People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

Blida-1 University

Faculty of technology

Department of Renewable Energies

A Thesis submitted in fulfillment of the requirements for Master's degree in Photovoltaic conversion

Thesis title

Smart farm with zero energy

Optimization of an integrated renewable energy system for energy self-sufficiency in a rural farm (a case study in El Djelfa,ALGERIA)

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Année universitaire

2022/2023

الملخص:

يستكشف هذا العمل إمكانية الاستفادة المثلى من نظام متكامل للطاقة المتجددة لتحقيق الاكتفاء الذاتي من الطاقة في مزرعة ريفية في الجلفة ، الجزائر. يشمل البحث تحجيم سخانات المياه بالطاقة الشمسية وأنظمة الضخ بالطاقة الشمسية باستخدام لتحديد النظام الهجين الأكثر HOMER Pro. بالإضافة إلى ذلك ، تم إجراء دراسة باستخدام برنامج PVsystبرنامج فعالية من حيث التكلفة ، مع مراعاة انبعاثات ثاني أكسيد الكربون. النظام المقترح ، يتألف من مصادر الطاقة المتجددة مثل الكهروضوئية ، وتوربينات الرياح ، والبطاريات ، مما يؤدي إلى انبعاثات صفرية. تسلط النتائج الضوء على فعالية النظام الأمثل في تحقيق الاكتفاء الذاتي من الطاقة مع تقليل التكاليف والأثر البيئي. يساهم البحث في الفهم الأوسع والتنفيذ العملي لأنظمة الطاقة المتجددة المتكاملة ، وتعزيز استقلالية الطاقة ، والاستدامة ، وتقليل الانبعاثات في إعدادات المزارع الريفية.

:الكلمات الرئيسية

برنامج PVsyst, الاكتفاء الذاتي للطاقة, المزرعة الريفية, سخانات المياه الشمسية, أنظمة ضخ المياه الشمسية, برنامج نظام هجين فعال من حيث التكلفة, HOMER Pro

Abstract:

This thesis explores the optimization of an integrated renewable energy system for energy self-sufficiency in a rural farm in El Djelfa, Algeria. The research encompasses the sizing of solar water heaters and solar pumping systems using PVsyst software. Additionally, a study is conducted using HOMER Pro software to determine the most cost-effective hybrid system, considering CO2 emissions. the system proposed, consisted of renewable energy sources such as PV, wind turbines, and batteries, resulting in zero emissions. The findings highlight the effectiveness of the optimized system in achieving energy self-sufficiency while minimizing costs and environmental impact. The research contributes to the broader understanding and practical implementation of integrated renewable energy systems, promoting energy independence, sustainability, and reduced emissions in rural farm settings.

Keywords:

Energy self-sufficiency, Rural farm, Solar water heaters, Solar pumping systems, PVsyst software, HOMER Pro software, Cost-effective hybrid system

Résumé :

Cette thèse explore l'optimisation d'un système intégré d'énergie renouvelable pour l'autosuffisance énergétique dans une ferme rurale à El Djelfa, en Algérie. La recherche comprend le dimensionnement des chauffe-eau solaires et des systèmes de pompage solaire à l'aide du logiciel PVsyst. En outre, une étude est menée à l'aide du logiciel HOMER Pro pour déterminer le système hybride le plus rentable, en tenant compte des émissions de CO2. Le système proposé se compose de sources d'énergie renouvelables telles que le photovoltaïque, les turbines éoliennes et les batteries, ce qui permet d'obtenir un taux d'émissions nul. Les résultats mettent en évidence l'efficacité du système optimisé pour atteindre l'autosuffisance énergétique tout en minimisant les coûts et l'impact sur l'environnement. La recherche contribue à une meilleure compréhension et à la mise en œuvre pratique de systèmes intégrés d'énergie renouvelable, favorisant l'indépendance énergétique, la durabilité et la réduction des émissions dans les exploitations agricoles rurales.

Mots-clés :

Autosuffisance énergétique, Ferme rurale, Chauffe-eau solaires, Systèmes de pompage solaires, Logiciel PVsyst ,Logiciel HOMER Pro, Système hybride rentable

Acknowledgement

I am deeply grateful to Allah for providing me with guidance, strength, and surrounding me with people and events that have contributed to the completion of this thesis.

I am sincerely thankful to Dr. Bouzaki Mohammed Moustafa, my supervisor and the Head of the Renewable Energies Departmentat the University of Blida-1. Despite his busy schedule, he found time to provide guidance and orientation for my work, which has been instrumental in shaping the direction and quality of this dissertation.

Additionally, I would like to express my gratitude to Dr. Domaz Toufik for his presence and contribution to the department. His presence has created a supportive environment and his willingness to help has been invaluable.

I would also like to extend my deepest appreciation to Mr. BENCHENINA Yacine for his exceptional support and invaluable contributions to my research. His guidance, corrections, and insights have played a significant role in the development and improvement of my work.

Lastly, I would like to express my gratitude to all the teachers, mentors, and colleagues who have contributed to my academic and personal growth. Their discussions, feedback, and encouragement have shaped my perspectives and enriched this research.

I am humbled and deeply appreciative of Allah's blessings and the support of everyone mentioned above. Their contributions, guidance, and presence have been pivotal in the successful completion of this thesis.

Dedication

I dedicate this thesis to my beloved parents, whose unwavering support, love, and encouragement have been the driving force behind my academic journey. Your belief in my abilities and constant motivation have shaped me into the person I am today. I am deeply grateful for the sacrifices you have made and the countless hours you have dedicated to nurturing my dreams.

