic Rankine	Superheated stear Rankine – organic Rankine – Stiriling
Steam conditions (˚C /bar)	380 to 540/100	540/100 to 160	260/50	NA
Maximum slope of solar field (%)	<1 – 3	<2 –4	<4	10% or more
Water requirement (m³/Mwh)	3 (wet cooling) 0.3 (dry cooling)	2 – 3 (wet cooling) 0.25 (dry cooling)	3 (wet cooling) 0.2 (dry cooling)	0.05 – 0.1 (mirror washing only)
Application type	On-grid	On-grid	On-grid	On-grid / off-grid
Suitability for air cooling	Low to good	Good	Low	Best

2.2 Location and Resource Assessment

Urban planners and agricultural leaders are calling for cities to produce more food locally. The aim is to meet rising population demand and avoid gridlock, pollution, and high food prices [38]. However, each country defines urban areas differently, usually in terms of urban centers, major cities, administrative centers, or municipalities. The populations of cities, towns, and villages are considered urban when their administrative boundaries exist. Quantitative thresholds vary the minimum population for urban status. The threshold is 2000 in several Latin American and West African countries, 200 in Iceland, and 10,000 in Italy and Benin. However, socioeconomic factors can complicate the definition of an urban population [39]. There are no applications for vertical farming techniques in Iraq at present. In this study, six locations CSP installation in Iraq is contingent upon identifying and analyzing the primary site factors for centralized CSP systems to achieve sustainable agriculture and urban power supply objectives. Cohen [40] identified these factors; other aspects, such as economic evaluation and waste products, are comparable to those of a conventional steam power plant. In addition, this study utilizes a set of standards from the IRENA-LBNL GIS study done by Wu et al. [41]. In their study to create renewable energy zones in Africa, they utilized a multi-criteria analysis. Their research employed the same methodologies as [40] and [42], but also included a multi-criteria evaluation.

2.2.1 Solar Resource Assessment

Iraq has an excellent solar power potential due to its long hours of light, few days with clouds, and elevated DNI, which reaches a peak power density of 2,310 kWh/m2/year [43]. This places Iraq in a very advantageous position and places it at the forefront of countries with the ability to produce electrical power using solar energy [36]. Figure 2 displays a satellite map of

Iraq, obtained from the freely available SOLARGIS Global Solar Atlas 2.0 [44]. This map provides a comprehensive depiction of the solar power capacity within the country. The utilization of this map is crucial for comprehending the geographical distribution of DNI all over Iraq. The DNI is a crucial factor to consider when evaluating the viability of a geographical area for the implementation of CSP technology. The metric quantifies the quantity of solar radiation that can be harnessed and transformed into usable energy. The availability of Iraq's DNI data spanning from 1999 to 2018 holds significant importance within this context. This dataset offers a comprehensive yearly average in kilowatt-hours per square meter (kWh/m2), which serves as a fundamental parameter for assessing the viability of CSP initiatives. It is worth mentioning that CSP systems are generally considered viable in locations where the direct normal irradiance (DNI) surpasses 1800 kWh/m2/year [45] and [46]. According to the data presented in Figure 2, it can be observed that a substantial proportion, exceeding two-thirds of Iraq's land area exceeds the specified threshold. This finding suggests that there exists considerable potential for the implementation of CSP projects in the country. However, additional evaluation is necessary considering DNI is not the only consideration that determines the viability of CSP projects in a particular location. The subsequent paragraphs elaborate more on the other influencing factors i.e., land use & cover, wind, water, and infrastructure. Table 2 provides an insight into the main assessment factors of CSP plants.

Figure 2. Long-Term Direct Normal Irradiance (DNI) for Iraq [44]

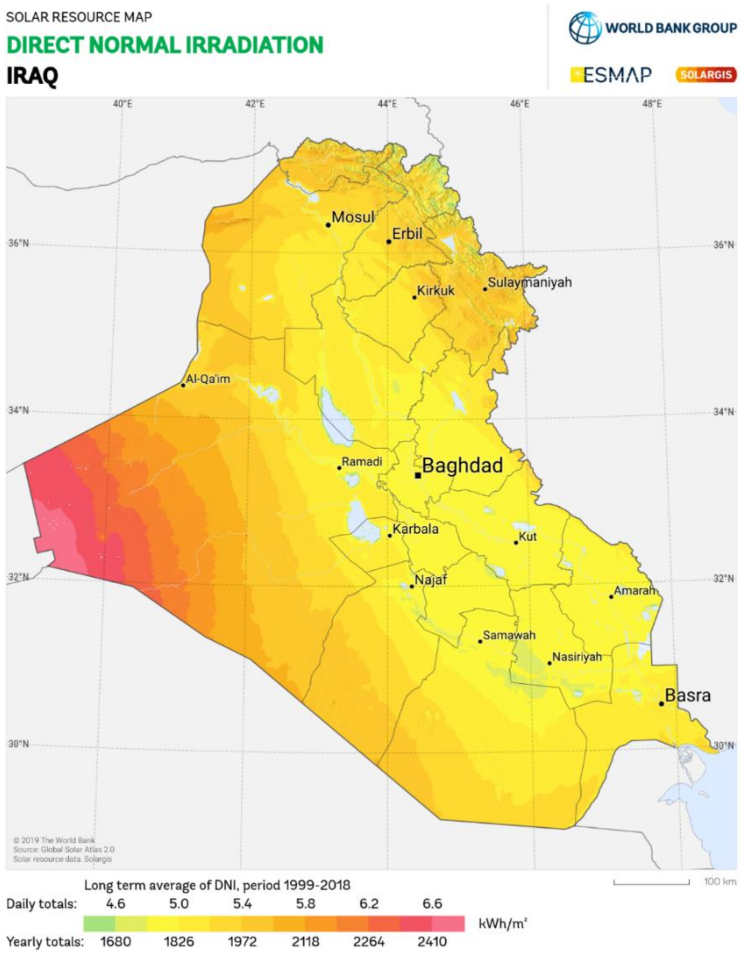


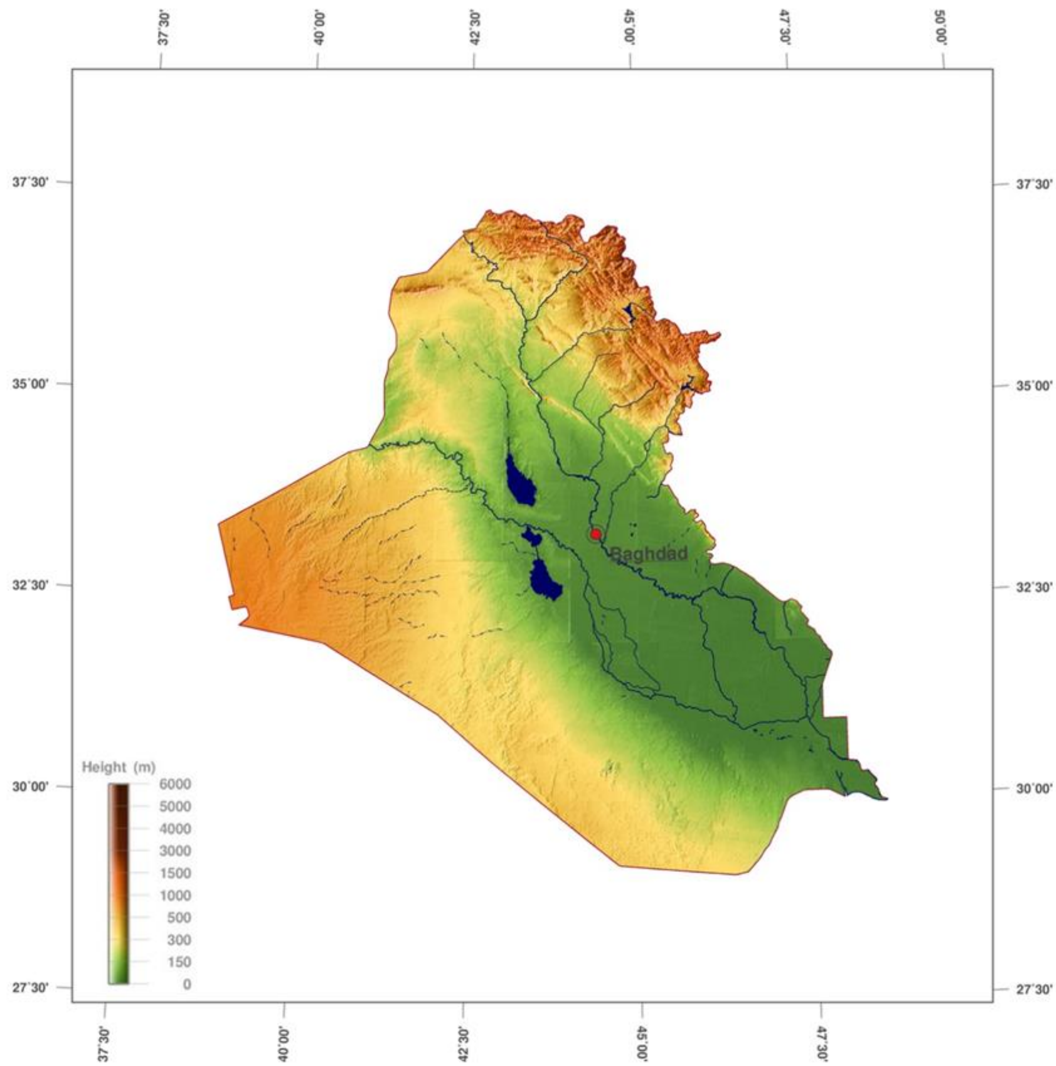
Table 2. Main Assessment Factors of CSP Plant

Site Parameter	General Requirement
Solar resource (DNI)	More than 1800 kWh/m^2/year
Land use	1 km^2 is required per 50 MWe of electricity production
Land cover	Low diversity of biological species, limited agriculture value, flat slope up to 3%
Wind Speed	Less than 15 m/s
Water requirements	Adequate supply (surface or groundwater), otherwise dry cooling
Infrastructure	Proximity to electrical grid (less than 10 km) Proximity to road networks (less than 10 km)

2.2.2 Assessment of Land Resources in Iraq

Land assessment for concentrating solar power (CSP) plants considers slope, structure, geology, soil quality, and population density. CSP plants require a large amount of land primarily due to the need to capture and concentrate sunlight effectively, which involves using mirrors arranged over a substantial area. The calculation of land requirements for CSP plants is based on several factors, including the technology used, the desired capacity (MWe), storage hours, the solar resource available at the location, and the specific design of the plant. Cohen et al. [40] and Tiba et al. [42] showed that CSP plants require 1 km^2 for every 50 MWe of power produced in a solar field without thermal energy storage (TES). Plants with higher thermal energy storage and capacity factors will require more land per megawatt-hour (MWh). CSP plants with TES systems and higher capacity factors tend to require more land because TES adds components and necessitates larger solar fields to store and deliver energy when needed. However, they can be more land-efficient on a per-unit-energy basis because they generate electricity for longer periods and at higher capacities, maximizing the use of the available land. This trade-off between land use and system efficiency is an essential consideration in the design and planning of CSP projects. CSP plants should also be in wastelands with no agricultural, forestry, or residential value and low biological habitat. [47,48] highlighted that CSP plants typically occupy large land areas and are best suited for areas with low land-use conflicts. CSP plants can have an impact on local habitats and ecosystems. A report by the European Academies Science Advisory Council [49] discussed the potential impacts of CSP plants on desert ecosystems. The report suggests considering desert ecosystem impacts when building and operating CSP plants. The report also recommends choosing sites with low land-use conflicts and environmental impact, using innovative technologies to reduce water use and air pollution, and protecting wildlife corridors and sensitive habitats. Moreover, CSP plants typically require land with high solar irradiance, which may not be suitable for agriculture or residential development. According to [50, 45] and [40], areas with a slope of 3% are considered moderate, compared to the most economically viable areas with a slope of less than 1%. In contrast, a thermally fired power plant must have a slope of between 1% and 3%. It is important in the land assessment for CSP plants to consider slope, structure, geology, soil quality, and population density. These land characteristics are relevant for CSP plant location because they can directly impact the construction, efficiency, and long-term operation of CSP systems. For example, the slope or terrain of the land is important because it affects the alignment and efficiency of the solar collectors, thus flat land is typically preferred for CSP plants because it allows for more straightforward mirror or heliostat positioning and better concentration of sunlight onto the solar receiver. The geology of the site can significantly impact the construction and long-term stability of the CSP plant. Hence, Stable geology is essential to ensure the safe and secure installation of heavy CSP infrastructure and to minimize the potential for ground settling, which could affect the precise alignment of mirrors or other components. Soil quality and composition can affect the stability of support structures, foundations, and the ability to anchor CSP components securely. Soil characteristics can also influence the feasibility of vegetation and dust control, which can affect the reflectivity of the land and, subsequently, CSP efficiency. High population density in the vicinity of a CSP plant can lead to potential conflicts over land use, land acquisition, and environmental concerns. It can also impact the availability of infrastructure, labor, and transportation for the CSP project. Additionally, the history of floods and earthquakes, the type of soil, the absence of sun obstructions, and the existence of sand particles or additional aerosols that could deteriorate the collector and receiver performance must be considered. Figure 3 illustrates a topographic map of Iraq.

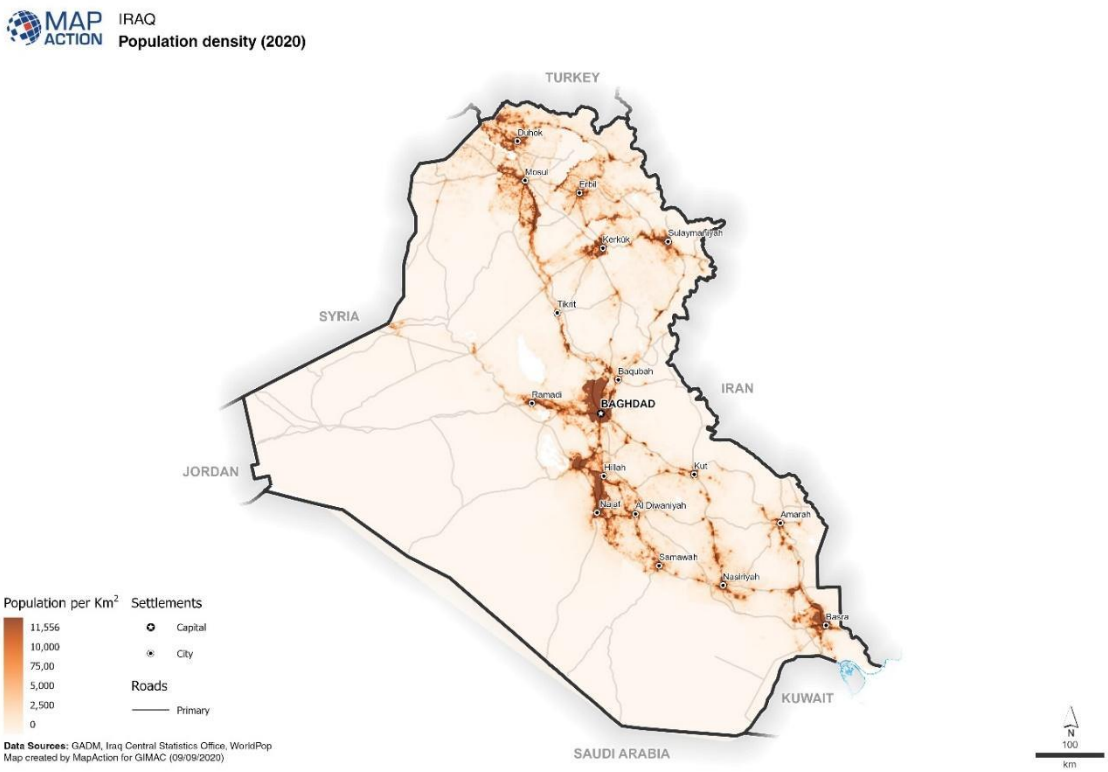
Figure 3. Iraq's Topography [51]



Iraq has a total area of 438 000 km^2, which is comparable to the size of California, and comprises alluvial plains, mountains, and desert. Except for the mountainous regions of the north and northeast, which have a Mediterranean climate, the climate of Iraq is predominantly continental and subtropical semiarid. Winters are typically mild and cold, and summers are dry with high to extremely high temperatures [52]. Iraq experiences significant temperature fluctuations throughout the year. The extreme heat can reduce the efficiency of CSP systems. The efficiency of the heat transfer fluid and power generation can decrease as temperatures rise, potentially leading to a decrease in overall plant performance. Rapid changes in temperature can lead to thermal stress on CSP components, potentially causing damage and reducing the system's lifespan. Moreover, Iraq is prone to dust storms, particularly during the summer months. These dust storms can significantly reduce the amount of sunlight reaching the reflectors and receivers. Fine dust particles can infiltrate and damage sensitive components, including receivers and tracking systems. The combination of high temperatures and dust exposure can accelerate corrosion of materials, affecting the longevity of CSP components. In comparison to Iraq's vast landmass, the inhabitant's density is relatively low. The population of Iraq stretched to 43.5 million in 2021 [11], therefore population density is approximately 100 people per square kilometer. As depicted in Figure 4 [53], most of the population is concentrated in the central and southern regions of Iraq and along the Tigris and Euphrates River. Desertification affects a large part of Iraq, and CSP plants could worsen it. To minimize their effects on decertified terrain, CSP plants must be strategically placed. This involves choosing sites with a low desertification risk and implementing strategies to reduce land clearing, water consumption, and other impacts. Iraqi CSP plants must be developed sustainably using integrated planning that addresses desertification and renewable energy sources. CSP plant developers and government agencies could identify desertification-prone areas for CSP development. Developers and government agencies could collaborate to mitigate CSP development's desertification impacts after identifying these areas. The area of Iraq susceptible to desertification is estimated to be 167,000 km^2, or 40% of the country's total area of

438,000 km^2 and is primarily located in the west [54]. This indicates that land availability will not be an issue in the future, even if only the SPT, which requires a larger land area, is utilized.

Figure 4. Iraq's Demography [53]



2.2.3 Assessment of Wind and Water Potential

The performance and structural integrity of CSP plants can be adversely impacted by high wind conditions, resulting in a decrease in the electricity generation capacity. Moreover, the impact of wind forces on CSP collectors can result in significant financial implications due to the expenses associated with repairing or replacing the damaged equipment. According to Cohen et al. [40] the structure accounts for 40% of solar field costs, so it is important to take this factor into consideration. In Iraq, the maximum annual wind speed varies between 5 and 10 meters per second, a range that falls below the threshold of 15 meters per second typically deemed excessive for the development of Concentrated Solar Power (CSP) plants. Therefore, in Iraq, the speed of the wind will not be a factor when selecting the location. Moreover, summer wind velocity is greater than winter wind velocity, which is advantageous because summer electrical energy demands are greater than winter electrical energy demands due to higher cooling and ventilation loads [36]. Nevertheless, it is important to consider the annual wind speed distribution and prevailing wind direction when choosing a location for a CSP facility. Water is employed in CSP facilities for the purposes of cooling, generating steam, and cleaning mirrors [42]. The amount of water required depends on the type of CSP plant and the design of the plant. As an illustration, it is worth noting that wet cooling towers necessitate a greater volume of water compared to dry cooling towers. Concentrated solar power (CSP) plants that use steam cycles need wet or dry cooling to condense the steam from the turbine exhaust. The lower the efficiency of the plant, the greater the cooling requirements [55]. Typically, wet cooling needs 2–3 m^3 water for each MWh [42]. The more expensive and less efficient than their wet counterparts, dry cooling towers are expensive as well. They reduce electricity production by about 7% and raise the expense of capital by 10% but need only 10% the amount of water as wet towers; consequently, water is only required for mirror cleaning, which accounts for about 1.4% of total water use [56]. The predominant portion of Iraq's territory is encompassed by surface water and groundwater, constituting the primary water resources of the nation. The Euphrates and Tigris rivers hold significant importance in Iraq as they serve as the primary sources of surface water for the nation. The primary utilization of water sourced from the Tigris and Euphrates rivers is concentrated within a narrow region adjacent to the river valleys in northern Iraq, as well as the central and southern Mesopotamian plains [57], see Figure 5. Groundwater plays a crucial role in sustaining human life and facilitating land development in numerous regions of Iraq, particularly in areas where access to fresh surface water sources is limited. According to Al-Jiburi and Al-Basrawi [57], the depth of groundwater exhibits significant variation across different regions, ranging from over 300 meters in the Western Desert to less than 10 meters in Mesopotamia, Figure 6 shows the depth of groundwater in different hydrological zones. When evaluating the appropriateness of land for CSP installations, CSP facilities should be strategically located in regions characterized by low wind velocities and ample availability of water resources.

Figure 5. Hydrogeological Zones of Iraq [57]

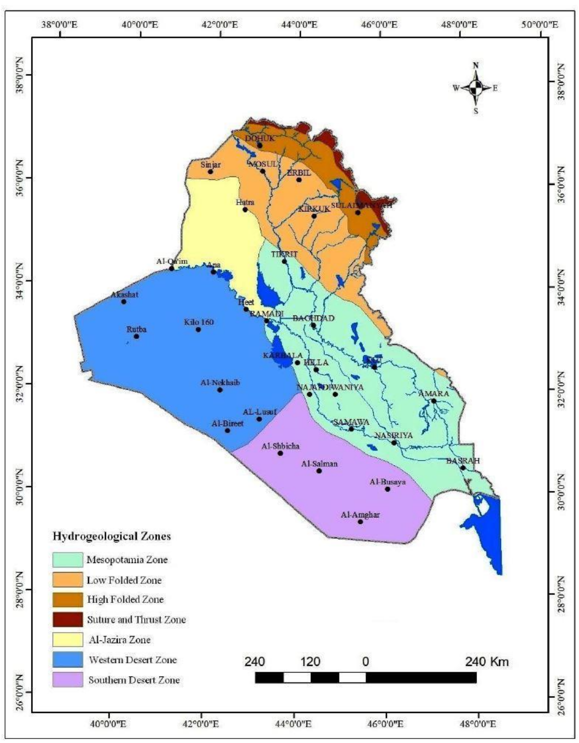
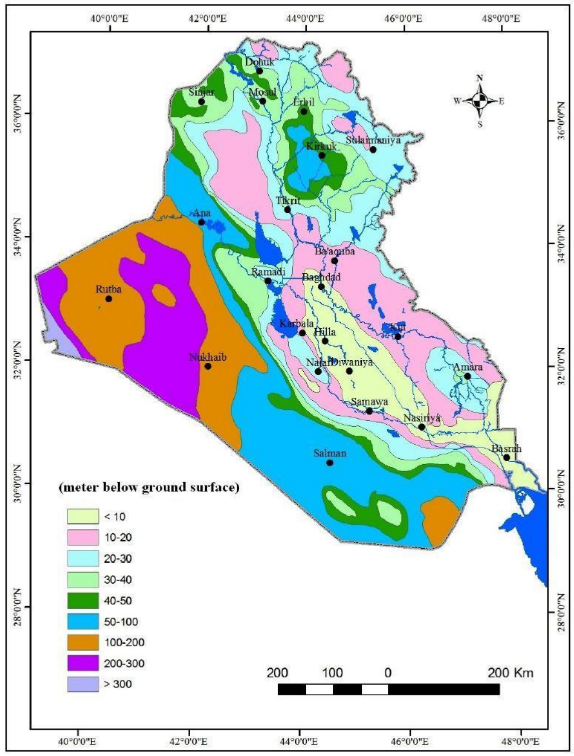


Figure 6. Depth of the Groundwater in the Hydrogeological Zones for Iraq [57]



2.2.4 Infrastructure Assessment

Infrastructure, such as the country's electrical grid and road networks, is a crucial aspect of the evaluation procedure. The cost of connecting a CSP project to the electrical grid is high, so proximity to an existing or planned grid is important. In the United States, transmission line costs for a 100-megawatt (MW) capacity line are estimated to range from $35,000 to $112,000 per kilometer [40] [42]. In addition, CSP construction budgets will differ depending on the necessity for electrical auxiliary subsystems (transformers and substations), and the land slope. Consequently, such plants need to be near transmission lines to reduce costs. Iraq's interconnected power grid network includes hydropower and thermal (gas, diesel, steam) plants, substations, with the transmission lines, mostly 132 kV and 400 kV, with total transmission line lengths of 4,306 km and 11,567 km, respectively, as shown in Figure 7 [58] [59].

Figure 7. Iraq Electrical Transmission Network – Load Centers and Transmission Directorates [59]

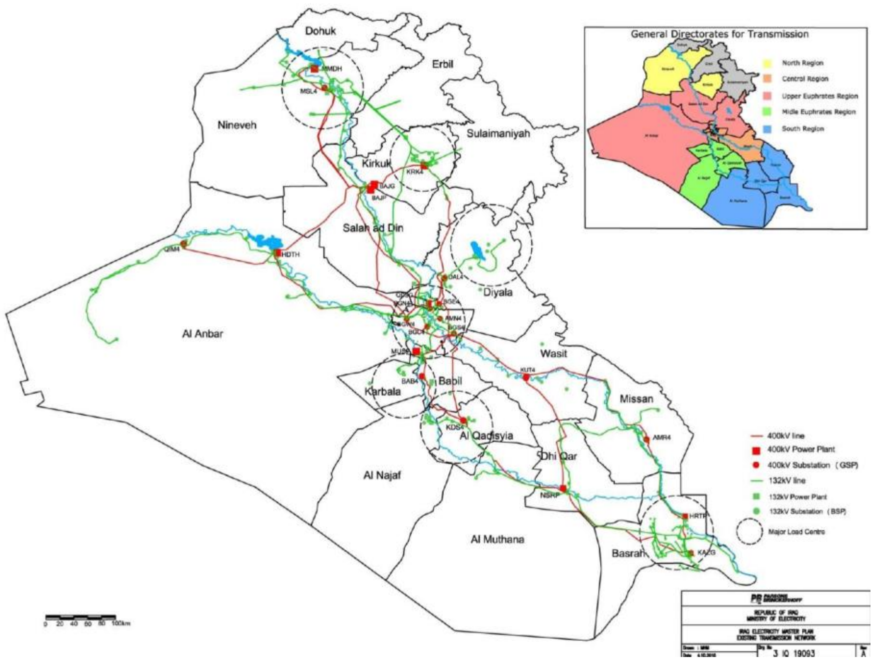
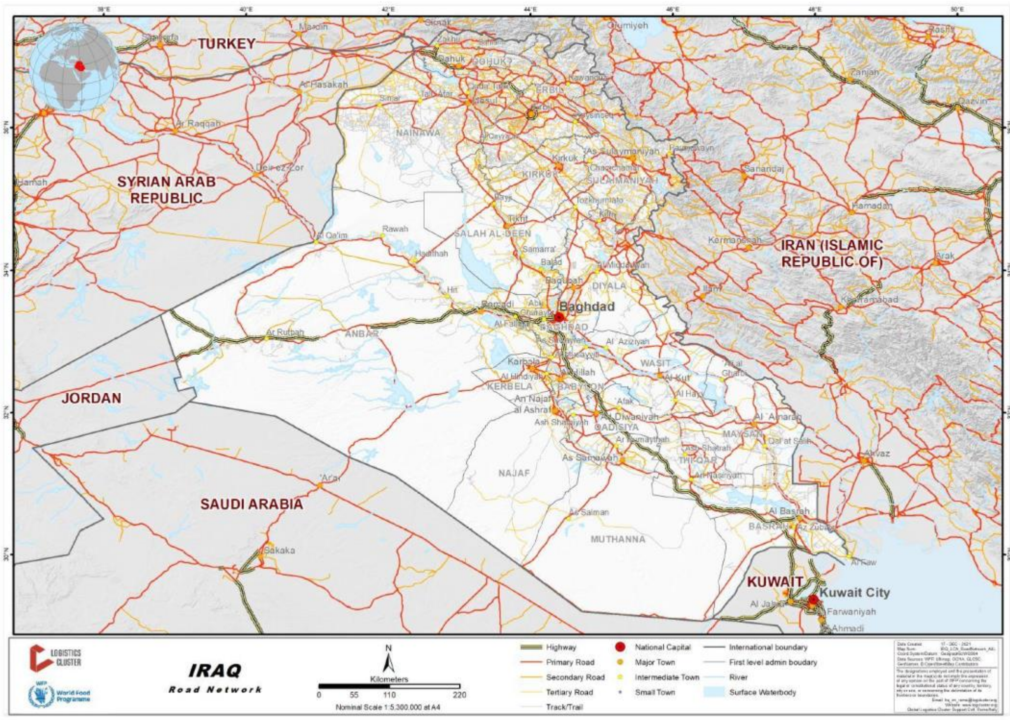


Figure 7 also depicts the country's Grid Supply Points (GSPs), Bulk Supply Points (BSPs), and significant load centers. With a few 132 kV connections to other Governorates, the 132 kV network functions as the regional load distribution system within each Governorate. The 400 kV electricity lines act as the national grid's bulk power transmission highway between the Governorates and neighboring nations, ensuring stability and minimizing disruptions caused by transmission line faults or power plant outages. According to the most recent estimate from the Iraqi Ministry of Planning, the Iraqi road network in 2018, including paved and unpaved main and secondary roads, as well as all other paved roads, totaled 58,592 kilometers. As shown in Figure 8, the overall length of the exterior road network is approximately 42,100 kilometers [60] [61].

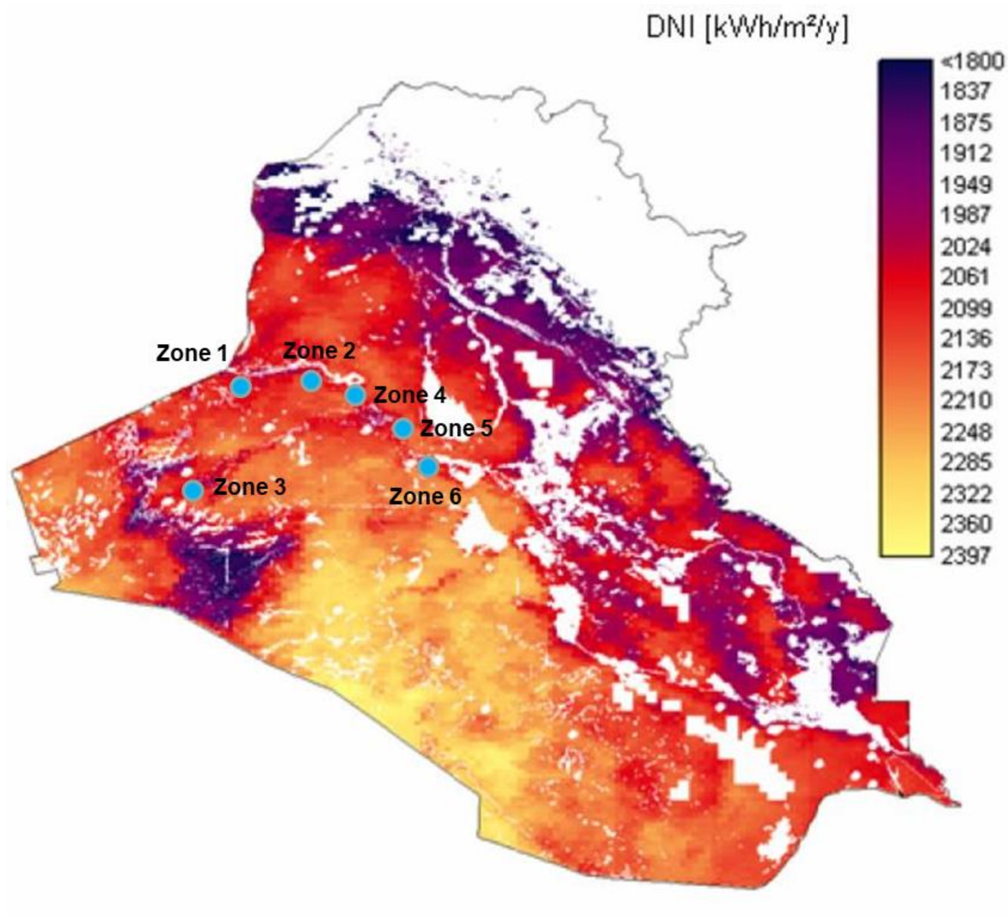
Figure 8. Iraq Road Network [61]



2.3 Nominated Locations for CSP Plants

Six regions were carefully selected for the scope of this study, taking into consideration a range of criteria. Firstly, the availability of water resources (both ground and surface), population density, and stable consumer demands were considered. Secondly, the presence of an existing power and road network capable of servicing the targeted areas was considered, which could reduce the cost of the projects. This study's primary objective is to assess the viability and potential of CSP technologies for sustainable agriculture in the arid lands of Iraq. To achieve this, DNI values of 1800 kWh/m^2/year or higher were considered necessary for achieving sufficient CSP efficiency and lower levelized cost of electricity (LCOE). Iraq's DNI solar map was created using ArcGIS and solar resource GIS data [44]. As a result, considering the other evaluation factors that were previously discussed, six areas emerged as potential sites for CSP plants, as illustrated in Figure 9. The six locations that were identified as candidates for accommodating CSP plants were mainly based on meteorological conditions, proximity to electricity transmission lines and roads, and land cover. The six chosen locations were confirmed by the information presented in Ref. [62] and [43], which ranked the Anbar region in western Iraq, which contains the six regions, as the area with the highest solar energy potential. Typical Meteorological Year (TMY) statistics in the form of Energy Plus Weather (EPW) files were generated for the six chosen locations using the PVGIS record. The study emphasizes the importance of DNI as the most critical parameter affecting the performance and efficiency of a CSP plant.

Figure 9. Direct Normal Insolation (DNI) for Iraq in kWh/m2/year, Along the Six Potential Locations for Hosting CSP Plants



2.4 Sustainable Vertical Farming

Vertical farming involves the cultivation of plants in vertically stacked layers inside a controlled setting. To replicate the natural environment, auxiliary systems that include lighting, heating, ventilation, and water irrigation are employed. Kalantari et al. [63], stated that vertical farms operate for 18 hours per day and when not in operation, lighting is turned off, halting photosynthesis. Vertical farms need to be as productive as possible to be profitable and have longer operation hours with specific plants, such as lettuce, can produce higher yield and hence achieve a higher production rate [64]. The power consumption is proportional to the cultivable area and rises as the area grows. The amount of electricity used by vertical farms will depend on the chosen crops to be cultivated. The crops used by a vertical farm determine its electricity use. Crops have different light and environmental needs. Leafy greens like lettuce and spinach can be grown more efficiently and with less energy than fruiting crops like tomatoes and cucumbers, which need higher light intensities and longer photoperiods [65]. Moreover, Romaine lettuce is an appropriate choice in this study because it represents a crop frequently grown in controlled environments, such as vertical farms. Its growing characteristics and environmental requirements are well-documented, making it a good candidate for this study. To this study, and based on the local market in Iraq, the amount of energy required to power vertical farms was based on Romaine lettuce to illustrate the energy consumption of vertical farms. The selection of Romaine lettuce as the specific crop for this investigation was based on its prevalence as a widely cultivated crop in Iraq, as well as its comparatively brief growth cycle. Utilizing Romaine lettuce as the selected crop for exploring the energy utilized by vertical farming systems in the Western region of Iraq is considered an appropriate choice.

The annual production capacity per unit of land area in a current vertical farming system with 10 layers is higher compared to an open field, with factors of 100 to 150. Additionally, it has the potential to be 200 to 250 times greater. In contrast, the annual productivity per square meter of land in an established vertical farm was approximately 3000 lettuce heads per square meter per year, whereas open fields yielded only 32 heads per square meter per year [6]. The productivity of a vertical farm is approximately 100 times greater than that of an open field and approximately 15 times greater than that of a greenhouse, with a yield of 200 heads per square meter per year [6]. In Arizona, traditional cultivation of head lettuce was limited to the usage of fossil fuels by farms throughout operations as well as the utilization of electrical power for the pumping of water used for irrigation. The investigation pertained to the energy consumption associated with the hydroponic cultivation of head lettuce in Arizona, with a specific emphasis on the energy requirements linked to additional artificial light, irrigation pumps, and systems for cooling and heating. The evaluation of the consumption of energy associated with supplementary artificial lighting was conducted under the assumption of a 24-hour light period that includes both natural and supplementary artificial light sources [66]. This approach was adopted to ensure optimal lettuce cultivation. Additionally, it was proposed that 50% of the needed radiation would be acquired via natural light.

2.5 Techno-Economic Modeling and Simulation

This section examines the viability of the suggested CSP systems according to the conditions of West Iraq. The proposed CSP systems were evaluated using four parameters, as described in the next paragraphs. Annual energy output (GWh), which refers to the sum of the hourly energy produced over the course of a year. The following equation is used to calculate annual energy output:

$$AE = \sum_{t=1}^{t=8760} Q_t \tag{1}$$

where t represents time (hour) and Q_t stand for the generated energy.

The capacity factor, defined as a ratio of the total number of hours of electricity generated in a CSP plant relative to its nominal capacity over the course of one year, can be computed by the following equation.

Capacity Factor = Net Annual Energy (kWh/yr) / System Capacity (kWdc or kWac) / 8760 (h/yr)

$$CF = \frac{\frac{AE}{NameSystem\ Capacity}}{8760} \quad (2)$$

Usage of water per year (m^3) which is needed in wet cooling (power-block) and heliostats cleaning. The annual water usage (AWU) is obtained by:

$$AWU = Cooling\ Water\ Usage\ (m^3)\ +\ Mirror\ Washing\ Water\ Usage\ (m^3) \quad (3)$$

$$Mirror\ Washing\ Water\ Usage\ (m^3) = Water\ Usage\ per\ Wash\ \times\ Total\ Reflective\ Area \times\ Washes\ per\ Year \quad (4)$$

Levelized cost of energy (LCOE) in USD/kWh which is a measure of the average costs of a power-plant over its lifetime [67].

$$LCOE = \frac{I_O + \sum_{t=1}^{N} \frac{O\&M}{(1+r)^t}}{\sum_{t=1}^{N} \frac{E_t}{(1+r)^t}} \quad (5)$$

where I_o represents the initial investment, r represents the real discount rate, n represents the lifetime, *O&M* represents the yearly expenses of maintenance and operation, and *Et* represents the annual energy generation.