To my beloved sister, I dedicate this thesis to you as well. I am grateful for the bond we share and for the inspiration you provide. This dedication is a tribute to our unique relationship

To my dear brother, you have always been my pillars of strength. Your presence, understanding, and encouragement have been invaluable throughout this journey.

I would also like to extend my heartfelt appreciation to all my friends, who have been by my side throughout this thesis journey. Your unwavering support, understanding, and words of encouragement have provided me with the much-needed inspiration and motivation to overcome obstacles. In particular, I want to express my gratitude to Anissa, you have been a constant source of motivation and encouragement throughout this research. your consistent presence and belief in my abilities have fueled my passion for this study and have been instrumental in its completion.

Special thanks go to Yacine, whose exceptional assistance and guidance played a pivotal role in the successful completion of this work. Your invaluable expertise, dedication, and commitment to helping me navigate through the challenges have been truly remarkable. I am sincerely grateful for your guidance and unwavering belief in my abilities.

To all the individuals who have contributed to my growth and success, I express my deepest appreciation. Your support, whether big or small, has left an indelible mark on my academic journey. This thesis stands as a testament to the collective efforts and unwavering support of my loved ones and friends and to the ones I lost.

I also dedicate this thesis to myself, I am proud of the person I have become throughout this journey, and I dedicate this work to the relentless pursuit of personal and intellectual growth. May this serve as a reminder of my capacity to overcome challenges, embrace new experiences, and continue striving for success in all aspects of life.

Thank you all for being a part of this incredible journey.

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Abbreviations

PV	Photovoltaic
MPPT	Maximum power point tracker
AC	Alternative current
DC	Direct current
W	watt
Isc	Short circuit current
A	ampere
Voc	Open circuit voltage
V	volt
Impp	Maximum power point current
Vmpp	Maximum power point voltage
Bj	Daily water needs
Cj	Daily consumption
Qj	daily energy input required
Tc	hot water temperature
Tf	cold water temperature
Qa	The annual energy input
Qcoll	the energy contribution from the solar collectors
Cs	Solar coverage
Kg	Kilogram
K	Kelvin
Kw	kilowatt
H	hour
PVGIS	Photovoltaic geographical information system
kor	correction factors for orientation
kti	correction factors for tilt

General Introduction

The optimization of an integrated renewable energy system for energy self-sufficiency in a rural farm context holds significant importance in today's world (Sayed et al., 2021). This thesis aims to explore and develop strategies to achieve energy self-sufficiency in a rural farm located in El Djelfa, Algeria, through the integration of renewable energy sources.

Renewable energy technologies have emerged as a promising solution for sustainable and environmentally friendly power generation. The global transition towards renewable energy has gained momentum due to their potential to reduce CO2 emissions and mitigate climate change. In rural areas with limited access to traditional electricity grids, the integration of renewable energy systems becomes even more critical, offering the opportunity to achieve energy self-sufficiency and reduce reliance on expensive and unreliable diesel generators.

The specific focus of this thesis is on optimizing the integration of renewable energy sources within a rural farm in El Djelfa, Algeria. The farm serves as a case study to implement tailored renewable energy solutions that align with the region's unique needs and geographical characteristics. By analyzing the energy needs and demands of the farm, along with the available renewable energy resources, an optimized and sustainable solution can be developed to ensure continuous and uninterrupted power supply.

To achieve this optimization, various aspects will be considered, such as the site assessment, meteorological data analysis, and the utilization of advanced modeling and simulation techniques. The selection and configuration of renewable energy components, including solar pumping systems and solar water heaters, will be guided by a conceptual framework that accounts for the distributed and fluctuating nature of renewable energy sources and the need for energy storage systems.

The results and analysis chapter will present the findings obtained from theimplementation of the integrated renewable energy system on the rural farm. It will showcase the effectiveness of the optimized system in achieving energy self-sufficiency and reducing thefarm's carbon footprint. The economic viability and cost-effectiveness of the system will also be assessed, ensuring its long-term sustainability.

By optimizing the integration of renewable energy sources in a rural farm setting, this research aims to contribute to the broader understanding and practical implementation of renewable energy systems in similar contexts worldwide. The findings and insights gained from this study can guide policymakers, farmers, and stakeholders in promoting sustainable energy practices and achieving energy self-sufficiency in rural communities.

In conclusion, this thesis focuses on the optimization of an integrated renewable energy system for energy self-sufficiency in a rural farm located in El Djelfa, Algeria. Through a comprehensive analysis of energy needs, available resources, and the utilization of advanced modeling techniques, the aim is to develop a customized solution that enhances efficiency, reduces costs, and fosters sustainable practices. The research contributes to knowledge and understanding of renewable energy integration in agricultural contexts, fostering energy independence, environmental stewardship, and long-term sustainability in rural communities.

Chapter I: Introduction to Renewable Energy Systems and Energy Self-Sufficiency in Rural Farms

I.1 Introduction

Renewable energy technologies have emerged as a dependable alternative for off-grid electricity generation, providing a reliable source to meet the energy needs of rural areas. This shift away from conventional resources allows for sustainable and environmentally friendly power solutions in areas with limited access to traditional grids.(Shahzad et al., 2017) The utilization of renewable energy resources has become crucial in today's context. These resources, such as solar, biomass, and wind, offer environmentally friendly and clean energy options that can be implemented at small-scale levels. Micro-grid systems based on renewable energy are particularly effective in making agricultural farms independent of conventional grid systems. These systems can provide a continuous and uninterrupted electricity supply, ensuring the smooth operation of farms without any disruptions.(Khan & Iqbal, 2005).