The computer program SAM was utilized to model the typical operations of the suggested CSP plants in Iraq to carry out the techno-economic assessment. SAM determines the hourly power produced as well as the specific economic metrics of the plant to determine the LCOE of the project. In 2004, NREL, Sandia National Laboratory, and the U.S. Department of Energy (DOE) developed the open-source SAM, which has become extensively utilized in the techno-economic modeling of renewable energy systems. A more detailed description of SAM and its capabilities which is developed and distributed by the US Department of Energy's National Renewable Energy Lab can be found in [68]. With a current capacity of 2.5 GWe, Spain is one of the CSP pioneering nations, accounting for approximately 35% of worldwide installed capacity in 2020 [69]. The expenses, design characteristics, operation, and financial outcomes of Spain's CSP experience is easily accessible in the open literature, as are its cost, detailed design features, and operation characteristics. In this study, SAM is used to implement the "hypothetical" relocation of a commercial Spanish CSP plant to West Iraq. The selected CSP plant is GEMASOLAR, a solar tower facility in Seville, Spain. In 2011, it was the first commercially successful solar power plant with molten salt heat storage technology. More information about GEMASOLAR is available in [70]. The study focuses on the solar tower technology because it is proven relatively inexpensive and has a higher efficiency compared to the other CSP types (i.e., Parabolic troughs and Fresnel reflectors). The study focuses on the solar tower technology because it is proven relatively inexpensive and has a higher efficiency compared to the other CSP types (i.e., Parabolic troughs and Fresnel reflectors). Other CSP technologies could also be considered in future work to assess the influence of different technologies on the outcome of similar studies. More details about the CSP technologies and their working principles can be retrieved from [71]. The GEMASOLAR plant model was developed and validated using SAM as shown in Table 3. Moreover, NREL has developed a SAM model of GEMASOLAR [72] [73] [74]. In the present study, the developed SAM model of GEMASOLAR was compared against the real and simulated metrics of the actual plant and NREL model, respectively. The developed model has given outputs that are nearly like the reported real values of GEMASOLAR and well matched the NREL's model as shown in Table 3.

Table 3. Key SAM Metrics for GEMASOLAR [70]

Metric	GEMASOLAR		
	Developed model value	**Real plant value (reported)**	**NREL model value**
Annual Energy (GWh)	109.97	110	107.35
CF (%)	72.5	74	70.4
Power Purchase Agreement (USD/kWh)	0.16	-	0.17
Total Land Area (acres)	450.00	457.00	438.18
Total Installed Cost (USD)	209,125,632	-	209,003,198

Prior to defining the variables in the CSP plant models, all relevant technical requirements and financial information were obtained primarily from GEMASOLAR, the CSP Plant NREL/ Solar PACES site [70], and the SAM default settings [75]. It is assumed that expenses and financing factors are comparable to the online-published original plant data and the SAM default values published in [70]. This is because estimating the LCOE should be based on current market cost data, which is difficult because of the discretion and rapid industry fluctuations. Despite this, these economic values are not unique to Iraq. Belgacom et al. [76] and Trabelsi et al. [77] had similar assumptions in assessing CSP potential in the countries of Libya and Tunisia, respectively.

The executed modeling is separated into the two following scenarios:

Scenario 1

The primary objective of this scenario is to evaluate the actual results of Spanish and compare it to the Iraqi plants. GEMASOLAR utilizes 15% fossil fuel backup, from secondary heating systems which improve the plant's availability and CF by guaranteeing uninterrupted power production throughout cloudy or nighttime conditions. The fossil fill fraction (FFF) was adjusted in SAM to be 0.27 (same as the NREL model) to reach the 15% fossil fuel backup of GEMASOLAR so that the annual energy output would match the actual plant's output. The FFF defines the solar output level at which the fossil backup will run during each hour for a specific period. An FFF of 1.0 indicates that that the fossil fuel backup operates to fill in every hour to 100% of the plant's design output (i.e., no solar portion); while for a FFF of 0.5, the plant would utilize the fossil fuel backup only when the solar output is at 50%. For this case, the LCOE was calculated using the original costs of the GEMASOLAR plants (i.e., expenses are backdated to 2011). The techno-economic assessment using SAM is a helpful resource for gauging the potential of building CSP plants in Iraq. SAM can help find the best places to build CSP plants and calculate how much electricity they'll produce by simulating their typical operations. SAM is used in this context to provide a detailed simulation of both the performance and financial viability of proposed CSP plants in Iraq. By calculating metrics like hourly power output and LCOE, it provides valuable information that can inform decisions about whether to proceed with the construction of these plants.

Scenario 2

The primary objective of this "imaginary" scenario is to compare the outputs of GEMASOLAR plants in Iraq and Spain with no fossil-backup alternative. The structure consists of a solar power plant with a zero Fossil Fill Fraction (FFF) value. The same technical and financial information applies to this scenario as in scenario 1. Moreover, the most recent costs have been revised in accordance with the CSP costs database maintained by NREL (i.e., 2022).

This study assumes that the modeled GEMASOLAR plant has the same operating conditions for the plant's sub-systems (i.e., solar field, receiver, HTF, power-block, and TES) in all opted locations, whereas the meteorological conditions (i.e., DNI, ambient temperature, wind speed, visibility, and cloud cover) are different according to the location. GEMASOLAR plant main parameters were used as inputs in this study by SAM, see Table 4. As stated earlier, it is assumed that expenses and financing factors are comparable to the online-published original plant data and the SAM default values. [70] [78].

Table 4. Key Design Features of GEMASOLAR CSP Plant [79] [70] [78]

Parameter	Value
Solar Field	
Heliostat width (m)	10.9
Heliostat height (m)	10.9
Max heliostat distance to tower (m)	8
Solar field land area multiplier	1.4
Number of Heliostats	2,650
Total reflective area (m^2)	304,750
Receiver System	
Receiver height (m)	14.22
Receiver diameter (m)	8.89
Number of panels	16
Required HTF outlet temp. (ºC)	565
Receiver thermal rating (MWth)	120
SM	2.5
Tower height (m)	140
HTF	Molten Salt - 60% sodium nitrate and 40% potassium nitrate
Power Block	
Design turbine gross output (MWe)	19.9
Estimated gross to net conv.	0.875 (e.g., nameplate capacity=17.4 MWe)
Turbine model	Siemens SST-600
Design HTF inlet temperature (ºC)	565
Aux heater outlet set temp. (ºC)	570
Min turbine operation	0.20
Condenser type	Evaporative
Ambient temp at design (ºC)	20
Thermal Storage	
Thermal storage capacity (hr)	15
Technology	Molten Salt - 60% sodium nitrate and 40% potassium nitrate
Initial hot HTF temp. (ºC)	565
Current dispatch schedule	Uniform dispatch
Fossil back-up	15%

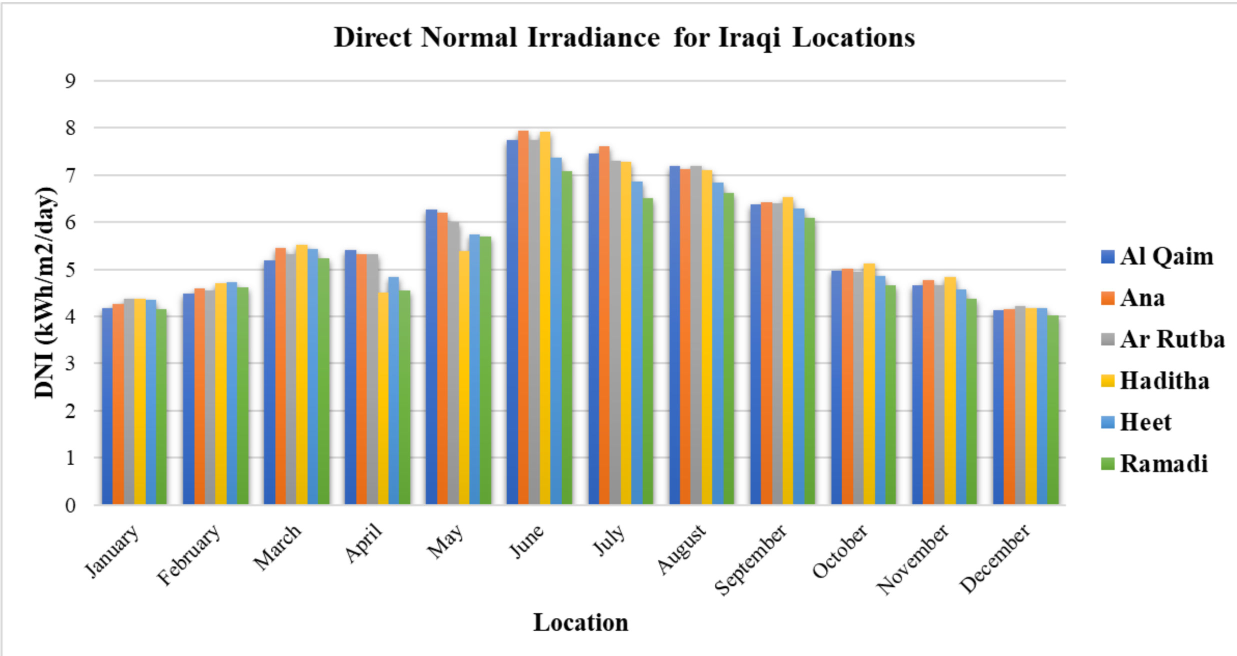
2.6 Results and Discussions

Al Qaim, Ana, Ar Rutba, Haditha, Heet, and Ramadi are the selected locations in western Iraq. Based on high DNI, empty landscapes, low population density, water availability, and being close to roadways and lines of transmission, these locations meet the requirements for constructing a CSP plant. The meteorological conditions and characteristics (please see, Table 5) were obtained from the NASA database using the interactive POWER viewer tool [80]. The PVGIS database was utilized to create Typical Meteorological Year (TMY) data in the format of Energy Plus Weather (EPW) data to all six selected locations to simulate the performance of solar power plants. TMY data presents the average annual weather patterns at a given location. They were generated by selecting which was the most "typical" month from a ten-year period of data stretching from 2007 to 2020. More information about the PVGIS data resources and calculation methods are found in [81]. The TMY data include calculated annual mean values for global horizontal irradiance, direct normal irradiance, diffuse horizontal irradiance, wind velocity, direction of the wind, temperature, and elevation. Detailed information about these parameters can be retrieved from the PVGIS user's manual in [82]. There are more details about PVGIS and its computation techniques in [81]. Figure 10 depicts the monthly variation in the average daily direct normal irradiance data for the evaluated locations over the course of one year.

Table 5. Characteristics of the Candidate Locations

Location	**Latitude (°N)**	**Longitude (°E)**	**Elevation (m)**	**DNI ($kWh/m^2/yr$)**	**Wind Speed at 2 Meters (m/s)**	**Ambient Temperature (°C)**	**Daylight Hours (hour)**	**Water Source**
Al Qaim	34.54	40.98	255	1963.2	2.9	21.9	12	Ground water/surface
Ana	34.25	42.05	193	1937.5	3.08	22.4	12	Ground water/surface
Ar Rutba	33.05	40.28	629	2243	2.95	22.2	12	Ground water/surface
Haditha	34.13	42.38	163	1912.4	3.05	23.0	12	Ground water/surface
Heet	33.64	42.82	108	1886.1	2.89	23.4	12	Ground water/surface
Ramadi	33.4	43.29	52	1824.6	2.87	24.3	12	Ground water/surface

Figure 10. The Average Daily Direct Normal Irradiance (DNI) Values for Six Iraqi Locations



It is important to note that the hourly electrical output is calculated by the SAM software based on plant availability, which is assumed to be 96% in this study to reflect realistic operation and unexpected/planned outages.

2.6.1 Scenarios Results

The simulated GEMASOLAR plant outputs for scenarios 1 and 2 are depicted in Figure 11 and 12, respectively. The research took place in the six Iraqi areas and the original Spanish plants for a full calendar year. Figure 11 displays the yearly energy output (kWh) for the original plant in Seville, Spain, validating the NREL's model. It is also seen that the GEMSOLAR has greater levels of annual energy production at the Iraqi areas in contrast to the original plant in Seville, except for the Ramadi location, which has the lowest output. The locations of Haditha and Ar Rutba have the maximum annual energy output of 123 and 122 GWh, respectively, surpassing the original plant output in Seville (i.e., 110 GWh). In Figure 12, GEMSOLAR achieved higher energy outputs in Iraqi locations where Haditha and Ar Rutba stood out with 115 and 114 GWh, respectively. The Seville solar power plant GEMASOLAR generated only 98.7 GWh of energy. The DNI has played a significant part in enhancing the harvesting of energy of the plant in both scenarios, and this, along with the relatively greater dry temperature of Iraqi locations, increased the thermal efficiency of the power block, explains why GEMASOLAR performs so well there compared to the original plant. The Ramadi location suffers the lowest DNI compared to all evaluated locations as shown in Figure 10 and that explains its worst energy output. The capacity factors are directly related to the energy output; hence the highest capacity factors were observed for Haditha and Ar Rutba as demonstrated in Figure 11 and 12 for both scenarios. This lines up with the results of the annual generation of energy discussed earlier. Based on the results obtained, it is evident that the CSP systems installed in the selected locations have the capacity to meet the energy requirements of the hypothetical vertical farm. Similarly, the water usage is linked to the energy output and the plant cooling mode (i.e., wet/dry), assuming that the water usage per wash and the number of washes is fixed. Table 6 shows that the annual used water is greater in Iraqi locations, especially in Haditha and Ar Rutba, because wet cooling is assumed in the above scenarios for all locations.

Figure 11. Scenario 1 (15% Hybrid) of GEMASOLAR Performance Outputs for the 6 Iraqi Locations and Seville, Spain

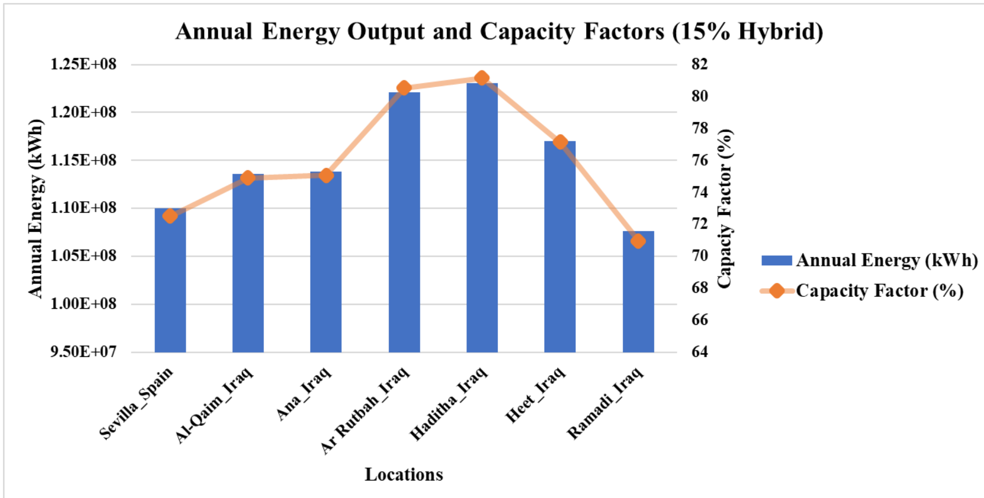


Figure 12. Scenario 2 (Solar-Only) of GEMASOLAR Performance Outputs for the 6 Iraqi Locations and Seville, Spain

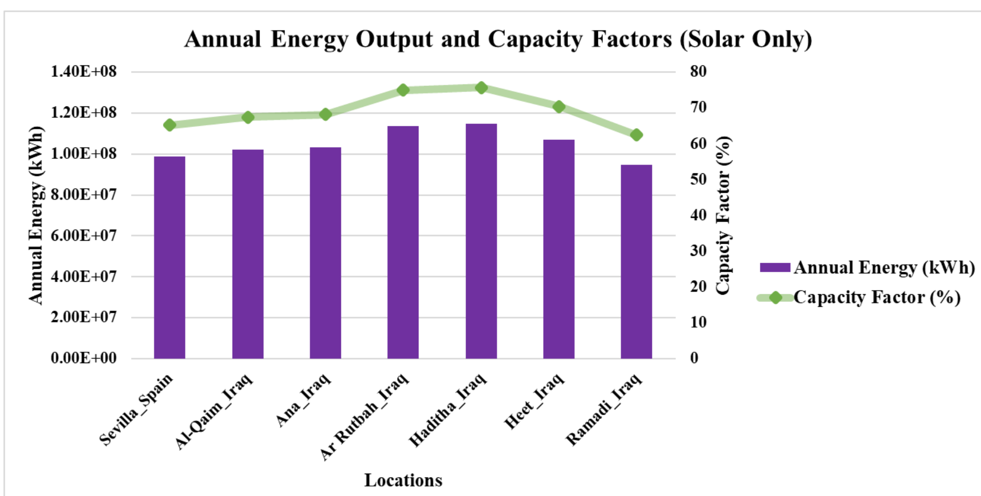
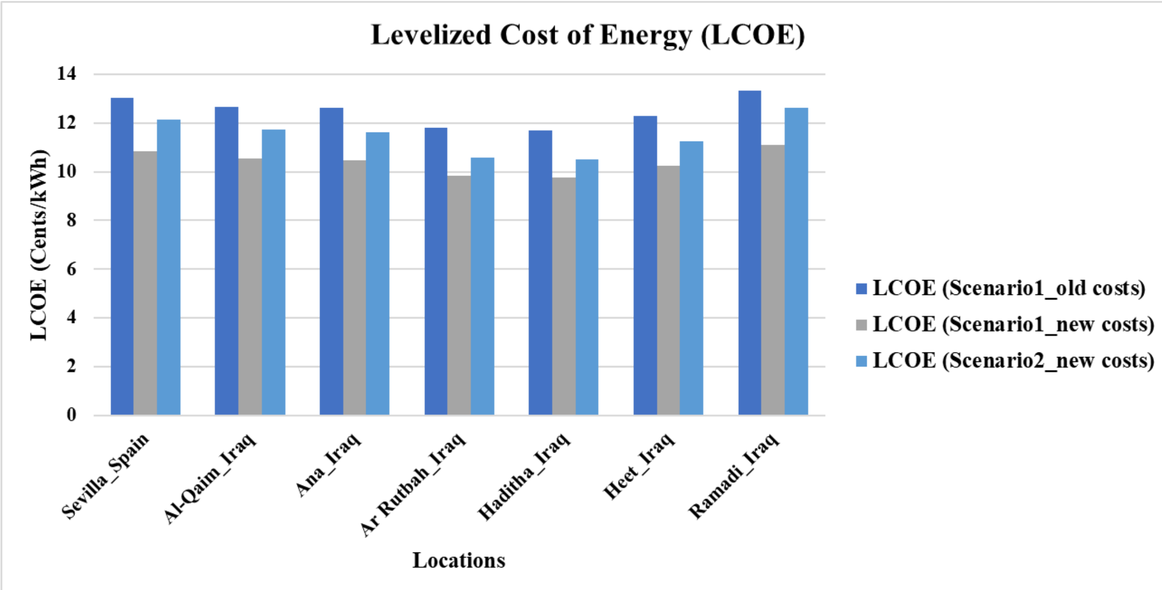


Table 6. Water Consumption at the Evaluated Locations

Location	Annual Water Usage (m3)
Sevilla_Spain	368,346
Al-Qaim_Iraq	375,892
Ana_Iraq	375,113
Ar Rutba_Iraq	394,967
Haditha_Iraq	399,526
Heet_Iraq	386,429
Ramadi_Iraq	365,272

The real LCOE values of GEMASOLAR for the various scenarios with both old and new plant's cost are depicted in Figure 13. It is observed that GEMASOLAR in Seville has the highest LCOE compared to Iraqi locations in all cases except for the Ramadi location. Haditha and Ar Rutba achieved the lowest LCOEs especially when considering the new GEMASOLAR's cost for scenario1, the LCOE has decreased by 4% when shifting from scenario 2 to scenario1 for both locations (i.e. Haditha and Ar Rutba), this is attributed to the high energy yield and capacity factors of the hybrid GEMASOLAR in these locations. It is noticed that the GEMASOLAR cost reduction for the period between 2011 and 2023 (i.e., old vs. new costs) further reduced the LCOE as observed in scenario2 which is about 10% for both location 1 and location 2. The Seville's LCOE has higher LCOE for both scenarios compared to Haditha and Ar Rutba. Both scenarios show that the proposed CSP has the potential to provide enough power for the hypothetical vertical farm mentioned in section 3, and even more power than is needed. This surplus power could be used to supply local communities or used to expand the capacity of the vertical farm.