I.2 Research Objectives

The overall objective of this thesis is to optimize an integrated renewable energy system to achieve energy self-sufficiency in a rural farm. To accomplish this, the following specific objectives will be pursued:

- Analyzing the energy needs and demands of a rural farm in El Djelfa, Algeria.
- Evaluating the available renewable energy resources in El Djelfa, Algeria.
- Developing optimization techniques to maximize efficiency and cost-effectiveness of the integrated renewable energy system.
- Assessing the feasibility and performance of the integrated renewable energy system in the rural farm.

These objectives will guide the research and provide a structured approach to addressing the challenges of implementing and optimizing the integrated renewable energy system for energy self-sufficiency in the specific context of the rural farm in El Djelfa, Algeria.

I.3 Significance of the Study

Implementing an optimized integrated renewable energy system in rural farms, particularly in El Djelfa, Algeria, holds significant potential benefits and impacts. Firstly, it can contribute to the achievement of energy self-sufficiency, which is crucial for sustainable development in rural areas. By reducing reliance on external energy sources and ensuring a reliable power supply.In addition, the integration of renewable energy systems in rural farms has implications for climate change mitigation and environmental sustainability. By displacing conventional fossil fuel-based energy sources, these systems can significantly reduce CO2 emissions and contribute to global efforts in combating climate change. This transition aligns with the goals of creating a more sustainable and low-carbon future.

Overall, the study's significance lies in its potential to promote sustainable development, enhance energy self-sufficiency, mitigate climate change, and alleviate financial burdens in rural areas. The findings of this research can serve as a valuable reference for policymakers, farmers, and other stakeholders seeking to implement optimized integrated renewable energy systems in agricultural settings.

I.4 Background and Motivation for the Study

The transition to renewable energy technologies is crucial in addressing the global need for sustainable and environmentally friendly power solutions. Renewable energy sources, including solar power, wind power, biomass, and hydropower, offer a clean and renewable alternative to traditional fossil fuels. The significance of these renewable energy sources lies in their ability to reduce CO2 emissions and mitigate the impacts of climate change (Jirabovornwisut et al., 2021).

In off-grid areas, where access to traditional electricity grids is limited, the implementation of renewable energy systems becomes even more important. These systems provide a viable solution for rural areas to achieve energy self-sufficiency, reducing their dependence on expensive and unreliable diesel generators. In the context of agricultural farms in rural areas, a continuous and uninterrupted power supply is crucial for various operations, such as irrigation, livestock management, and processing of agricultural products.

By embracing renewable energy systems, rural areas can not only achieve energy self-sufficiency but also reduce their carbon footprint and contribute to a sustainable future. These systems offer an opportunity to alleviate the environmental impacts associated with conventional energy sources and foster sustainable practices within the agricultural sector.

Optimizing the integration of renewable energy technologies in rural farms holds immense potential. By understanding the specific energy needs and demands of these farms, tailored solutions can be developed to ensure a reliable and efficient power supply. The optimization process involves identifying the optimal mix of renewable energy sources, such as solar, wind, and biomass, and implementing energy storage systems to address intermittency issues. Furthermore, considering the economic viability of these systems is crucial to ensure long-term cost-effectiveness.

I.5 Introduction to Energy Self-Sufficiency

Energy self-sufficiency is a vital aspect of sustainable development, particularly in rural areas where access to consistent and reliable energy supplies can be challenging(Mutia & Hgaki, 2019) The limited access to reliable and affordable energy in rural areas has profound implications for various aspects of society, including productivity, health, education, climate change mitigation, food security and communication services. It is argued that the provision of sustainable energy solutions can bring about a transformative effect on individuals and local communities by increasing self-sufficiency, empowerment and interdependency. By democratizing resources and reducing inequalities through increased availability of energy sources such as solar and wind power generation systems combined with optimization techniques to enhance efficiency, it becomes possible to alleviate the financial burden faced by rural populations. This integrated approach not only ensures continuous power supply but also contributes to overall system reliability while minimizing fluctuations associated with single-variable renewable energy systems. In recent years, research has focused on studying different optimization techniques for enhancing the efficiency of integrated renewable energy systems in rural areas. These optimization techniques aim to provide continuous power at lower costs, thus reducing the financial pressure on people living in rural areas. For instance, studies have examined capacity allocation and optimal scheduling of integrated energy systems in rural areas. Additionally, research has studied the impact of various energy supply methods on meeting specific energy demands in rural areas. Furthermore, a significant body of research has concentrated on the design optimization and technical and economic analysis of rural off-grid integrated energy systems. In rural areas, where access to consistent and reliable energy supplies can be challenging, achieving energy self-sufficiency is crucial for sustainable development.(Jha et al., 2022

I.6 Challenges in Rural Farm Energy Management

The optimization of an integrated renewable energy system for energy self-sufficiency in a rural farm presents various challenges that need to be addressed. One challenge is the availability and reliability of resources. In rural areas, the availability and reliability ofresources such as solar and wind energy can be uncertain. This uncertainty can affect the efficiency and reliability of the integrated renewable energy system. Another challenge is the management and allocation of these resources to meet the specific energy demands of the rural farm. To overcome these challenges, it is important to implement optimization techniques that take into account the variability of renewable energy resources and optimize their utilization based on the specific energy demands of the rural farm.(Hatamifard et al., 2023) Further challenges exist in the form of technical and economic factors. Technical factors include the management and coordination of different renewable energy sources, as well as the integration of energy storage systems to mitigate fluctuations in power output. Furthermore, economic factors include the cost-effectiveness of implementing integrated renewable energy systems in rural farms. These challenges can be addressed through the use of optimization techniques that consider factors such as resource availability, demand variability, and cost-effectiveness. (Ali et al, 2023).

I.7 Overview of Integrated Renewable Energy Systems

An integrated renewable energy system refers to a combination of different renewable energy sources, such as solar, wind, and biomass, along with energy storage systems and other energy management technologies, to meet the energy needs of a specific location or project. The goal of an integrated renewable energy system is to optimize the utilization of these various resources in order to achieve energy self-sufficiency and reduce reliance on traditional power sources.(Zhang et al., 2021)

The integration of renewable energy sources allows for the generation and distribution of power at a lower cost, making it more accessible to remote and rural households. Optimization Techniques for Energy SystemsOptimization techniques play a crucial role in enhancing the efficiency and reliability of integrated renewable energy systems. These techniques involve the use of modern technologies, such as artificial intelligence, to manage and allocate resources effectively. (Jha et al., 2022).

I.8 General Information on renewable energies

I.8.1 Solar radiation

Solar radiation refers to the electromagnetic radiation emitted by the sun. It encompasses a wide range of energy types organized by wavelength and frequency in the electromagnetic spectrum. The portion of the spectrum that reaches Earth from the sun ranges from 100 nm to 1 mm. This range is further divided into three categories: ultraviolet, visible, and infrared radiation. Infrared radiation, accounting for 49.4% of solar radiation, includes wavelengths from 700 nm to over 1 mm, while visible light contributes 42.3% and falls within the range of 400-700 nm. Ultraviolet radiation makes up slightly over 8% and comprises wavelengths between 100-400 nm.

Solar radiation can be captured and converted into useful forms of energy. It plays a crucial role in the advancement of renewable energy technologies like solar photovoltaic and solar thermal systems. These technologies utilize solar radiation generate electricity or heat water for various applications, be it domestic industrial.

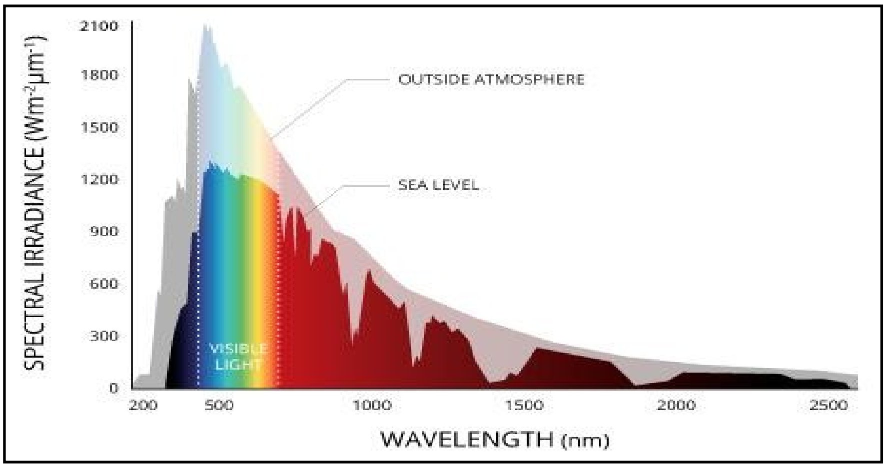


Figure I.1 – Solar radiation

a) Types of solar radiation

Depending on the form in which it reaches the Earth:

- **Direct solar radiation**

This type of radiation penetrates the atmosphere and reaches the Earth's surface without dispersing at all on the way.

- **Diffuse solar radiation**

This is the radiation that reaches the Earth's surface after having undergone multiple deviations in its trajectory, for example by gases in the atmosphere.

- **Reflected solar radiation**

This is the fraction of solar radiation that is reflected by the earth's surface itself, in a phenomenon known as the albedo effect.

- **Global radiations**

The global irradiance is sum of all the radiations received, includes direct sunlight and diffuse sunlight and the radiation reflected by the ground and the objects that are on its surface, it is measured by a pyranometer.

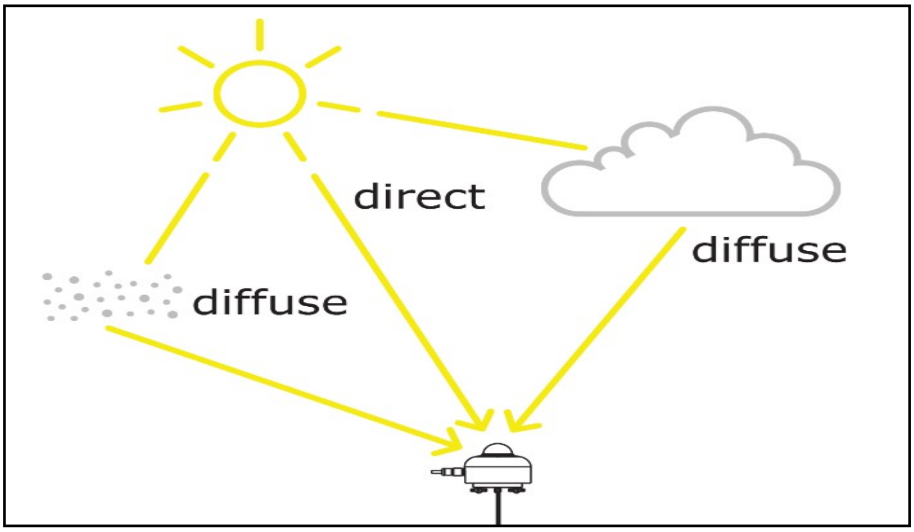


Figure I.2 – Types of solar radiation:

b) Photovoltaic solar energy

Photovoltaic solar energy is a rapidly expanding industry worldwide. It involves the conversion of sunlight into electricity through a technology based on the photoelectric effect. This effect relies on specific materials that can absorb photons (particles of light) and release electrons, thereby generating an electric current. Photovoltaic solar energy is a form of renewable energy that is both sustainable and environmentally friendly, as it is derived from an inexhaustible and non-polluting source of energy.

c) Components of the photovoltaic system

In general, photovoltaic systems require four essential components: solar PV panels, a charge controller, a battery bank, and an inverter. Additional components may include a utility meter, an electric grid connection, and protective devices.