Figure 13. LCOE for the Six Iraqi Locations and Seville, Spain



2.6.2 The Power Requirements of a Vertical Farm

To estimate the energy required, a hypothetical vertical farm was used for this research. To estimate the technical aspects regarding the energy consumption for the hypothetical vertical farm, this study relies on commercially available vertical farm technologies that are being used in the region. Hence, this paper used the information provided by I Farm Co. [65] to estimate the energy consumption of the hypothetical vertical farm, which is assumed to be of the same size for all locations, see Figure 14 for vertical farm illustration. Previous studies have shown that the land area necessary for VF infrastructure is significantly smaller compared to the land requirements of conventional farming for reaching an equal crop yield [83]. Romaine lettuce is a crop that is extensively cultivated and consumed, with a notable prevalence in controlled environments such as vertical farms [84]. The utilization of Romaine lettuce as the benchmark crop enables a comprehensive examination of the energy demands of vertical farming practices within the specific conditions of arid regions, such as Western Iraq. In this study, the authors aim to investigate the viability of concentrating solar power technologies for vertical farming in the arid climate of western Iraq. Due to the limited availability of research regarding the use of vertical farming and sustainable agriculture practices in Iraq, this study will use available published data by Barbosa et al [66] for Yuma, Arizona, USA, which represents another arid region with a climate similar to that of Iraq. Yuma, Arizona, and Anbar, Iraq, exhibit similar climatic characteristics. Both regions are characterized by arid and hot desert conditions, marked by limited precipitation and a substantial reliance on irrigation to support agricultural activities [85]. This commonality in climatic conditions aids as an important basis for the usage of Yuma as a benchmark for the purposes of this study. The observed similarity in climatic conditions implies that vertical farming may present a feasible alternative for agricultural production in both regions. Vertical farming has the potential to cultivate crops in arid regions characterized by scarce water resources. Nevertheless, it is vital to acknowledge that there exist few distinctions between the regions. Yuma exhibits a comparatively advanced agricultural infrastructure in contrast to Anbar [66]. Traditional farming methods in Anbar, Iraq, produced less lettuce due to outdated methods and seasonal constraints [86]. Anbar uses both electricity-powered pumps and diesel pumps for extraction groundwater and Euphrates River water extraction. Yuma is also characterized by a mild winter compared to relatively colder winters in the Anbar region west of Iraq [85]. The potentially heightened climate conditions in Iraq may necessitate increased energy consumption for the purpose of sustaining optimal growth conditions within vertical farming systems. Furthermore, the absence of well-established agricultural infrastructure in Iraq may present numerous challenges to the widespread implementation of vertical farming.

Figure 14. Vertical Farming Systems [65]

Romaine lettuce yields and electrical resource demands between conventional and VF production methods in the West of Iraq region of Anbar was examined in this section. In conventional farming, the average Romaine lettuce yield was reported to be 0.65 kg/m2/y in Anbar province with a total annual production of 3399 metric tons, where the six locations for CSP were investigated, as reported by the Iraqi Central Statistical Organization in the Ministry of Planning [86]. The very low yield in the Anbar region in Iraq is since lettuce in Iraq is only grown during winter season with outdated farming approaches. In general, the irrigation practices employed for crops in the Anbar region involve the utilization of both electricity-powered pumps for extracting groundwater and diesel-powered pumps for extracting water from surface resources such as the Euphrates River. This lettuce yield from conventional farming is interpreted, using the equivalent data for Yuma, Arizona reported in Ref. [66], to electricity supply of approximately 0.3 kwh/kg/y which is equivalent to an annual electricity consumption of 1.02E+06 kWh for the total areas that are currently cultivated in Anbar province. In contrast, VF cultivation in Anbar region have the potential to produce significantly higher lettuce yields of approximately 41 kg/m2/y to 68 kg/m2/y according to the methods used by Barbosa et al [66] and I Farm Co. [65] respectively, representing an increase of (63 to 104) times when compared to conventional farming. The use of supplementary artificial lighting and temperature regulation enables year-round lettuce cultivation in vertical farming systems. Vertical farming application has resulted in a significant increase in lettuce yields, particularly in the Anbar region of Iraq. This improvement can be attributed to several factors. Regardless of external climate fluctuations, controlled environmental conditions, including precise regulation of temperature, humidity, and light intensity, create an optimal growth environment year-round. Additionally, vertical farming permits multiple harvest cycles throughout the year, with lettuce ready to be harvested every 30 days, resulting in approximately 12 harvests annually [6], compared to one cycle in the winter season in Anbar region in Iraq. Despite these advantages, it is necessary to address the obstacles posed by high energy demands. This notable improvement was achieved at the expense of elevated energy demands, approximately 83 times greater, with energy requirements amounting to 25 kWh/kg/y. This figure is equivalent to an annual electricity consumption of 85E+06 kWh to produce the same annual production of lettuce at 3399 metric tons that is currently produced in Anbar province. In this regard, the challenges include increased energy costs, potential environmental impacts due to heightened energy consumption, and the need for a stable energy supply. In order to ensure sustainable and productive agriculture in arid regions such as Anbar, Iraq, mitigation strategies include integrating renewable energy sources such as solar and wind power, adopting energy-efficient technologies, and conducting comprehensive economic analyses to optimize energy use. Examining the results of the annual generation for the six Iraqi locations in Figure 11 and Figure 12, each single one of the locations can satisfy the entire requirements of vertical farming activities which can produce an equivalent amount of current production yield of the lettuce from conventional farming. It is important to note that this study represents the first examination of the variations across conventional and vertical farming lettuce cultivation in Iraq, with energy availability being selected as a vital factor in the examination.

2.7 Conclusion

Vertical farming represents a sustainable solution for agriculture in the 21st century, as it maximizes space efficiency and yields higher crop output compared to traditional farming. Furthermore, the controlled environment reduces freshwater consumption by 70-95%, which is crucial for arid climate countries. Despite these advantages, vertical farming's high energy consumption has been an important issue. Several research have suggested environmentally friendly energy generation strategies for vertical farms to maximize energy efficiency. However, research on the economic and technological implications of adopting Concentrated Solar Power (CSP) technologies within vertical farming systems is lacking. With an eye toward optimizing energy consumption in vertical farming, this paper offers an analysis of the performance of CSP application in Iraq's future vertical farming system.

This research identifies six locations that would be desirable for CSP plants due to their favorable conditions (high DNI, empty landscapes, a low density of people, accessibility to water, and proximity to roadways and transmission lines). These locations in the west of Iraq are Al Qaim, Ana, Ar Rutba, Haditha, Heet, and Ramadi. Techno-economic analysis indicates that Iraq's performance in hosting GEMASOLAR surpasses Spain's. Specifically, locations 3 and 4 exhibit remarkable productivity, generating the most energy at the lowest Levelized Cost of Energy (LCOE). In contrast, location 6 is less productive when compared to Seville. In particular, the highest annual energy output of 123 and 122 GWh, respectively, was achieved by installing GEMASOLAR at location1 and location 2, surpassing the original plant output in Seville of 110 GWh. In addition, Seville's LCOE is higher than those in both locations 1 and 2.

In addition to Techno-economic analysis of CSP, this study also sheds light on the Romaine lettuce yields and electrical resource requirements in Iraq's Anbar province. Conventional agriculture in

Anbar, where the six locations of CSP were analyzed, displayed a low lettuce yield of 0.65 kg/m2/year, attributed to outdated practices and limited winter cultivation, resulting in an approximate electricity consumption of 0.3 kWh/kg/year. In contrast, VF cultivation showcased the potential for significantly higher lettuce yields, ranging from 41 kg/m2/y to 68 kg/m2/y, representing an impressive 63- to 104-fold increase compared to conventional farming. VF's ability to employ artificial lighting and temperature regulation enables year-round cultivation with multiple harvest cycles. However, this notable improvement comes with approximately 83 times greater energy requirements, necessitating 25 kWh/kg/y or an annual electricity consumption of 85E+06 kWh to match Anbar's existing lettuce production. The results indicate that in Iraq, it is possible to cultivate the chosen crop using a VF system powered by electricity generated through CSP. These findings are relevant for regions with climates like Iraq. There are several obstacles in Iraq that could hinder the successful implementation of CSP-powered vertical farming. To begin, significant investments are required to develop the necessary infrastructure for CSP plants and vertical farms. Furthermore, in an arid region like Iraq, ensuring a consistent water supply, addressing high initial costs are complex tasks. Technical expertise and regulatory frameworks are all present difficulties. Furthermore, persuading government agencies and private investors of the viability of this approach may take time and effort. However, if these issues are effectively addressed, vertical farming may be a viable solution to Iraq's food security problems. This study could have a substantial impact on future agricultural and energy policies in Iraq and comparable regions. The study demonstrates that CSP-powered vertical agriculture is a viable option for food production in hot, arid regions. This could aid in the fight against food insecurity in these regions. The study also demonstrates that CSP-powered vertical farming can provide these regions with renewable energy. This could help them reduce their dependence on fossil fuels and achieve their climate change objectives. This study can be used to evaluate the potential of regional renewables based on CSP technologies for VF operation. The present work provides a starting point for evaluating CSP potentials, and further studies can be conducted with more local data for more accurate estimation.

CHAPTER 3. ECONOMIC EVALUATION OF PV WATER PUMPING SYSTEMS IN AGRICULTURE SECTOR IN THE MIDDLE EAST

The reduction of fossil fuel consumption is a widely supported movement across various sectors. In the agricultural sector, water pumping and irrigation systems consume a significant amount of electricity. Solar power offers a promising solution to reduce dependency on fossil fuels in agriculture, particularly in regions like the Middle East with abundant solar resources. This study conducts an economic evaluation of integrating solar energy into agricultural irrigation networks. The solar water system includes a centrifugal pump that transports water from deep wells at 10 meters depth to the surface using Mono silicon Photovoltaic modules for power supply. Simulations using the PVSYST program were conducted to assess the economic feasibility of utilizing solar-powered water pumping systems in four different locations: Bahtim (Egypt), Abu Dhabi (United Arab Emirates), Al Udied (Qatar), Wadi Al Dawasir (Saudi Arabia). The study reveals that Egypt has favorable climate conditions for implementing a solar water system for irrigation, with an average solar radiation level of around 160 kWh/m2/day. Among the countries examined, the United Arab Emirates stands out as having significant access to solar power, averaging 175 kWh/m2/day. During winter seasons, any deficit in solar power can be supplemented by the nearby electrical grid. The estimated implementation cost of the system in Egypt is $5645, with a projected payback period of approximately one year, indicating a high level of profitability. When examining the costs associated with the implementation of these systems, it is observed that the United Arab Emirates (UAE) incurred expenses totaling $6044. Similarly, Qatar and Saudi Arabia experienced costs of $6112.6 and $5825 respectively. The economic evaluation indicates that the integration of solar energy into irrigation networks for agricultural applications in Egypt is both highly viable and financially advantageous.

Reducing fossil fuel consumption is a priority across sectors, with agriculture being a major energy consumer. Agriculture requires a lot of fossil fuel-based electricity for water pumping and irrigation. Solar power is a promising alternative to fossil fuels, especially in regions like the Middle East with abundant solar resources. This chapter examines the economics of integrating solar energy into agricultural irrigation networks in the Middle East, including climate and system descriptions. Monocrystalline silicon photovoltaic modules power a centrifugal pump that lifts water from deep wells to the surface in the solar water system under study. We also use PVSYST to simulate and assess the economic viability of solar-powered water pumping systems in four Middle Eastern countries: Bahtim (Egypt), Abu Dhabi (UAE), Al Udied (Qatar), and Wadi Al Dawasir (Saudi Arabia).

Objective 1: To assess the climate conditions in the Middle East, including temperature patterns, solar radiation, and their implications for the feasibility of solar-powered water pumping systems in agricultural irrigation.

Objective 2: To provide a detailed system description of the solar water pumping system, including the components, such as photovoltaic modules and the centrifugal pump, and their technical specifications.

Objective 3: To introduce the PVSYST program and its role in the simulation, design, and analysis of photovoltaic systems, and to present the key characteristics of the photovoltaic panels used in the study.

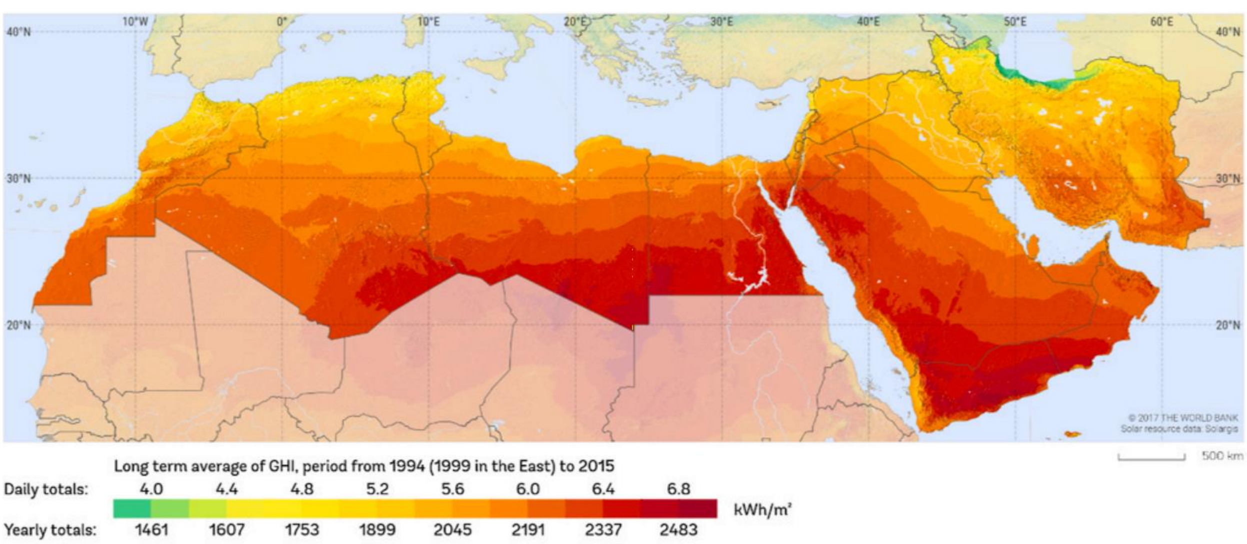
Objective 4: To describe the characteristics and technical specifications of the centrifugal pump utilized in the simulation, including power, voltage, current, head, flow rate, and efficiency, and explain how it functions within the system.

3.1 Methodology

3.1.1 Climate Conditions in the Middle East

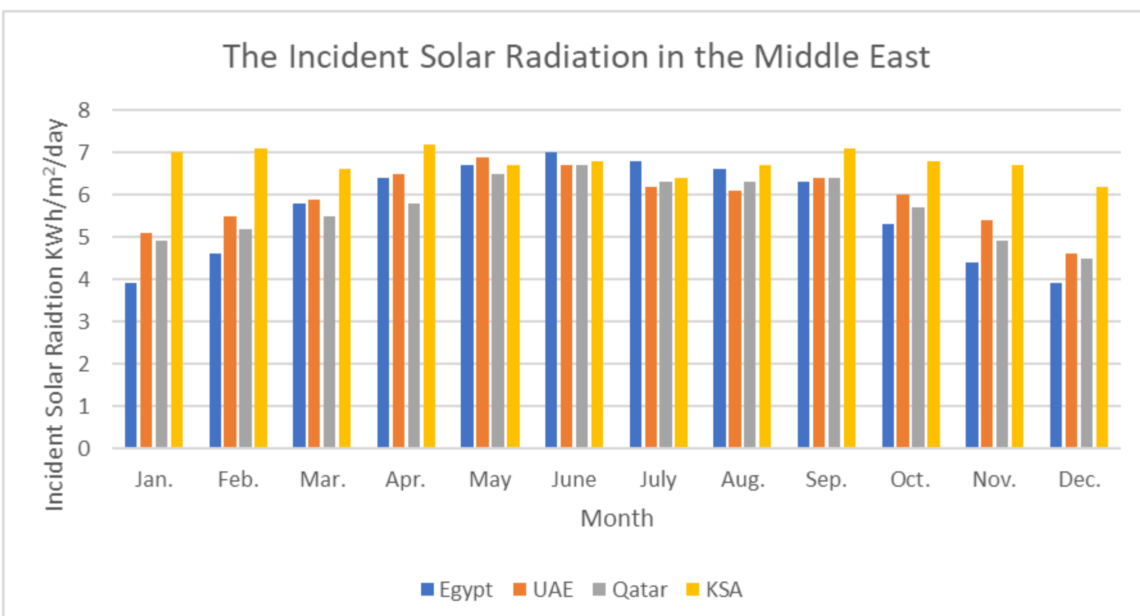
The climate of the Middle East is characterized by its aridity and high temperatures [29,30]. Most of the region is classified as a hot desert climate (BWh), with an average annual temperature greater than 64 °F (18°C) [31]. Summer temperatures in the desert can often exceed 120 °F (49 °C), while winter temperatures can drop below freezing in some mountainous areas (Figure 15) [32,33]. Climate change is having a significant impact on the Middle East [34]. Temperatures are rising at a faster rate than the global average, and precipitation is becoming more erratic [35]. This is leading to more frequent and severe droughts, heatwaves, and floods. The impacts of climate change are already being felt in the Middle East. For example, droughts in recent years have led to food shortages and widespread displacement. Heatwaves have caused hundreds of deaths, and floods have damaged infrastructure and crops.

Figure 15. Global Horizontal Radiation in The Middle East [33]



This region is a major producer of oil and natural gas, accounting for approximately 57% and 41% of the world's oil and natural gas reserves, respectively [36]. As a result, fossil fuels (coal, oil, and gas) continue to dominate its energy mix. Faced with these energy difficulties, MENA must create alternative energy security measures. Subsidies for fossil fuels also penalize oil countries, resulting in substantial waste, especially because these energies are finite. Nonetheless, the renewable nature of energy sources (solar and wind) opens the possibility of producing clean energy [36]. According to Figure 16, the Middle East has a great potential for PV technology that may be used in many disciplines and mitigate the impacts of fossil fuel.

Figure 16. Average Incident Solar Radiation in Egypt, UAE, KSA, and Qatar in kWh/day from PVSYST (1991-2010)



Among the Middle East countries, the Kingdom of Saudi Arabia has high solar radiation during the whole year, as well as the four countries have around 6.5 kWh/m^2/day in summer months and the value decreases in winter and fall seasons. These data confirm a strong hypothesis that the Middle East has a great opportunity to use an alternative energy source in four months from April to September each year. In the winter season, there is less chance to produce considerable energy from PV. This study is performed under the climatic condition of different sites of four countries, Egypt, United Arab Emirates, the Kingdom of Saudi Arabia, and Qatar as shown in Table 7.

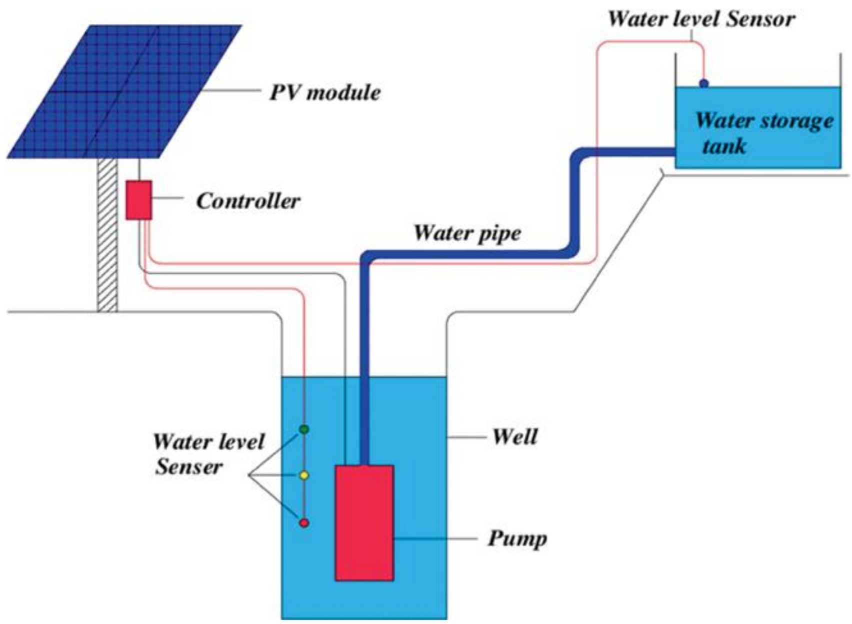
Table 7. Climatic Information of Selected Sites for PV Water Pump

Property / Location	Bahtim	Wadi Al Dawasir	Al Udied	Abu Dhabi
Latitude	30.1351°	20.4555°	24.2654°	25.3529°
Longitude	31.2742°	44.8110°	54.8599°	51.1645°
Earth temperature amplitude °C	22.8	17.4	28.4	28.3
Daily solar radiations horizontal (Annual) kWh/m^2/d	1896.2	2307	2039.7	1962.7

3.1.2 System Description

Today the agriculture practices suffered from fossil fuel consumption and water pumping was the highest fuel consumption among the other practices [37]. Therefore, finding alternative approaches is essential to reduce the economic and environmental impacts. The projected system in the simulation comprises a main lifting centrifugal pump that transports water from a deep well roughly 10 meters deep to the surface for irrigation purposes. Figure 17 displays the system sketch. The electricity generated by the PV solar cells is used by the centrifugal pump to lift the water to the ground. The water was collected in a tank with a capacity of 4000 m^3.

Figure 17. Solar Water Pumping System [38]



PVSYST is a powerful software package for the design, simulation, and analysis of photovoltaic (PV) systems [39-42]. PVSYST has been extensively applied within the academic domain for the purpose of designing, simulating, and optimizing photovoltaic (PV) systems [43]. The software's robust modeling capabilities and comprehensive database of PV components have rendered it a valuable resource for researchers exploring the performance of PV systems across diverse operational scenarios. Table 8 displays the PV characteristics in the PVSYST program. The photovoltaic system used consists of 40 monocrystalline silicon modules, each with a peak power of 250 Wp. The system has an efficiency of 16.96%. The system is controlled using an MPPT-AC-inverter, which ensures that the system operates at its maximum efficiency. The system is controlled using an MPPT-AC-inverter. The open circuit voltage (V_{oc}) of the system is 833 V and the short circuit current (I_{sc}) is 17.3 A.

Table 8. PV Panels Characteristics Using PVSYST Program

Parameter	Value
Cell type	Si Mono
No. of Modules	40 Module
Efficiency	16.96 %
Max. Operating power	250 Wp
Control mode	MPPT-AC-Inverter
Reference Solar Irradiance	1000 W/m^2
Volt open circuit (V_{oc})	833 V
Current short circuit (I_{sc})	17.3 A

Regarding the pump utilized in the simulation, as shown in Table 9, it is powered by a tri phase AC motor and has a maximum power of 6300 W, voltage of 700 V, maximum current of 9.0 A, head of 100 meters, flow rate of 10.2 m^3/h, and efficiency of 44.2%. The pump's multistage design allows it to achieve high heads and flow rates, while its AC motor and high voltage provide the power needed to deliver its maximum performance.

Table 9. Centrifugal Pump Characteristics Using PVSYST Program

Parameter	Value
Type	Centrifugal Multistage
Motor	AC motor, triphasic
Max. Power	6300 W
Voltage	700 V
Max. Current	9.0 A
Head	100-meter W
Flowrate	10.2 m^3/h
Efficiency	44.2%

3.2 Results and Discussion

3.2.1 Solar Availability in The Middle East

The amount of solar energy that can be harvested is at its peak during the summer months, when the days are longer, and the sun's intensity is higher. Because of this, most solar power projects in the Middle East are situated in desert regions, which have less cloud cover and therefore receive more sunlight. The Middle East is one of the most promising places in the world for the expansion of solar power. It has a high solar power availability, a large amount of land that is available, and an increasing demand for electricity. Because of this, analysts believe that within the next few years, the Middle East will emerge as a significant player in the global market for solar power [44]. Figure 18 compares the amount of solar energy that can be generated in Egypt, the United Arab Emirates, Qatar, and Saudi Arabia in terms of kilowatt-hours produced per square meter daily. The availability of solar energy is extremely high in all four countries, with average values ranging from 160 kWh/m2/day in Egypt to 175 kWh/m2/day in the UAE. This indicates that there is a significant opportunity for the development of solar power in each of the four countries. The availability of solar power in Egypt is exceptionally high, with an average value of 160 kWh/m2/day. While in the UAE, which had the greatest availability of solar power out of the four countries, with an average value of 175 kWh/m2/day. The availability of solar energy in Qatar is exceptionally high, with an average value of 172 kWh/m2/day. The availability of solar energy in Saudi Arabia is exceptionally high, with an average value of 168 kWh/m2/day. In general, the Middle East has an extremely high availability of solar power. Because of this, the region is an excellent candidate for the development of solar power.

Figure 18. Compares Between the Power Generated of PV in Four Countries, Egypt, UAE, Qatar, Saudi Arabia

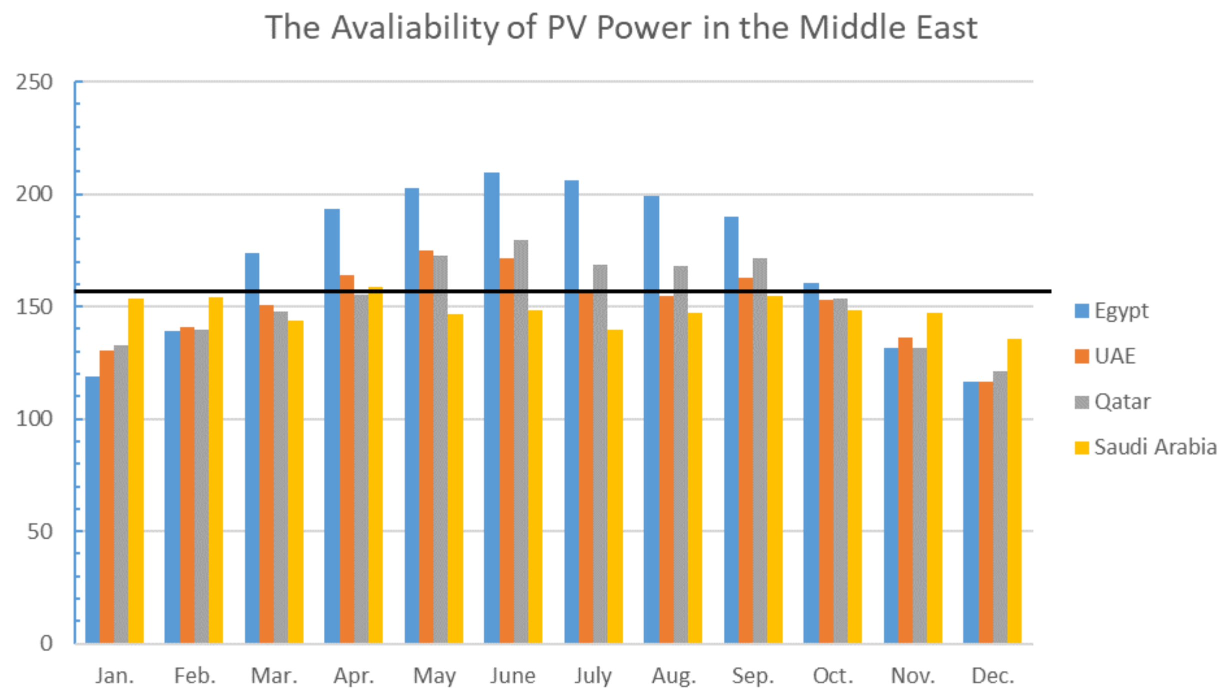
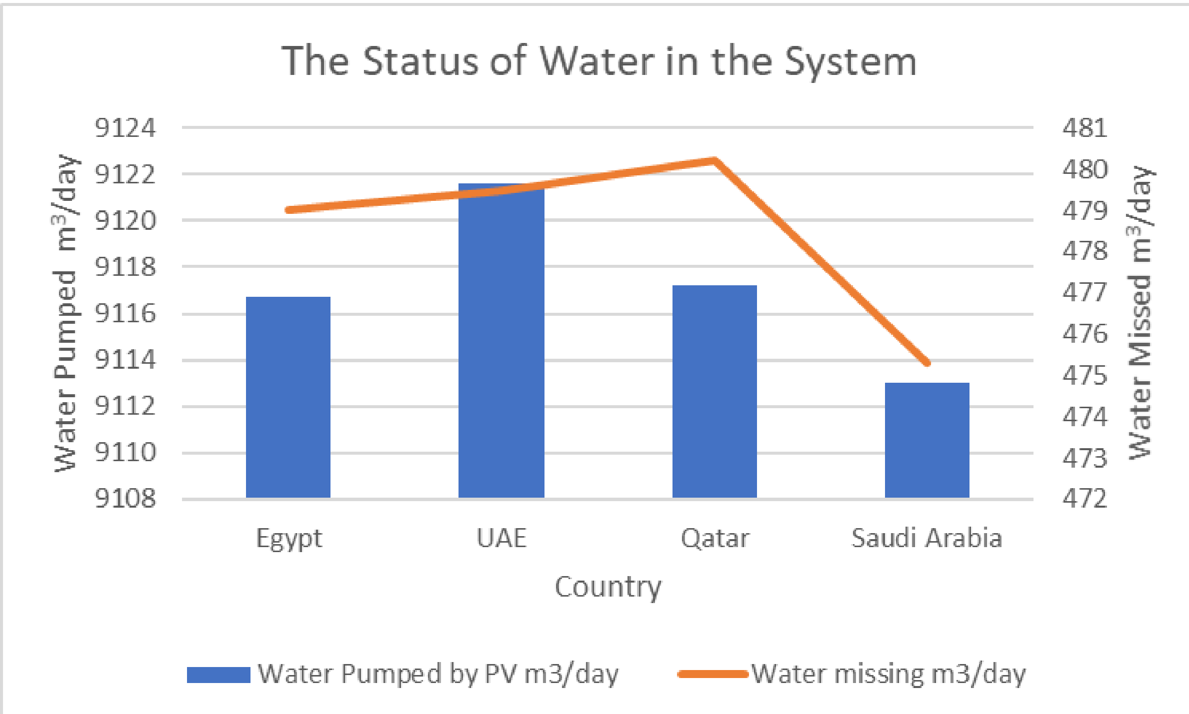


Figure 19 illustrates the water status of each PV-powered system. As expected, the United Arab Emirates (UAE) produced the most water by applying a solar water pumping system (9121.6 m3/yr), followed by Qatar (9117.2 m3/yr), and Egypt (9116.7 m3/yr). This is likely due to the combination of two factors: Higher solar radiation availability: The UAE and Qatar have some of the highest solar radiation levels in the world, which means that their PV systems can generate more electricity per square meter of panel area. Greater investment in solar water pumping systems: Both the UAE and Qatar have made significant investments in solar water pumping systems in recent years. This has helped to drive down the cost of these systems and make them more accessible to farmers and other water users. The remaining water demand in each country will need to be pumped using fossil fuels, such as diesel or gasoline. This will increase the overall cost of water production and have a negative impact on the environment.

Figure 19. Illustrates the Water Production Simulation Using Solar Power (PVSYST) in Four Countries, Egypt, UAE, Qatar, Saudi Arabia

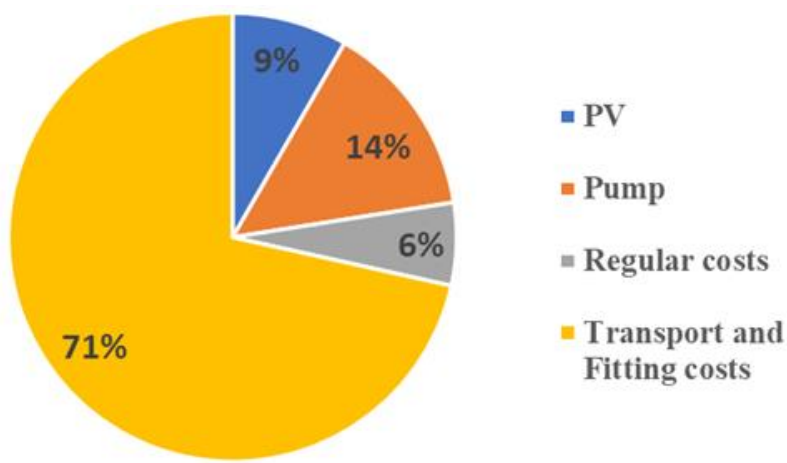


3.2.2 Economic Analysis

Through an in-depth economic evaluation using the PVSYST system, it has been determined that the core structure comprises photovoltaic modules and a centrifugal pump along with its associated fittings. PVsyst is a powerful software tool that can be used to design, simulate, and optimize photovoltaic (PV) systems. It can also be used to perform economic evaluations of PV systems, considering the initial investment, operating and maintenance costs, and energy production. The initial outlay for setting up this arrangement is calculated to be around $5132. As can be seen in

Figure 20, the costs associated with transportation and installation constitute the greatest proportion (71%) of the initial investment. This is since photovoltaic (PV) modules are typically produced in other countries and then need to be transported to the location where they will be installed. The cost of the pump and its accessories accounts for approximately 14% of the total investment, with PV coming in third at 9%. The economic evaluation of a PV-powered water pumping system using PVsyst shows that the system has a relatively low initial investment and cost of water. However, it is important to note that the transport and fitting costs can be high, especially if the system is being installed in a remote area.

Figure 20. System Components Initial Costs



When evaluating a photovoltaic (PV) water pumping system, in addition to the initial investment and the cost of water, there are several other factors to take into consideration. Although this study did not tackle these factors because of its nature, it is important to mention it for future studies in this area. These factors include government incentives, energy security, and the environmental impact. It is possible to receive financial incentives from several different governments to encourage the installation of photovoltaic (PV) systems. These incentives can help to reduce the initial investment and make the system more affordable. PV-powered water pumping systems can also help to reduce a country's reliance on imported fossil fuels. This is something that can be especially important for nations located in the Middle East and North Africa (MENA) region, which are heavily dependent on oil and gas imports. In addition, photovoltaic (PV) water pumping systems produce no emissions, which means they can contribute to the reduction of air pollution and emissions of greenhouse gases. In general, photovoltaic (PV) water pumping systems are a viable and environmentally friendly option to produce water. They have the potential to cut costs, increase energy security, and lessen the negative impact that the production of water has on the environment.

The average water consumption per hectare of land was calculated using three different crops. The average water need was computed, as indicated in table 10 **[45]**. It is possible to use the average water consumption per hectare of land as a basis for a variety of decisions, including the following: In the context of agricultural planning, the amount of water required to irrigate various crops can be calculated based on the average water consumption of the crops in question. This information can be use in the process of developing plans for agriculture that are both sustainable and effective in their use of water. Water management: The average water consumption can be used to develop water management strategies that ensure there is enough water available for agriculture and other sectors. This helps to ensure that there will be no shortages of water in the future. Adaptation to climate change: One way to evaluate the susceptibility of agriculture to the effects of climate change is to calculate its typical water consumption. This information can be used in the creation of adaptation strategies that help to lessen the likelihood of crop failure brought on by a lack of water. When it comes to understanding and effectively managing water resources in agricultural systems, the calculation of the average water consumption per hectare of land is an essential tool.