- **The photovoltaic generator**

A solar panel is a collection of photovoltaic solar cells. These cells are made up of semiconductor materials. Their main function is to capture sunlight as a source of radiant energy and convert it into direct current (DC) electricity. Solar panel technology is continuously progressing, with ongoing advancements aimed at improving efficiency.

- **Six Main Components of a Solar Panel**
- Solar photovoltaic cells (a series of silicon crystalline cells).
- Toughened Glass - 3 to 3.5mm thick.
- Extruded Aluminium frame.
- Encapsulation - EVA film layers.
- Polymer rear back-sheet.
- Junction box - diodes and connectors.

- **Technologies and types of silicon-based photovoltaic cells:**

There are three types of PV cell technologies that dominate the world market: monocrystalline silicon, polycrystalline silicon, and thin film (Amorphous silicon solar cells).

- **Monocrystalline solar panels:**

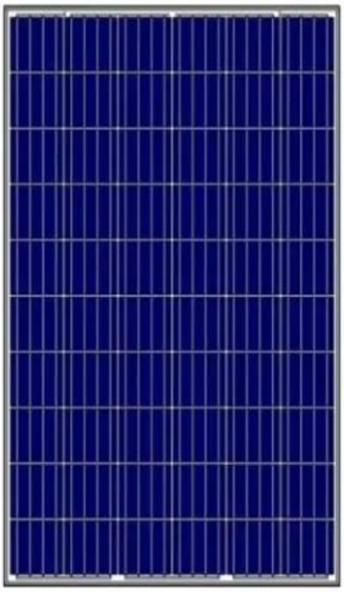
Monocrystalline solar panels are constructed using monocrystalline solar cells, which are known for their high efficiency rates typically ranging between 15% to 20%. These panels exhibit better heat tolerance and utilize production methods that are less sustainable compared to other types of solar panels. As a result, monocrystalline solar panels tend to have a higher price point.

The manufacturing process of monocrystalline silicon solar cells involves a technique known as the Czochralski method. In this method, a silicon crystal is placed in a vat of molten pure silicon at a high temperature. The process facilitates the formation of a single silicon crystal, known as an ingot. This ingot is then sliced into thin silicon wafers that are subsequently used in the construction of solar modules.

- **Polycrystalline solar panels**

Polycrystalline solar panels consist of multiple polycrystalline solar cells. These cells, like monocrystalline solar cells, are made from silicon crystals. However, the production process differs. In the case of polycrystalline cells, the silicon crystal cools and fragments naturally, rather than being extruded as a single pure ingot. These fragments are then melted and shaped into cubes, which are subsequently cut into thin wafers. This production process is less precise compared to monocrystalline cells, allowing for faster and more cost-effective production of solar cells.

Polycrystalline solar cells are typically square-shaped and have a blue color. They are designed to fit closely together, minimizing any gaps between the cells. However, due to the fragmented nature of the silicon, polycrystalline panels operate with slightly lower efficiency compared to monocrystalline panels. Polycrystalline panels generally have an efficiency rating ranging from 13% to 16%. Despite the slightly lower efficiency, polycrystalline panels are widely used in the industry.



- **Amorphous silicon solar panels**

Thin film modules consist of a thin layer, typically around 1 µm thick, sandwiched between two glass panes, making them highly flexible and durable. Among the different types, Si-amorphous (amorphous silicon) thin film PV generators outperform Si-monocrystalline and Si-polycrystalline modules. They also exhibit better performance in elevated temperature conditions compared to crystalline silicon cells. However, the trade-off is a lower efficiency level.

Thin film technology allows for more cost-effective production methods, but this comes at the expense of reduced efficiency. Other types of thin film cells include Copper Indium Gallium Selenide (CIGS) and Cadmium Telluride (CdTe). These cell technologies offer higher efficiencies than amorphous silicon, but they contain rare and toxic elements.

- **Charge controller**

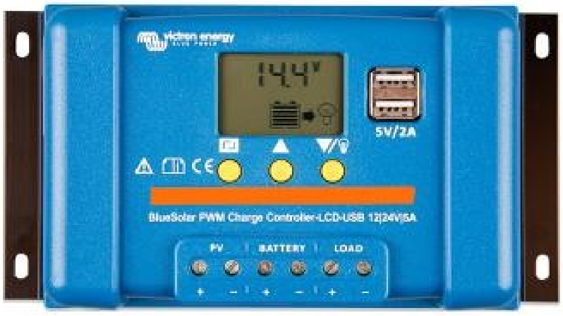
A charge controller is responsible for managing and controlling the flow of electricity from the PV generator to the battery. Its primary function is to regulate the voltage and current coming from the PV array to prevent overcharging and overdischarging of the battery, thereby protecting the lifespan of both the solar panels and the connected battery. Additionally, charge controllers allow for the selection of the appropriate battery type for optimal performance.

Some solar charge controllers come equipped with an LCD display, providing information and settings adjustments. Others have simpler interfaces with dials that can be manually turned to select voltage and other parameters. Advanced charge controllers may offer Bluetooth connectivity, enabling app-based control and monitoring functionalities.

There are two main types of solar charge controllers: PWM and MPPT charge controllers.

- **PWM charge controllers:**

Stands for pulse-width modulation .These controllers are best suited for small systems; they are less expensive and less efficient than MPPT charge controllers.