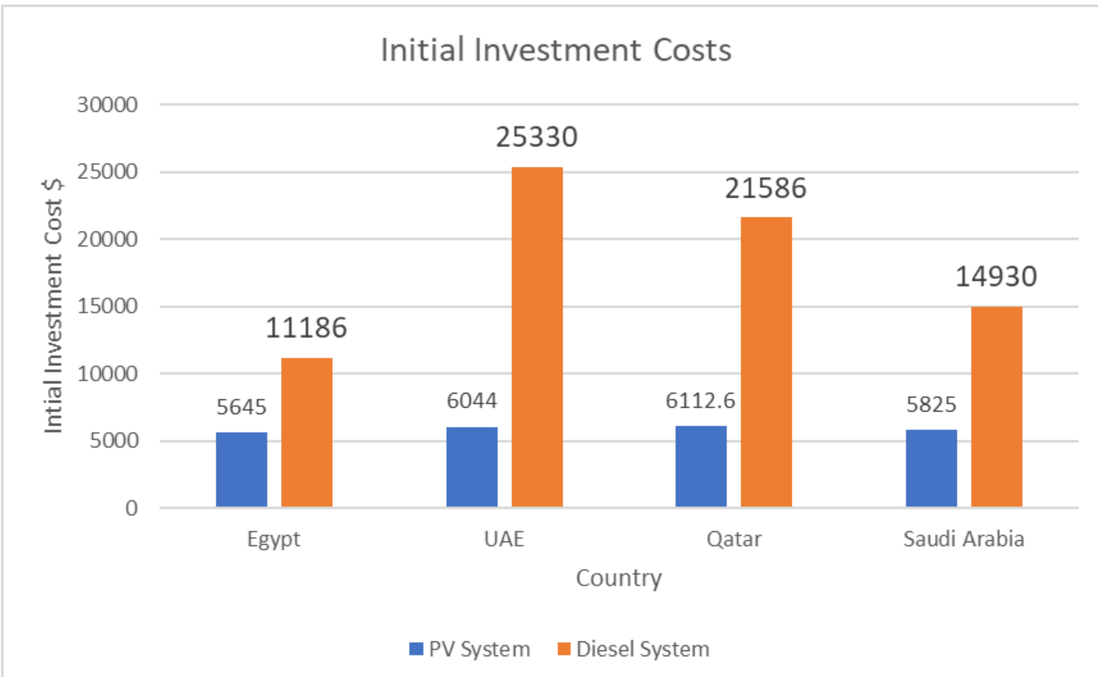
Even though there are some drawbacks associated with using only three crops to calculate the average water consumption per hectare of land, this method can still be a helpful tool for estimating the amount of water that is required in a particular region. However, it is essential to be aware of the restrictions imposed by the calculation and to exercise extreme caution when applying the results.

Table 10. Average Monthly Water Need for Crops

Crop	Required Water Volume (m^3/hectare)	Average (m^3/hectare/yr.)
Rice	850	750
Wheat	700	
Cotton	700	

It is anticipated that the proposed hectare will have a grain yield of approximately 3122.64 kg/hectare [46]. According to the modeling system, the cash value of the crops would be 1,766.5 dollars per ton per year [47] if each system planted the crop once per calendar year. As a result, the profits made from selling the crop production of one hectare in one year amount to 5516.1 dollars. The water deficit in the proposed system is pumped through the grid, and the final initial investment of each country is depicted in Figure 21 by tracking the price of fuel in the Middle East [48-51]. A typical diesel-powered system and a PV-powered water pumping system in the Middle East are compared regarding the amounts of money spent on both systems in Figure 21. According to the bar chart, the initial investment cost of a PV system is typically much less than the initial investment cost of a diesel system in each of the four countries. However, the disparity in price can change significantly from one nation to the next. Both photovoltaic (PV) and diesel energy generation systems have the lowest initial investment costs in Egypt, with PV systems costing approximately $5,645 and diesel systems costing $11,186 respectively. The initial investment cost for PV systems in the UAE comes in at $6044. The initial investment cost for diesel systems in the UAE, at $25330, is the highest of the four countries analyzed in this study. The initial investment cost for PV systems in Qatar is calculated to be $6112.6. There is an initial investment cost of $21586 associated with diesel systems in Qatar. The initial investment cost for photovoltaic systems in Saudi Arabia is 5825 dollars. On the other hand, the initial investment for diesel systems in Saudi Arabia is a whopping $14,930.

Figure 21. Comparison of Initial Investment Costs Between Diesel and PV Systems in The Middle East



The cost of installing a solar-powered water pump depends on several factors, including the size of the system, the type of components used, the labor costs, and the cost of financing. Larger systems will cost more to install, as will systems that use higher-quality components. Labor costs can vary depending on the country and region, and the cost of financing can vary depending on the lender and the borrower's credit score. Despite the higher upfront cost, solar-powered water pumps can be a cost-effective investment in the long run because they have low operating and maintenance costs. They can also help to reduce a country's reliance on imported fossil fuels, which can save money in the long run. In the Middle East, investing in photovoltaic (PV) water pumping systems has the potential to be both profitable and sustainable. They provide several benefits, including reduced reliance on imported fossil fuels, lower operating, and maintenance costs, and improved environmental performance. Although the initial investment cost of a photovoltaic (PV) system is typically higher than the initial investment cost of a diesel system, the magnitude of the price gap between the two types of systems can vary significantly from one nation to the next.

3.3 Conclusion

The objective of this study was to evaluate the economic and environmental viability of utilizing solar water pumping as a potential alternative to decrease reliance on fossil fuels in agricultural operations within four Middle Eastern nations: Bahtim (Egypt), Abu Dhabi (UAE), Al Udied (Qatar), and Wadi Al Dawasir (KSA). The PVsyst software was employed to conduct simulations of the complete system components over a one-year period, considering the atmospheric parameters specific to each study location. The findings of the research underscored the importance of utilizing solar energy as the predominant power source for the pumping system, with notable implications for both the environment and the economy.

The environmental advantages:

Solar water pumping systems have the capacity to generate no emissions, thereby contributing to the mitigation of air pollution and the reduction of greenhouse gas emissions. Solar water pumping systems have the potential to mitigate the dependence on finite fossil fuel resources. Solar water pumping systems have the potential to contribute to the conservation of water resources by enabling the extraction of water from deeper aquifers that are typically inaccessible to conventional diesel-powered pumps.

The economic advantages:

Solar water pumping systems exhibit a notable advantage in terms of their cost-effectiveness, as they are characterized by low operating and maintenance expenses. In recent years, there has been a consistent downward trend in the cost of solar panels, resulting in increased affordability of solar water pumping systems. Solar water pumping systems have the potential to mitigate energy expenses for agricultural practitioners, thereby enhancing their financial viability.

The study yielded several specific findings. Egypt exhibits a notable degree of consistency in solar radiation throughout the year, thereby satisfying the power demands of the pumping system. The system demonstrates a high level of efficiency in Bahtim, Egypt because of the abundant availability of water and solar radiation. When considering economic evaluation, it is observed that Egypt's system demonstrates the lowest initial investment costs, accompanied by a one-year internal rate of return. This indicates the remarkable profitability of the solar-powered system. The United Arab Emirates (UAE) exhibits the highest average water production compared to other countries, potentially attributed to its notably high average solar radiation levels.

The study's results suggest that the implementation of solar water pumping systems is strongly advised for long-term use, particularly in regions such as the Middle East where there is abundant solar radiation. Solar water pumping systems have the potential to mitigate the consumption of fossil fuels, decrease energy expenses for agricultural practitioners, and enhance water conservation efforts.

CHAPTER 4. EXPLORING ENERGY-SAVING POTENTIAL FOR INDUSTRIAL SECTOR UTILIZING ENERGY EFFICIENCY MANAGEMENT APPROACH: HADITHA DAM IN IRAQ AS A CASE STUDY

Achieving energy efficiency is of utmost importance in Iraq, especially considering the ongoing energy crisis since 2003. The implementation of energy-efficient practices in the industrial sector presents a viable solution to address Iraq's electricity demand challenges and mitigate high energy costs. Currently, there is a significant discrepancy between the nameplate power generation capacity and the actual utilization capacity, which continues to grow rapidly. With an estimated peak electricity demand of 28 GW in Iraq, only about 19 GW can be generated. Additionally, it is concerning that no energy efficiency management programs are currently being implemented in the industrial sector of Iraq. This study aims to introduce a set of tailored energy-efficient practices specifically designed for implementation at the Haditha Hydroelectric Power Plant - an operational facility with a capacity of 660 MWe located in Haditha, Al Anbar Province, Iraq. To achieve this objective, an energy audit and assessment were conducted at Haditha HPP to propose potential practices for improving energy efficiency in the plant. The study measured the energy and cost savings that could be achieved through five different energy-efficient recommendations. The results indicated that implementing these recommendations would lead to annual electrical energy savings of 11,221,667 kWh/yr, equivalent to a cost reduction of $920,996 per year. Additionally, the total implementation cost for all five recommendations was estimated at only $123, Iraq, which has had an energy crisis since 2003, prioritizes energy efficiency. Energy-efficient industrial practices can help Iraq meet its rising electricity demand and lower energy costs. The gap between nameplate power generation capacity and actual utilization capacity highlights the need to optimize energy use. Alarmingly, Iraqi industry lacks energy efficiency management programs. This chapter introduces a set of customized energy-efficient practices for the Haditha Hydroelectric Power Plant (HPP), a 660 MWe facility in Haditha, Al Anbar Province. Haditha HPP meticulously conducted an energy audit and assessment to identify plant-wide energy efficiency improvements. The study compares five energy-efficient recommendations' energy and cost savings. The results show that these measures could save 11,221,667 kWh/yr, or $920,996 annually. Only $123,680 is estimated to be spent on all five recommendations.680.

Objective 1: Audit Haditha Hydroelectric Power Plant energy consumption, equipment, and systems to find energy inefficiencies.

Objective 2: Find Haditha Hydroelectric Power Plant equipment and processes that waste energy.

Objective 3: Assess energy and cost savings from energy-efficient practices. Quantifying electricity consumption and cost reductions.

Objective 4: Determine Haditha Hydroelectric Power Plant energy-efficient practice implementation costs.

Objective 5: Give Haditha Hydroelectric Power Plant management clear, actionable energy efficiency recommendations that avoid budgetary impacts.

Objective 6: Identify areas for future research, acknowledging Iraq's economic constraints, and suggest ways to apply energy conservation practices to facility architecture.

4.1 Energy Audit Components

Energy audits can be conducted by various groups. In the United States, electric, gas, and utility companies provide complimentary residential energy audits. The audit process typically encompasses the analysis of monthly bills, the inspection of the dwelling within a unit, as well as the inspection of all energy appliances within the unit, including those of commercial and residential grade. Moreover, the evaluation encompasses the measurement of insulation for both ceilings and walls, as well as the inspection of ducts, HVAC systems, and other appliances and lighting fixtures of industrial grade. Commercial and industrial businesses can also avail themselves of energy audits offered by these companies. These audits are conducted by a team of highly skilled engineers who possess the necessary expertise and utilize sophisticated equipment to carry out intricate operations. It is imperative to acknowledge that there exist two distinct categories of audits, namely complementary and remunerated. In the case of complementary audits, they typically involve straightforward walkthroughs, while paid audits offer a comprehensive and detailed examination. Nevertheless, both approaches still take into account factors such as lighting, HVAC systems, water heating, insulation, and certain motors within the respective unit.

It is probable that a sizable commercial or industrial enterprise would engage the services of an engineering consulting firm to conduct an energy audit. In certain instances, an organization may opt to employ an energy manager or establish a specialized team dedicated to energy management, thereby assigning them the responsibility of undertaking such a task. The primary objective of this team is to regularly perform audits to verify the utilization of energy-efficient technology. In various countries, governments may participate in this procedure and offer auditing services at no cost or with financial assistance. As an illustration, the United States Department of

Energy (U.S. DOE) has implemented a program wherein universities throughout the United States oversee Industrial Assessment Centers (IACs) that conduct complementary energy audits for small and medium-sized manufacturing enterprises. At present, the Industrial Division of the U.S. Department of Energy (DOE) provides funding for a total of 30 Industrial Assessment Centers (IACs). The U.S. Department of Energy (DOE) offers the Institutional Conservation Program (ICP) as an additional service. The administration of the ICP is facilitated by state energy offices, which allocate funds for conducting audits of educational institutions, healthcare facilities, and other pertinent establishments. This approach has the potential to be implemented in developing nations, such as the Republic of Iraq, to facilitate the provision of complementary services to the industrial sector.

The current investigation was carried out because of a collaborative effort between the author and the Ministry of Electricity in Iraq; more specifically, the study was carried out in conjunction with the Haditha Dam Hydropower Plant. An energy audit had been planned to be carried out for the facility that was mentioned earlier thanks to this collaboration. The author has conducted a comprehensive energy analysis on a variety of plant facility equipment that has a high demand for energy. The purpose of this research is to provide the plant management with a concise and actionable recommendation that will have a small impact on their budget if they choose to implement it.

4.2 Practices Designed for Haditha Hydroelectric Power Plant

This section provides a comprehensive description of a proposed recommendation. The recommendations were derived from a comprehensive examination of each prospective candidate, with the aim of identifying those that offer the greatest potential for energy conservation. The Haditha Hydropower Plant (HPP) offers several potential candidates for energy-saving practices. However, this study focuses solely on selecting the most efficient equipment that provides significant energy savings while maintaining low implementation costs. The primary factor contributing to this phenomenon is the prevailing economic conditions in Iraq, characterized by a lack of substantial financial allocation towards energy conservation measures. This chapter presents the findings regarding the annual cost savings and implementation costs associated with each of the proposed recommendations.

The purpose of the research conducted in this chapter is to analyze the operations of Haditha HPP to identify, evaluate, and propose strategies for energy conservation and cost reduction in equipment operations. The recommendations put forth are derived from the empirical data collected and analyzed by the plant engineers. The study's scope is constrained by the prevailing conditions in Iraq, thus necessitating a partial examination of the Haditha Hydroelectric Power Plant, with certain aspects not being comprehensively addressed. Future research can be expanded to incorporate various significant energy conservation practices, particularly those pertaining to the architectural structure of the building.

4.2.1 Install Variable Frequency Drive on 100 kW Turbine Governor Pump

The proposed recommendation:

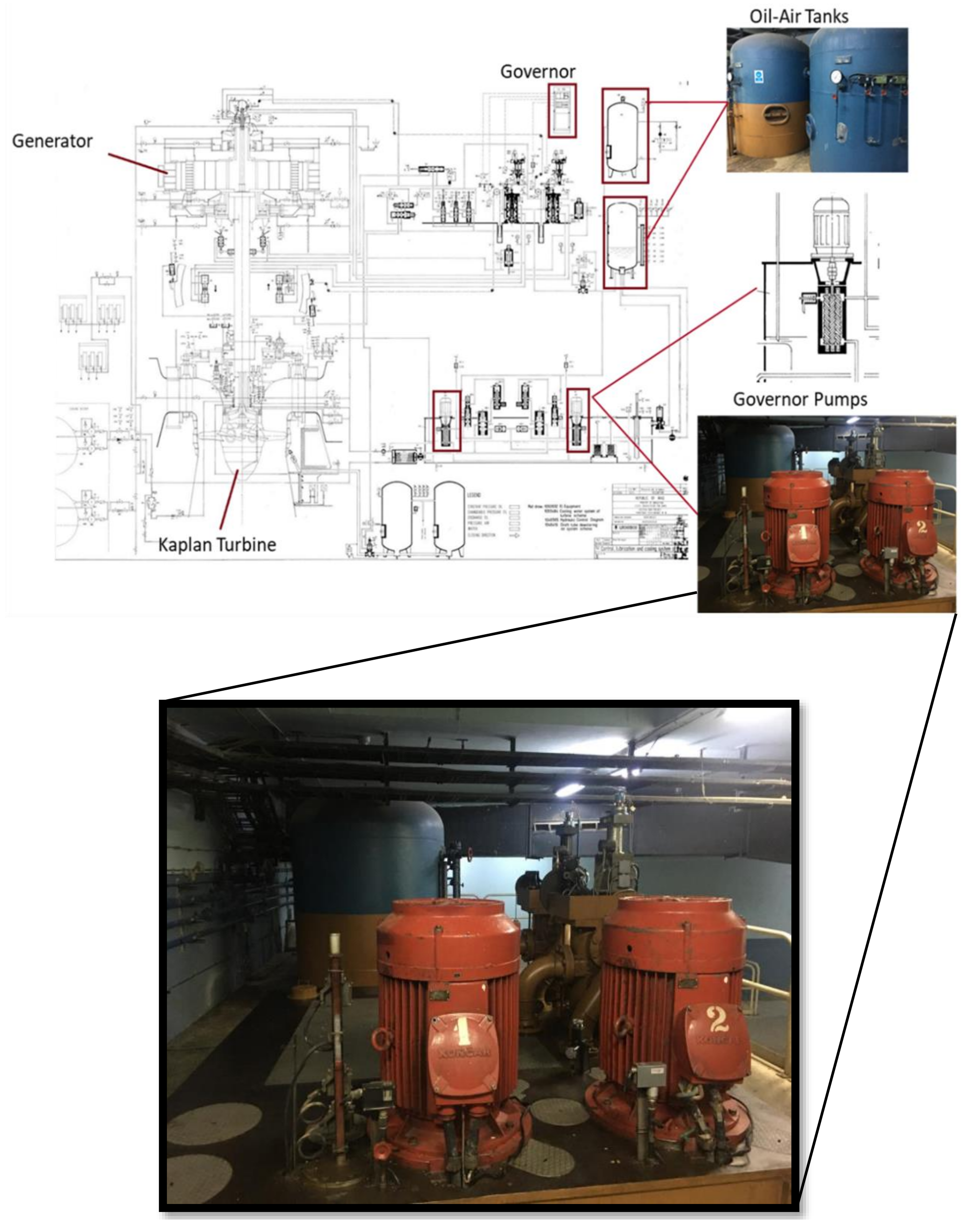
Install a variable frequency drive (VFD) on the 100 kW Kaplan turbine governor pumps. These pumps are used to provide pressurized oil to the governor's system tanks.

Figure 22 shows the complete diagram of the hydraulic system used in the Haditha HPP Kaplan turbine. As shown in the diagram, two pumps are used (one in standup mode) to pressurize and pump the oil into the oil-air tanks. This pressurized oil will be used in controlling the opening of the wicket gate to regulate the flow into the turbine and thus controlling the power output. Moreover, the pressurized oil is also used to control the angle of the Kaplan turbine blades, this is intended to get a higher efficiency from the turbine. As long as the turbine is running, the pumps are operating even if the pressure in the tanks reaches the desired and prespecified values. Thus, this system is a great candidate for energy saving practices.

Current Practice and Observations:

In numerous industrial scenarios, the implementation of variable speed control is highly cost effective. VFD works on changing the electrical motor speed through a continuous manipulation of both the voltage and the frequency of the supplied electrical signal to the motor based on the system requirements. This is achieved by converting the AC into a DC electrical signal and then by using different switching mechanisms to invert the DC signal into synthetic AC output signal with controlled voltage and frequency [87]. Energy savings result from reduced power consumption by motors. As the system power requirements are reduced, the power consumed by the equipment can be reduced by an amount significantly greater than can be achieved with the existing controls. Haditha hydropower plant has six (100 kW) Kaplan turbine governor pumps, one for each turbine, for the governor system that is not running at full load all the time, and it is a good candidate for VFD.

Figure 22. Haditha HPP Governor System for Kaplan Turbine Unit



Anticipated Savings

The affinity laws estimate that the change in the power of the motors varies as the cube of the speed of the motor, or flow changes, as per the following:

$$\frac{Power_{current}}{Power_{proposed}} = \left[\frac{Speed_c}{Speed_p}\right]^3 = \left[\frac{Flow_c}{Flow_p}\right]^3 \qquad (1)$$

where,

$Speed_c$ = Current speed of the motor.

$Speed_p$ = Proposed speed of the motor.

$Flow_c$ = Current flow of the pump.

$Flow_p$ = Proposed flow of the pump.