- **MPPT charge controllers:**

Stands for maximum power point tracking .The second controller work well for larger off-grid systems, they are slightly more expensive than PWM charge controllers.

- **The Batteries:**

Solar batteries are designed to store the energy generated by photovoltaic panels for later use, ensuring a reliable power supply in all situations. These batteries are available in various voltages, such as 2V, 6V, or 12V. The capacity of the batteries, measured in Amperes hour (Ah), is inversely proportional to the voltage. Therefore, 2V batteries typically have the highest storage capacity.

Batteries are electrochemical devices that are influenced by factors such as climate, charge/discharge cycles, temperature, and age. Their performance is influenced by the location and patterns of usage. Batteries are rated based on their "cycles," indicating the number of times they can be charged and discharged. Deep-cycle batteries, which can handle repeated deep cycles, are best suited for PV power systems.

There are four main types of batteries commonly used in solar power systems: lead-acid, lithium-ion, nickel-cadmium, and flow batteries. Each type has its own characteristics and advantages in terms of performance, lifespan, and cost.

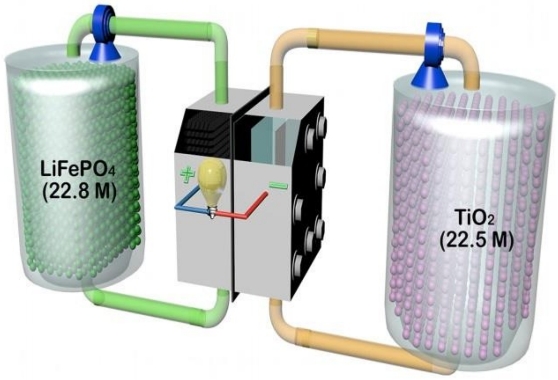
- **The lead–acid battery**

The lead-acid battery, being the earliest type of rechargeable battery developed, exhibits relatively low energy density and has a limited cycle lifespan. It is characterized by a low number of charging-discharging cycles throughout its lifetime, low discharge intensities, and slow charging rates. The lead-acid battery is composed of two electrodes immersed in a sulfuric acid electrolyte. Each cell of a lead-acid battery has a nominal voltage of 2.2V. The voltage of a single cell can vary from 1.8V when fully discharged under load to 2.10V in an open circuit when fully charged. Despite these limitations, lead-acid batteries are commonly used in renewable energy systems. **[18]**

- **Flow battery:**

A flow battery is an electrochemical cell that relies on two chemical components dissolved in liquids, which are circulated separately on opposite sides of a membrane. Chemical reactions occur within the battery to provide chemical energy. Flow batteries operate by allowing liquid electrolytes to flow between two chambers within the battery, resulting in energy production. These batteries are known for their high efficiency, often achieving a depth of discharge of 100%. However, they have a low energy density, meaning the tanks containing the electrolyte liquids need to be large to store a significant amount of energy. The cell voltage of flow batteries typically ranges from 1.0V to 2.43V.

Flow batteries have the potential to enable widespread use of renewable energy, but their viability depends on their ability to store large amounts of energy cost-effectively and supply it to the grid.



- **A lithium-ion battery:**

A lithium-ion battery is a highly advanced rechargeable battery technology that utilizes lithium ions in its electrochemistry to store energy. It offers significant advantages in power storage systems, including high energy density, excellent performance, and wide temperature adaptability. Lithium-ion batteries can operate within a temperature range of -20°C to 60°C, and with appropriate treatment, they can even function in temperatures as low as -45°C.

Lithium-ion batteries are controllable, non-polluting energy storage devices that are well-suited for various applications. They can be fully integrated with solar street lighting systems, providing reliable and efficient energy storage.

- **The nickel–cadmium battery :**

The nickel–cadmiumbattery is a type of rechargeable battery. It achieves 10 000 cycles at 15% depth of discharge (From 100 Ah to 1830 Ah (C120 rate)). And operate in extreme temperatures ranging from -30°C to +50°C. Ni–Cd cells have a nominal cell potential of 1.2 volts. Solar nickel cadmium battery is the best choice for photovoltaic applications, stand-alone hybrid systems and renewable energy applications.

- **Inverter:**

A photovoltaic inverter is a power inverter that transforms the variable direct current (DC) output from a photovoltaic solar panel into a utility frequency alternating current (AC). It serves as the crucial link between the solar panels and the electrical distribution panel, enabling the integration of solar energy into the existing electrical grid system.

- **Solar inverters classified into four types:**
  - **Stand-alone inverter (off-grid inverter) :**

Stand-alone inverter is used for remote stand-alone application with battery backup where the inverter draws its DC power from batteries charged by PV array and converts to AC power.

  - **<u>Grid tie inverter:</u>**

(Grid connected inverter) grid tie inverter is used specifically for grid connected application that does not require battery backup system. Grid tie inverter converts DC power produced by PV array to AC power to supply to electrical appliances and sell excess power back to utility grid.

- **Battery backup inverters:**

Battery backup inverters are special inverters which are used to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.

- **Intelligent hybrid inverters:**

Intelligent hybrid inverters manage photovoltaic array, battery storage and utility grid, which are all coupled directly to the unit. Their primary function is self-consumption with the use of storage.

So there are three main types of solar PV systems: grid-tied, hybrid and off-grid.

- **Grid-tied systems:**

An on-grid solar system or grid tied, is a solar PV system which connects directly to the National Grid. This kind of Solar PV System is the most common amongst home and business owners. This solar system doesn’t require a battery storage system, and is connected to the Grid directly via a Solar or micro inverter. As the solar panels convert sunlight into energy, your home uses this green energy supply to power your appliances. When you generate any excess solar energy, this electricity is exported back to the Grid.