This relationship is used to estimate the energy use of a given motor with a variable frequency drive.

Table 11 shows the relation between the motor relative power consumption with the usage of VFD control approach, compared against a motor with standard controls [88]. One thing to be taken into consideration is that the affinity laws are not precisely followed for VFD power consumption. This is since some losses sustained by the VFD will reduce the efficiency of the electrical motor. Hence, while using VFD control, as the flow rate decreases, the total efficiency of both VFD and motor system will be decreased. Subsequently, the real power consumption is higher compared to the theoretical power consumption, which is predicted by the affinity laws, with additional deviation at lower flow rates.

The annual energy savings (ES), and the corresponding energy cost savings (ECS), can be calculated according to the following:

ES = CEU PEU (2)

ECS = ES · Avoidable cost of electricity (3)

where

CEU = Current time weighted energy usage for a given motor, kWh

PEU = Projected time weighted energy usage for a given motor, kWh.

Table 11. Power Consumption of Motor With Flow Rate

Load %	Power Consumption of Motor	
	No Control %	VFD %
100	100	105
95	100	86
90	100	73
85	100	64
80	100	57
75	100	50
70	100	44
65	100	38
60	100	32
55	100	26
50	100	21
45	100	17
40	100	14
35	100	11
30	100	8
25	100	6
20	100	5

The current energy usage, CEU, and proposed energy usage, PEU, can be estimated as follows:

$$CEU = \frac{kW \times LF \times OH}{\eta_{m,Existing}} \quad (4)$$

and

$$PEU = \frac{kW}{\eta_{m,PrPr\,o\,posed}} \cdot (FR_1 \cdot H_1 \cdot OH) \quad (5)$$

where

kW = power of motor, 100 kW

OH = Annual operating hours of motor; 8,760 total hr/yr

FR_1 = Power consumption of VFD motor, originally at 100% load, 50%

H_1 = Fraction of time the motor will operate at 100% load: 75%

LF = Load factor, average fraction of rated power at which motor operates; 0.75

$\eta_{m,Existing}$ = Efficiency of motor, 0.85

$\eta_{m,proposed}$ = Efficiency of motor, 0.90 (average efficiency of full load and part loads).

In the calculation of this specific case, it is supposed that the electrical motor will run at 100% for the operating hours.

$$CEU = \frac{100 \times 0.75 \times 8760}{0.85}$$

= 772,941 kWh/yr

$$PEU = \frac{100}{0.90} \cdot (0.50 \cdot 0.75 \cdot 8760)$$

= 365,000 kWh/yr

ES = 772,941 kWh/yr   365,000 kWh/yr

= 407,941 kWh/yr.

The total cost savings for a single governor pump, TCS, according to the Iraqi government prices for governmental sector is:

TCS = 407,941 kWh/yr × $0.1/kWh

= $40,794 /yr.

The cost of proposed recommendation:

The estimated cost for a VFD controller intended for a 100-kW pump is estimated to be $4,700, with an additional $500 for the installation costs. The total annual electricity savings for this proposed recommendation is estimated to be 407,941 kWh. The electrical cost savings is expected to be $40,794; this includes an implementation cost of $5,200. The payback period for such an investment is very short, which is about 1.5 months. This calculation is for one pump only; the Haditha plant has 6 pumps in total which operate (ideally) at the same time, one for each unit. So, in the case all the Kaplan units are put into operation the total saving can reach up to $250,000, with total energy saving reaching close to 800,000 kWh/yr.

4.2.2 Install Variable Frequency Drive on Main Pump Station

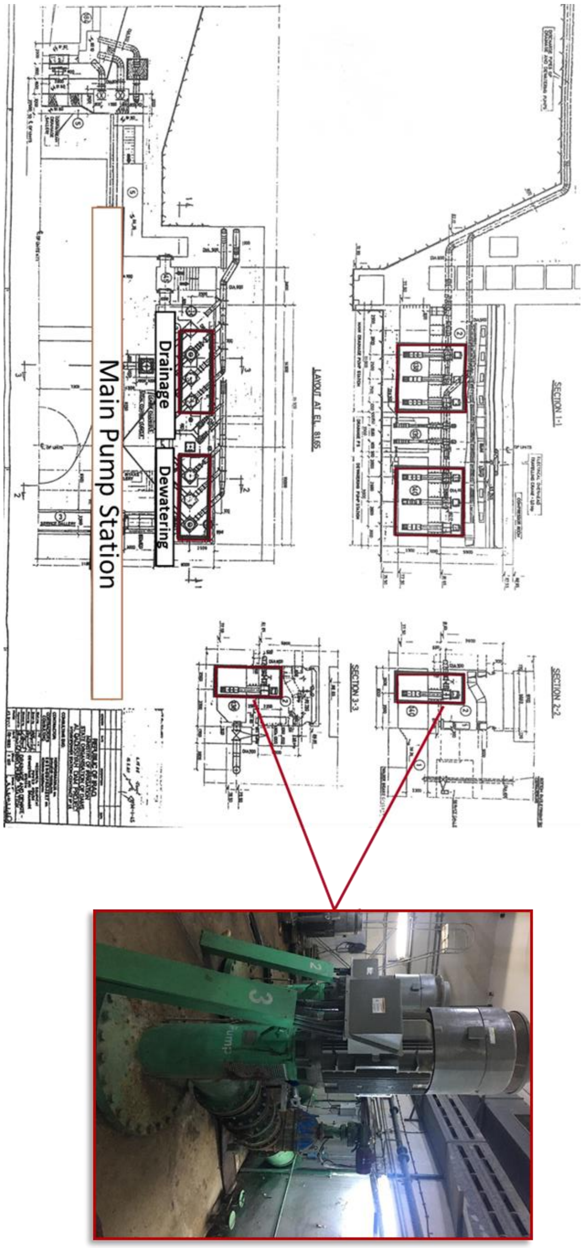
The proposed recommendation

Install VFD controllers on the six (186 kW) main pump station's turbine pumps.

Current Practice and Observations:

The potential for energy savings from upgrading the main pump station in Haditha HPP is considered in this section. Due to the nature of the Haditha dam, an embankment earth-filled dam, the plant has a central pump station plant to collect the water, which consists of multiple vertical turbine pumps. The most essential parts of this pump station plant are: three dewatering pumps and an additional three drainage pumps. The aim of this pump station is to keep the integrity of the dam structure safe by pumping out all the excess water from the dam body into the river. These pumps are extremely vital to maintain the integrity of the dam. The water will be drained from all over the dam structures through a network of extended galleries. The water is first collected in these concrete galleries and then directed to the main pump station tanks. The pumps will work according to a control system that monitors the water levels in the water tanks beneath the pump station. As soon as the water level reaches the operation level of the pumps, a signal will operate the pumps until all the water is directed to the river. The current pumps do not have any VFD controllers installed on them and because they do not operate at full load all the time, they are a great candidate for energy savings. All six pumps have the same technical specifications which use an electrical motors rating of 186 kW. Figure 23 illustrates the different parts of the pumping station with all the components.

Figure 23. Haditha HPP Main Dewatering and Drainage Pump Station



Anticipated Savings

The implementation of installing a new VDF controller is described in the following. The calculation is repeated as shown in section 3.1, but with the updated value for the pump station motor capacity. The annual energy savings (ES), and the corresponding energy cost savings (ECS), can be calculated according to the following:

ES = CEU PEU (6)

ECS = ES · Avoidable cost of electricity (7)

where

CEU = Current time weighted energy usage for a given motor, kWh

PEU = Projected time weighted energy usage for a given motor, kWh.

The current energy usage, CEU, and proposed energy usage, PEU, can be estimated as follows:

$$CEU = \frac{kW \times LF \times OH}{\eta_{m,Existing}} \tag{8}$$

and

$$PEU = \frac{kW}{\eta_{m,PrPr\,o\,posed}} \cdot (FR_1 \cdot H_1 \cdot OH) \tag{9}$$

where

kW = power of motor, 186 kW

OH = Annual operating hours of motor; 2,880 total hr/yr

FR_1 = Power consumption of variable frequency drive motor, originally at 70% load, 44%

H_1 = Fraction of time the motor will operate at 70% load; 80%

LF = Load factor, average fraction of rated power at which motor operates; 0.75

$\eta_{m,Existing}$ = Efficiency of motor, 0.85

$\eta_{m,proposed}$ = Efficiency of motor, 0.90 (average efficiency of full load and part loads).

In the calculation of this specific case, it is supposed that the electrical motor will run at 100% for the operating hours.

$$CEU = \frac{186 \times 0.75 \times 2880}{0.85}$$

= 472,658 kWh/yr

$$PEU = \frac{186}{0.90} \cdot (0.44 \cdot 0.8 \cdot 2880)$$

= 209,510 kWh/yr

ES = 472,658 kWh/yr 209,510 kWh/yr

= 263,148 kWh/yr.

The total cost savings for a single pump, TCS, according to the Iraqi government prices for governmental sector is:

TCS = 263,148 kWh/yr × \$0.1/kWh

= \$26,314 /yr.

The cost of proposed recommendation:

The estimated cost for a VFD controller intended for a 186-kW pump is estimated to be $6,500, with an additional $500 for the installation costs. The total annual electricity savings for this proposed recommendation, based on one pump, is estimated to be 263,148 kWh. The electrical cost savings is expected to be $26,314; this includes an implementation cost of $6,500. The payback period for such an investment is about 3 months. This calculation is for one pump only; Haditha plant has 6 pumps in total intended for the pump station, two of the pumps will operate at the same time, one for drainage and the other for dewatering purposes. So, in this operational scenario the total saving can be doubled reaching a value of $52,628, with a total energy saving reaching 500,000 kWh per year.

4.2.3 Install Variable Frequency Drive on the 50-bar Air Compressors

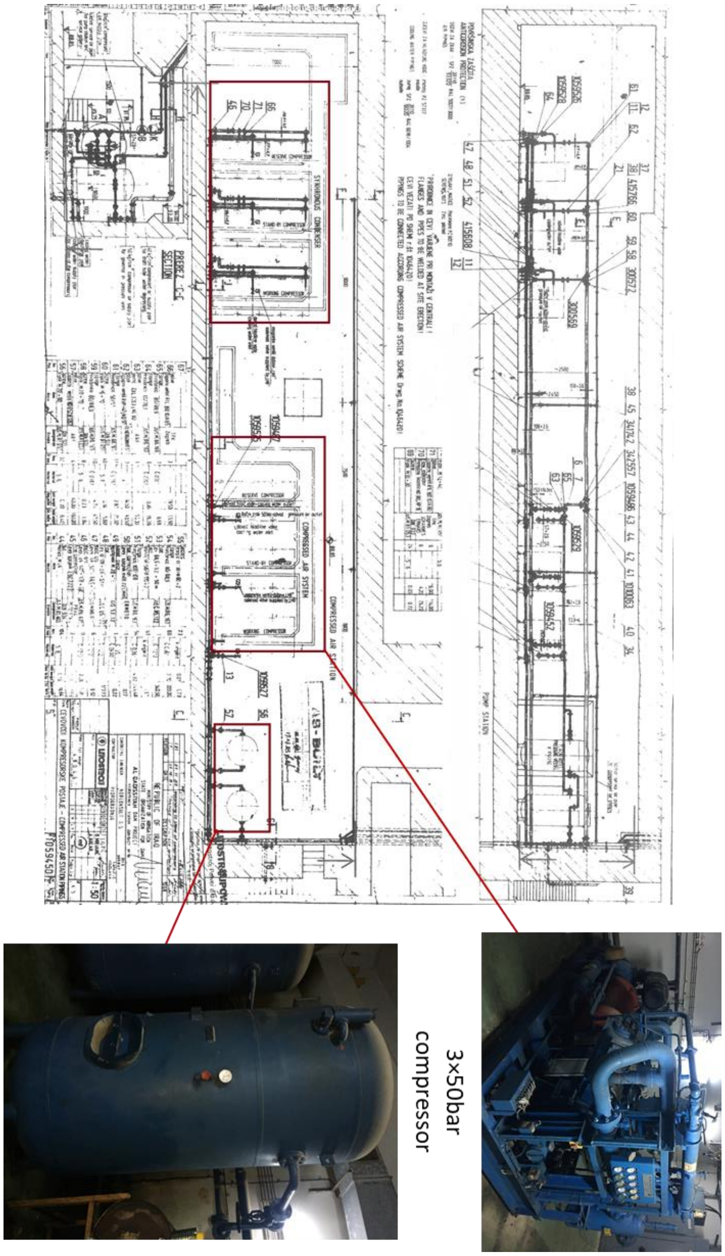
The proposed recommendation

Install VFD controllers on the three electrical motors, each (186 kW), for the 50-bar compressed air system.

Current Practice and Observations:

The potential for energy savings from upgrading the electrical motors of the three 50-bar air compressors intended for the compressed air grid in Haditha HPP is considered in this section. The electro-mechanical systems in Haditha HPP crucially depend on the supply of compressed air with different capacity and pressure values. Several systems, such as turbines and electrical switchgear fire-fighting systems depend on compressed air in its operational process. The Haditha plant has two main compressed air systems, and the one discussed here is the 50-bar system. The system contains three LMF 50 bar piston type air compressors (VHGD 3922 W5). Each compressor uses an electrical motor with a power capacity of 105 kW. The compressors are connected to two air tanks, this way the compressors will feed the two tanks with the required pressure until a signal from the pressure switches, installed on the tanks, stops the compressor. Unfortunately, due to the bad conditions of the compressors and the increased usage of compressed air in the plant, the compressors operate for an extended time to meet the demand for the compressed air. The current compressors motors do not have any VFD controllers installed on them. The schematic and the actual pictures of the compressed air system are depicted in Figure 24.

Figure 24. The Compressed Air System in Haditha HPP



Anticipated Savings

The implementation of installing new VDF controllers is described in the following. The calculation is repeated as shown in previous sections, but with the updated value for the 50-bar compressor motor capacity. The annual energy savings (ES), and the corresponding energy cost savings (ECS), can be calculated according to the following:

$$ES = CEU \quad PEU \qquad (10)$$

$$ECS = ES \cdot \text{Avoidable cost of electricity} \qquad (11)$$

where

CEU = Current time weighted energy usage for a given motor, kWh

PEU = Projected time weighted energy usage for a given motor, kWh.

The current energy usage, CEU, and proposed energy usage, PEU, can be estimated as follows:

$$CEU = \frac{kW \times LF \times OH}{\eta_{m,Existing}} \qquad (12)$$

and

$$PEU = \frac{kW}{\eta_{m,PrPr o posed}} \cdot (FR_1 \cdot H_1 \cdot OH) \qquad (13)$$

where

kW = power of motor, 105 kW

OH = Annual operating hours of motor; 2,160 total hr/yr

FR_1 = Power consumption of variable frequency drive motor, originally at 100% load, 50%

H_1 = Fraction of time the motor will operate at 100% load: 75%

LF = Load factor, average fraction of rated power at which motor operates; 1.00

$\eta_{m,Existing}$ = Efficiency of motor, 0.85

$\eta_{m,proposed}$ = Efficiency of motor, 0.90 (average efficiency of full load and part loads).

In the calculation of this specific case, it is supposed that the electrical motor will run at 100% for the operating hours.

$$CEU = \frac{105 \times 1.00 \times 2{,}160}{0.85}$$

= 266,823 kWh/yr

$$PEU = \frac{105}{0.90} \cdot (0.5 \cdot 0.75 \cdot 2{,}160)$$

= 94,500 kWh/yr

ES = 266,823 kWh/yr   94,500 kWh/yr

= 172,323 kWh/yr.

The total cost savings for a single pump, TCS, according to the Iraqi government prices for governmental sector is:

TCS = 172,323 kWh/yr × $0.1/kWh

= $17,232 /yr.

The cost of proposed recommendation:

The estimated cost for a VFD controller intended for a 105-kW compressor motor is estimated to be $4,700, with an additional $500 for the installation costs. The total annual electricity savings for this proposed recommendation, based on one compressor, is estimated to be 172,323 kWh. The electrical cost savings are expected to be $17,232; this includes an implementation cost of $5,200. The payback period for such an investment is about 4 months.

4.2.4 Replace Metal Halide Fixtures With T5 High Bay

The proposed recommendation

In this section a recommendation to replace Haditha's plant powerhouse metal halide (MH) fixtures with four lamp T5 High Bay. The replacement will be done according to a 1:1 ratio of T-5 to MH fixtures to ensure proper lighting conditions.

Current Practice and Observations

The process of removing all the MH fixtures and replacing them with a T5 High Bay in the main powerhouse of the plant is a very promising recommendation to be included in the energy efficiency practices for Haditha HPP. The powerhouse contains 96 MH fixtures which can be swapped with the T5 fixtures. Increasing lighting efficiency has been one of the major goals for many lighting fixtures producers in recent years. New emerging technology has led to advanced lighting components that have an extended operational life and consume much lower wattage, while not sacrificing any lumen output.

Fluorescent Lighting

The usage of proper T-5 lamps (the T denotes the fluorescent lamp tube diameter in 1/5ths of an inch), with advanced electronic ballasts provide a high-quality lighting with much less power usage compared to existing MH lights in Haditha HPP. Moreover, the T-5 fluorescent lamps render color significantly better than the existing old MH lights, hence providing excellent lighting for the generating units main powerhouse. An added benefit will be the ease of maintenance and the lower heat generated by the T-5 fixtures compared to the MH lights currently in use.

Anticipated Savings

The savings will be a direct result of replacing the MH fixtures in the powerhouse area with T-5 high-bay lamp fixtures, which will be described in this section of the study. The MH fixtures power ratings and replacement bulbs power ratings are outlined in the table below.

Table 12 illustrates the quantities and the replacement prices to switch the 400-Watt MH bulbs with the new T-5 fixtures containing 4, 28-Watt lamps. According to the technical specifications of the T-5 light, the following proposed recommendation should deliver the same levels of light in the powerhouse as for the MH fixtures.

Table 12. Current and Proposed Fixtures

Current Fixtures			
Quantity	**Wattage**	**Lifetime**	**Cost**
96	400	20,000	$25

Proposed Fixtures					
# per fixture	**Fixtures**	**Lamp Quantity**	**Wattage**	**Lifetime**	**Cost**
4	96	384	28	36,000	$5

Here, we present a calculation for the 400 W MH fixtures and the T-5 replacements. The estimated energy conservation, EC, is given below:

$$EC = \frac{((N_1 \times CFW) - (N_2 \times PFW)) \times OH}{C_1} \quad (14)$$

where

N_1 = Number of MH fixtures; 96

CFW = Current fixtures wattage; 400 W

N_2 = Number of T5 High Bay required; 384

PFW = The power of fixture proposed in powerhouse; 28 × 4 = 112 W

OH = Operating hours of lights in powerhouse; 8,760 hr/yr

C_1 = Conversion constant; 1,000 W/kW.