- **Off-grid solar systems:**

An off-grid system operates independently without any connection to the national grid. As energy prices continue to rise, there is an increasing demand for energy independence. A comprehensive off-grid solar system includes all the necessary components to generate solar energy on your own. Unlike hybrid systems, off-grid systems often incorporate backup generators and other renewable sources to ensure that the batteries are fully charged throughout the year. This system is designed to provide electricity even in remote locations, making it suitable for off-grid living or areas without access to the national power grid.

- **Hybrid solar systems:**

Hybrid solar systems combine the technology of solar panels and solar batteries to create an eco-friendly energy solution that offers a backup energy supply. While these systems remain connected to the national grid, any solar energy generated is first stored in a home battery solution before being sent to the grid. This setup provides flexibility as, even when the battery is depleted, you can still draw power from the grid. A hybrid solar system serves as an ideal middle-ground solution.

One significant advantage of a hybrid solar system is the ability to expand the battery storage capacity at any time. Additionally, since you are still connected to the grid, you can take advantage of charging your batteries during off-peak hours when electricity rates are lower. This allows for cost-saving opportunities and greater control over energy usage.

d) Solar water heaters:

Solar water heaters are devices that utilize the energy from the sun to heat water for various purposes such as domestic use, swimming pools, and industrial applications. They are designed to harness solar radiation and convert it into usable heat, reducing the reliance on traditional energy sources such as electricity or gas.

The basic components of a solar water heater typically include:

- **Solar collectors:**

These are the key components that absorb sunlight and convert it into heat energy. The collectors are usually flat panels or evacuated tubes made of materials with high solar absorption properties, such as copper, aluminum, or glass.

- **Heat transfer system:**

This system carries the heat collected by the solar collectors to the water storage tank. It consists of pipes, pumps, and heat exchangers that transfer the thermal energy efficiently.

- **Water storage tank:**

This tank stores the heated water for later use. It is usually insulated to minimize heat loss and can have additional backup heating elements for cloudy days or high-demand periods.

Solar water heaters can be categorized into two main types based on the circulation of water:

- **Active solar water heaters**:

These systems use pumps or other mechanical devices to circulate water or heat transfer fluid through the collectors and into the storage tank. They are suitable for areas with colder climates or when longer distances are involved between the collectors and the storage tank.

- **Passive solar water heaters:**

These systems rely on natural convection or thermosiphon principles to circulate water through the collectors and into the storage tank. The heated water rises naturally due to density differences, eliminating the need for pumps or external power sources. Passive systems are simpler in design and typically used in areas with warmer climates.

e) Solar pumping:

Solar pumping refers to the use of solar energy to power water pumps or other fluid pumps, eliminating the need for grid electricity or fossil fuel-powered engines. It is a sustainable and environmentally friendly method of pumping water or fluids, particularly in areas with limited or unreliable access to electricity.

Solar pumping systems typically consist of photovoltaic (PV) panels, which convert sunlight into electrical energy, and a pump that runs on this solar-generated electricity. The PV panels capture sunlight and convert it into direct current (DC) electricity, which is then used to power the pump. In some cases, batteries or other energy storage systems are used to store excess electricity generated during peak sunlight hours for use during periods of low or no sunlight.

Solar pumping systems can be used for various applications, including irrigation in agriculture, livestock watering, drinking water supply for rural communities, and water supply for remote locations such as farms, ranches, or off-grid dwellings. The systems can be designed to operate either directly on solar power during daylight hours or by using a combination of solar power and stored energy for continuous operation.

f) Biomass:

Biomass refers to organic matter derived from plants and animals, which can be used as a source of renewable energy. It includes a wide range of biological materials such as wood, agricultural residues, dedicated energy crops, algae, and organic waste.

The term "biomass" is often used in the context of bioenergy production, where the organic matter is converted into useful forms of energy, such as heat, electricity, or biofuels. Biomass can be utilized through various processes, including combustion, gasification, anaerobic digestion, and pyrolysis.

The use of biomass as an energy source is considered renewable because it relies on the natural carbon cycle. When biomass is burned or converted into biofuels, it releases carbon dioxide (CO_2) into the atmosphere. However, this carbon dioxide is part of the natural carbon cycle and is reabsorbed by plants through photosynthesis, effectively creating a carbon-neutral or low-carbon energy system.

Biomass offers several advantages as a renewable energy source. It is abundant and widely available, as it can be derived from various sources, including agricultural and forestry residues, which would otherwise be discarded or left to decompose. Biomass can also provide a reliable source of baseload power, helping to diversify the energy mix and reduce dependence on fossil fuels.

g) Electrolyser:

Also known as an electrolytic cell or water electrolysis device, is a device that uses electrical energy to facilitate the decomposition of water (H_2O) into its constituent elements, hydrogen (H_2) and oxygen (O_2), through an electrochemical process called electrolysis.

During electrolysis, an electric current is passed through an electrolyte solution or a molten salt, which contains ions that can conduct electricity. The electrolyser consists of two electrodes, typically made of a conductive material such as platinum or titanium, which are immersed in the electrolyte solution.

When an electric current is applied, the positive electrode (anode) attracts negatively charged ions (anions) in the electrolyte, and the negative electrode (cathode) attracts positively charged ions (cations). In the case of water electrolysis, the positively charged hydrogen ions (H^+) are attracted to the cathode, while the negatively charged hydroxide ions (OH^-) are attracted to the anode.

At the cathode, the hydrogen ions gain electrons from the electrical circuit and are reduced to form hydrogen gas (H_2), which is collected as the desired product. At the anode, the hydroxide ions lose electrons and are oxidized, releasing oxygen gas (O_2) as a byproduct.