The lamp replacement cost saving for the old lamp, LRS, is calculated by applying the following equation:

$$LRS = \left(\frac{L_1 \times LC_1}{AL_1} - \frac{L_2 \times LC_2}{AL_2}\right) \times OH \quad (15)$$

where

LC_1 = current lamp cost; $25

LC_2 = proposed lamp cost; $5

N_3 = number of lamps to be replaced; 384

AL_1 = average lamp life (old); 20,000 hrs

AL_2 = average lamp life (proposed); 36,000 hrs

L_1 = number of existing lamps; 96

L_2 = number of proposed lamps; 384

Hence, the annual cost savings, ACS, can be estimated as follows:

ACS = (EC · Energy rate) + Lamp replacement cost savings.

The projected energy conservation, EC, for swapping all of these MH lamps with T-5 high-bay lamps is evaluated as follows:

$$EC = \frac{((96 \times 400W) - (96 \times 112W)) \times 8{,}760\ hr/yr}{1{,}000 W/kW}$$

= 242,196.48 kWh/yr.

The lights lamp replacement cost is:

$$LRS = \left(\frac{96 \times 25.00}{20{,}000} - \frac{384 \times 5.00}{36{,}000}\right) \times 8760$$

= $613/yr.

The annual cost savings, ACS, is:

ACS = 242,196.48 kWh/yr · $0.1/kWh + $613/yr

= $24,832/yr.

The cost of proposed recommendation:

The cost of implementing this proposed recommendation includes the equipment and labor costs required for the new T-5 lamps and ballasts. Each T-5 fixture costs about $150 (with lamps). Assume that the time for replacement is one hour for 2 fixtures per hour at a labor rate of $40/hr, the total labor cost is $1,920. Therefore, the full cost of executing this recommendation is about $16,320. The annual electricity savings for this recommendation will be 242,196.48 kWh. The electrical cost savings is expected to be $24,832/yr, and with $16,320, in implementation costs, the payback period will be about 8 months.

4.2.5 Installation of Air-Induced Nozzles on Service Air Guns

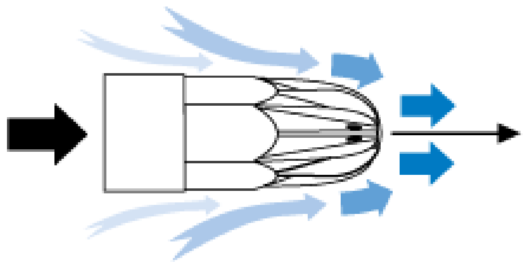
The proposed recommendation

Introducing induction air nozzles for the service compressed air applications inside Haditha HPP, which is used for cleaning and emergency and scheduled maintenance work. The nozzle is integrated with regulators for compressed air service tubes used in the power plant. The aim is to minimize compressed air usage and thus saving power in the process.

Current Practice and Observations

Haditha HPP has approximately two-hundred service air outlets, which are generally used during the daily cleaning and maintenance work. These air outlets are used during the unit maintenance. The main usage is for cleaning purposes of the turbine components and the auxiliary systems. To simplify the power saving calculations; it was assumed that only half of the air outlets are being used at the same time. To use high pressure compressed air directly for cleaning purposes is not safe, but also not efficient energy usage. The recommendation for such usage is to invest in purchasing a new forced air-induced nozzle, which will work perfectly for such situations. Air nozzles depend on the kondo effect, which is small, directed nozzles, to magnify the airflow of the compressed air up to 25 folds or more [89]. Figure 25 shows an illustration of the air-induced nozzles with multiple air streams (nozzles) that surround the outer surface of the main nozzle. During the air movements along the outer surface of the nozzle, the surrounding air will be sucked into the mainstream ejecting from the nozzle head. This process will produce a high air volume with a very high velocity blast while using minimal compressed air in the process. The ejected air from the nozzle will always be ejected outside to be vented in a safe way [89].

Figure 25: EXAIR Service Air Nozzle



Anticipated Savings

The values of the environmental characteristics used in this calculation are listed in Table 13. The pressure at the compressed air outlet used for the air cleaning guns is 116 psi.

Table 13. Compressed Air System Parameters

Parameter	Value
Air temperature at compressor inlet, °F	88
Air temperature at point of nozzle °F	70
Compressor operating pressure, psig	725
Line pressure at point of nozzle psig	116
Compressor motor size, HP	140
Compressor motor efficiency	0.85
Compressor type	piston
Annual operating hours of nozzles	150

The usage of existing air hoses without gun heads, values of the air flow rate, power lost from the compressed air leaks, energy lost and the air leakage from cost from different hole sizes were evaluated for the above conditions. All the calculations are presented at the end of this section. Table 14 tabulates the results for this part.

Table 14. Cost of sample Practices Without Air-Nozzles

Nozzle Diameter (inches)	Flow Rate (cfm)	Power Usage (hp)	Energy Usage (kWh/yr)
1/16	5.45	2.38	2,272
1/8	21.78	9.54	9,109
1/4	111	48.65	46,454

Reviewing table 4, it is suggested that 1/16-inch air-induced nozzle diameters be used for the plant service guns. Only 100 nozzles are used at a specific time, but the total number of nozzles is 200. Thus, we use 100 nozzles to calculate the energy savings.

Table 15. Summary of Savings

Nozzle Location	Number of Nozzles	Existing Nozzle Diameter [in]	Proposed Nozzle Diameter [in]	Energy Conservation [kWh/yr]	Cost Savings [$/yr]
Haditha HPP	100	1/4	1/16	4,418,200	$441,820

The electricity savings, ES, is calculated as:

$$ES = N_1 \cdot EU_1 \quad N_2 \cdot EU_2 \qquad (16)$$

where

N_1 = Number of air guns currently in use; 100 (plant owns 200 in total)

EU_1 = Electricity consumption of one air gun each year; 46,454 kWh/yr

N_2 = Number of induced air nozzles proposed; 100 (plant should replace all 200)

EU_2 = Electricity consumption of one induced air nozzle each year; 1,017 kWh/yr.

Therefore,

ES = 100 ·46,454 100 · 2,272

= 4,418,200 kWh/yr.

The total cost savings, TCS, is calculated as follows:

TCS = 4,418,200 kWh/yr · $0.1/kWh

= $441,820/yr.

The cost of proposed recommendation:

Each individual air nozzle will cost approximately $50, with a labor cost estimation in-house maintenance is $40 per hour. It is estimated that replacing the 100 regulators will take 24 hours, so the total cost of this proposed recommendation is about $5,960. The annual electricity savings for this proposed recommendation is estimated to be 4,418,200 kWh. The annual cost savings is estimated around $441,820 and, with a cost for implementation around $5,960, the payback period will be almost less than a week.

Compressed Air Flow, Loss in Power, and Expected Energy Savings Calculations:

The flow rate of the air (volumetric) ejected from the existing air holes depends on whether the flow is choked or not. If the ratio between atmospheric pressure and line pressure is lower than 0.5283, the flow can be choked, which means traveling at a rate less than the speed of sound. The ratio of 14.7 psia atmospheric pressure to 116 psia line pressure is 0.12, hence, the air flow is choked. The free air flow rate, V_f, ejected from a leak under choked flow conditions can be evaluated as shown below:

$$V_f = \frac{NL \times (T_i + 460) \times \frac{P_l}{P_i} \times C_1 \times C_2 \times C_d \times \frac{\pi D^2}{4}}{C_3 \times \sqrt{T_l + 460}} \qquad (17)$$

where

V_f = Volumetric flow rate of free air; cubic feet per minute

NL = Number of air leaks; 1

T_i = Temperature of the air at the compressor inlet; °F

P_l = Line pressure at leak in question; 116 psia

P_i = Inlet (atmospheric) pressure; 14.7 psia

C_1 = Isentropic sonic volumetric flow constant; 28.37 ft/sec-°$R^{0.5}$

C_2 = Conversion constant; 60 sec/min

C_d = Coefficient of discharge for square edged orifice; 0.8

π = Pythagorean constant; 3.1416

D = Leak diameter; 1/8 in

C_3 = Conversion constant; 144 in^2/ft^2

T_l = Average line temperature; °F.

In order to estimate the value of the power loss due to leaks, an assumption will be made to consider the required used power to operate a compressor to compress the lost air volume from the value of the atmospheric pressure, P_i, to the value of compressor outlet pressure, P_o, is as follows.

$$L = \frac{P_i \times C_3 \times V_f \times \frac{k}{k-1} \times N \times C_4 \times \left[\left(\frac{P_o}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_a \times E_m}, \tag{18}$$

where

L = Power loss due to air leak; in HP

k = Specific heat ratio of air; 1.4

N = Number of stages; 3

C_4 = Conversion constant; $3.03 \cdot 10^{-5}$ HP-min/ft-lb

P_o = Compressor operating pressure; 140 HP

E_a = Air compressor isentropic (adiabatic) efficiency;

E_a = 0.82 for single stage screw compressors

E_a = 0.75 for multi-stage reciprocating compressors

E_a = 0.82 for rotary screw compressors

E_a = 0.72 for sliding vane compressors

E_a = 0.80 for single-stage centrifugal compressors

E_a = 0.70 for multi-stage centrifugal compressors

E_m = Compressor motor efficiency; 0.85

The annual energy conservation, EC, are calculated below:

$$EC = L \cdot H \cdot C_5 \tag{19}$$

where

C_5 = Conversion factor; 0.746 kW/ HP

H = Annual time during which leak occurs; 1280 hr/yr.

4.3 Conclusion

A series of energy-efficient guidelines were specifically formulated for the practical application at the 660-MWe Haditha Hydroelectric Power Plant in Iraq. The recommendations were derived from a comprehensive energy auditing process that examined the existing operational practices employed at Haditha HPP. The energy audit primarily targeted the principal auxiliary systems within the plant that possess significant potential for substantial energy conservation. The study encompassed a comprehensive analysis of the energy utilization in each system, including the technology employed and potential energy-efficient alternatives. Additionally, the study provided recommendations for modifying operational practices or adopting energy-saving equipment to achieve effective energy conservation.

Comprehensive calculations were performed for each recommendation with the objective of achieving optimal energy savings while minimizing implementation costs. This approach ensures that the proposed recommendations can be readily supported by the plant management. The recommendation presented compelling evidence of significant energy-saving potential within the power plant. Table 16 presents the energy-saving recommendations derived from the Haditha HPP energy audit, along with the corresponding potential annual cost savings amounting to $920,996. This study has successfully identified five energy savings opportunities that are characterized by their low cost. All the recommendations that have been identified are linked to an implementation cost that is less than $16,000. If the management of Haditha Hydroelectric Power Plant were to adopt the recommendations, it is estimated that the plant would achieve an annual energy savings of approximately 11,221,667 kilowatt-hours. The total cost associated with implementing these recommendations is projected to amount to $123,680.

Table 16. Summary of Recommendations for Haditha HPP

No.	Description	Annual Savings	Total Annual Cost Savings	Implementation Cost
1	Install Variable Frequency Drive on 100 kW Turbine Governor Pump	407,941 kWh/yr*6	$40,794*6	$5,200*6
2	Install Variable Frequency Drive on Main Pump Station	263,148 kWh/yr*6	$26,314*6	$6,500*6
3	Install Variable Frequency Drive on the 50-bar Air Compressors	172,323 kWh/yr*3	$17,232* 3	$5,200*3
4	Replace Metal Halide Fixtures with T5 High bay	242,196.48 kWh/yr	$24,832	$16,320
5	Installation of Air-Induced Nozzles on Service Air Guns	4,418,200 kWh/yr	$441,820	$5,960
Total		**11,221,667 kWh/yr**	**$920,996**	**$123,680**

The findings of this study demonstrate that the adoption of energy-efficient strategies in the design and construction of industrial facilities will lead to a substantial reduction in energy consumption. The significant cost savings associated with low implementation costs hold great promise for the industrial sector in Iraq. This study aims to offer the Iraqi government and private industrial facility owners a comprehensive understanding of the potential for achieving energy efficiency in Iraq.

CHAPTER 5. CONCLUSION

In the face of an increasing convergence of environmental issues, the pursuit of sustainable solutions in the domains of agriculture and energy arises as a promising source of optimism. This dissertation conducted an extensive investigation into the intersections mentioned, specifically emphasizing Iraq and the wider Middle East region. These areas are significantly affected by the looming challenges of food insecurity, water scarcity, and energy demand. This conclusion combines the findings derived from this study with different areas of investigation, each making a distinct contribution towards outlining a pathway for achieving a more sustainable future.

Vertical farming presents a potential solution for the challenges faced by modern agriculture in the 21st century, as it offers the advantages of optimizing spatial utilization and significantly enhancing crop productivity. This study acknowledges the significant contribution of vertical farming in mitigating food security challenges, particularly in areas characterized by arid climates. Vertical farms have been designed to create an environment-controlled setting that effectively mitigates the consumption of freshwater. This reduction in freshwater usage ranges from an impressive 70% to 95%, making it a critical factor for countries facing water scarcity. Nevertheless, the issue regarding the substantial energy consumption associated with vertical farming has raised doubts about its potential. The incorporation of Concentrating Solar Power (CSP) technologies into vertical farming systems has been proposed as a potential resolution to this energy dilemma. To assess the economic and technological consequences of implementing CSP within the framework of vertical farming in Iraq, this study has identified six optimal sites that possess certain desirable characteristics. These include ample direct normal irradiance (DNI), expansive landscapes, low population density, easy access to water resources, and proximity to vital infrastructure. The techno-economic analysis produced noteworthy outcomes. The hosting performance of Iraq in GEMASOLAR outperformed that of Spain, as evidenced by the impressive productivity observed at locations 3 and 4. These locations exhibited significant energy generation at the most cost-effective Levelized Cost of Energy (LCOE). Significantly, it is worth noting that both location 1 and location 2 surpassed the initial production capacity of the plant in Seville, thereby emphasizing the remarkable prospects for concentrated solar power (CSP) in Iraq's vertical farming endeavors.

The study explored the extensive capacity of solar energy to transform the agricultural sector, with a specific focus on the Middle East region. The economic assessments conducted on solar-powered irrigation systems in Egypt, the United Arab Emirates, Qatar, and Saudi Arabia have demonstrated not only favorable financial outcomes but also a significant influence on both the environmental and economic aspects of these regions. Solar water pumping systems have exhibited their environmental efficacy, providing an opportunity to address air pollution, mitigate greenhouse gas emissions, and diminish reliance on finite fossil fuel reserves. Furthermore, these systems facilitate the extraction of water from subterranean aquifers at greater depths, thereby making a valuable contribution to the conservation of water resources. From an economic standpoint, solar water pumping systems demonstrate a notable advantage due to their low costs associated with operation and maintenance. The decreasing price of solar panels in recent years has additionally enhanced the cost-effectiveness of these systems. The findings were notable, as Egypt consistently displayed a stable level of solar radiation, and the system showcased a high level of efficiency in the Bahtim region. The United Arab Emirates (UAE) demonstrated exceptional performance by achieving the highest average water production.

Furthermore, this dissertation expands its scope by providing customized recommendations specifically designed for the Haditha Hydroelectric Power Plant (HPP) in Iraq. This undertaking is supported by a thorough energy audit, which examines the auxiliary systems of the plant in detail. Five cost-effective opportunities for energy savings are thoroughly identified. Each recommendation presented in this analysis outlines significant annual savings, resulting in a potential projection of annual cost savings amounting to $920,996. These savings are compared to the relatively low implementation cost of $123,680. The results of this study highlight both the practicality and the benefits of adopting energy-efficient approaches in industrial areas. This approach has the potential to result in significant energy conservation while requiring minimal investment.

The collective results of these research endeavors offer significant insights for future endeavors. The author emphasizes the significant impact that renewable energy and sustainable practices can have in effectively addressing pressing agricultural, energy, and environmental issues in Iraq and the wider Middle Eastern region. Although there are certain challenges that need to be overcome, such as the requirement for significant financial investments, ensuring a reliable and continuous water supply, and establishing appropriate regulatory frameworks, it is evident that there exists a considerable potential for transformative outcomes. Vertical farming, which utilizes concentrated solar power (CSP) as its energy source, presents a viable solution for achieving sustainable agriculture and addressing the issue of food insecurity in arid regions. Solar water pumping systems have the potential to substantially mitigate the consumption of fossil fuels, reduce energy costs for agricultural practitioners, and augment endeavors towards water conservation.

Study Limitations:

Costs of Initial Implementation: Integrating CSP technologies into vertical farming systems involves substantial upfront costs. The need for specialized infrastructure, such as concentrated solar collectors, energy storage facilities, and the adaptation of existing CSP plants, could pose a financial challenge for Iraq. Funding constraints and the initial investment required may limit the widespread adoption of this sustainable agriculture approach.

Infrastructure and Technology Transfer: Transferring CSP technologies from a commercial plant in Seville to Iraq involves overcoming logistical challenges. The adaptation and installation of CSP infrastructure require skilled technicians and engineers, which may be scarce in Iraq. Moreover, the lack of an established CSP industry in the country might hinder the efficient transfer and maintenance of such advanced technologies.

Operational and Maintenance Challenges: CSP systems demand regular maintenance and operation oversight to ensure optimal performance. The harsh climate conditions in Iraq's arid regions, including sandstorms and extreme temperatures, could pose challenges for maintaining and protecting the delicate components of CSP infrastructure. Adequate training and support systems must be in place to address these challenges effectively.

Water Resource Management: While vertical farming is known for its efficient water usage compared to traditional agriculture, the overall water demand for the CSP system and vertical farms must be considered. In arid regions like Iraq, water scarcity is a critical issue, and allocating water resources for both CSP operations and crop cultivation might be a potential limitation. Developing water-efficient cultivation methods and technologies is essential to ensuring sustainability.

Limited Crop Diversity: The study uses Romaine lettuce as a benchmark crop, but it is important to consider the applicability of vertical farming using CSP to other crops. Assessing the diversity of crops suitable for vertical farming in Iraq, both technically and economically, is crucial for its broader agricultural impact.

Energy Storage and Distribution: The intermittent nature of solar power production and the need for year-round cultivation in vertical farming require effective energy storage solutions. Developing reliable energy storage systems that can sustain operations during periods of low solar radiation or nighttime is essential. Additionally, establishing a robust energy distribution network to deliver power to remote vertical farming locations is a logistical challenge that needs careful planning.

Policy and Regulatory Framework: Successful implementation of CSP-powered vertical farming in Iraq relies on a supportive policy and regulatory environment. Policies addressing land use, energy tariffs, and incentives for sustainable agriculture must be developed and implemented to encourage the adoption of this technology. Overcoming bureaucratic hurdles and creating a favorable legal framework are essential steps for long-term success.

In conclusion, while CSP presents a promising avenue for sustainable agriculture in Iraq, addressing the outlined limitations is crucial for successful implementation. To use CSP-powered vertical farming to its fullest potential in reducing food insecurity and promoting environmental sustainability in Iraq's dry regions, a plan must be made that includes financial, technical, environmental, and regulatory factors.

Upon thorough examination, this dissertation not only presents a conceptual framework but also outlines a strategic plan for attaining sustainable and resilient communities amidst urgent environmental predicaments. Through the utilization of renewable energy sources and the implementation of innovative agricultural practices, the trajectory towards a more promising and environmentally sustainable future becomes tangible. The potential implications of this research on agricultural and energy policies in Iraq and similar regions are substantial, shedding light on a feasible trajectory towards a more sustainable and secure future.

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