The overall chemical reaction occurring in an electrolyser can be represented as follows:

$$\mathbf{2H_2O(l) \rightarrow 2H_2(g) + O_2(g)}$$

Electrolysers play a crucial role in various applications, particularly in the field of renewable energy and hydrogen production. They enable the production of hydrogen gas, which is considered a clean and versatile energy carrier, as it can be used in fuel cells for electricity generation or as a raw material for chemical processes.

h) Fuel Cell:

A fuel cell is an electrochemical device that converts the chemical energy from a fuel, typically hydrogen, into electrical energy through a controlled reaction with an oxidizing agent, usually oxygen from the air. It operates based on the principle of generating electricity directly from the electrochemical reaction of fuel and oxygen, without the need for combustion.

The basic structure of a fuel cell consists of an anode (negative electrode), a cathode (positive electrode), and an electrolyte. The anode and cathode are separated by the electrolyte, which allows ions to pass through while preventing the mixing of fuel and oxidant gases. The electrolyte can vary depending on the type of fuel cell technology used.

When hydrogen is used as the fuel, it is supplied to the anode side of the fuel cell. At the anode, hydrogen molecules are split into protons (H^+) and electrons (e^-) through a process called electrochemical oxidation. The protons are then transported through the electrolyte to the cathode side of the fuel cell.

Meanwhile, on the cathode side, oxygen (usually from the air) is supplied, and it combines with the protons that have passed through the electrolyte, along with electrons from an external circuit, to form water or other byproducts, depending on the specific fuel cell technology.

The movement of electrons through an external circuit from the anode to the cathode creates an electric current that can be utilized to power electrical devices or charge batteries.

Fuel cells offer several advantages, including high efficiency, low emissions, quiet operation, and modularity. They can be used in various applications, ranging from small portable devices to large-scale power generation systems. Additionally, fuel cells have the potential to use a variety of fuels, including hydrogen, methanol, natural gas, and even biomass.

I.9 Conclusion

In conclusion, this thesis focuses on optimizing an integrated renewable energy system for energy self-sufficiency in a rural farm in El Djelfa, Algeria. Through a thorough site assessment, evaluation of available renewable energy resources, and consideration of the farm's energy demands, an optimized and sustainable solution can be developed. The researchcontributes to knowledge and understanding of renewable energy integration in agricultural contexts, fostering energy independence, environmental stewardship, and long-term sustainability in rural communities.

This case study provides valuable insights into integrating renewable energy systems in rural farms, not only in El Djelfa, Algeria, but also in similar regions. The findings serve as a guideline for farmers and policymakers aiming to promote sustainable energy practices in agricultural settings.

Chapter II: Methodology for Renewable Energy System Analysis and Site Assessment

II.1 Introduction

This chapter lays the groundwork for the development and implementation of a Smart Farm with Zero Energy in the rural expanse of El Djelfa, Algeria. The success of this ambitious endeavor hinges on a meticulously crafted methodology that encompasses comprehensive site assessment, precise load analysis, and strategic system optimization. By integrating cutting-edge software applications, such as HOMER Pro and PVsyst, alongside a deep understanding of farm layout, meteorological data, and energy needs, this chapter serves as the cornerstone for achieving energy self-sufficiency in a resource-constrained environment. Through a systematic approach, we aim to chart a course towards a sustainable and resilient agricultural landscape

II.2 Site assessement

II.2.1 Farm layout and distribution of livestock and crop distribution

The present study focuses on the site assessment of a farm located in Ain El Bell, El Djelfa, Algeria. The farm is geographically positioned at coordinates 34.415 latitude and 3.2 longitude, with an elevation of 1092 meters.

To visually represent the farm layout, Sketchup software was employed, resulting in the creation of informative figures that illustrate the spatial arrangement of the farm. These figures offer valuable insights into the distribution and organization of livestock and crops within the farm premises

Figure II. 1 – Farm layout using Sketchup (top view).

The rural farm selected for this thesis encompasses a diverse range of livestock, including 30 cows, 120 sheep, 2000 chickens, and 5 horses. These animals form an integral part of the farm's operations and contribute to its overall productivity and sustainability. Their presence on the farm presents unique challenges and opportunities in managing their welfare, nutrition, and overall well-being. Through careful monitoring and implementation of effective husbandry practices, the farm aims to optimize the health and productivity of these livestock while maintaining a sustainable and environmentally conscious approach. The inclusion of different animal species adds to the complexity and significance of the integrated renewable energy system being developed to ensure a self-sufficient energy supply for the diverse needs of the farm's operations.

Figure II. 2 – Farm layout animal shelters side

As the previous figures illustrate the farm accommodates two houses, one serving as the primary residence for the farm owners, complete with a refreshing pool. The second house is designated for the three workers employed on the farm.

Figure II. 3 – Farm layout parking lot and main house side

Moreover, the presence of a well and a water tank ensures ample storage of water resources for the farm's needs. In addition, the farm also includes a parking lot to provide convenient parking spaces for vehicles on the premises, and storage units.

II.2.2 Meterological data

In this study, essential meteorological data was obtained using the photovoltaic geographic information system (PV-GIS) to accurately determine the site conditions of Ain El Bell (coordinates 34.415 latitude and 3.2 longitude). The PV-GIS platform facilitated the extraction of vital meteorological information to precisely characterize the site.

On February 5, 2023, the data extraction process was conducted, resulting in the acquisition of valuable parameters from the year 2010 until 2020, including monthly solar irradiation estimates and monthly average temperature. This comprehensive dataset enables a thorough analysis of the site's solar potential and climatic conditions, allowing for a more accurate assessment of renewable energy options and resource optimization for the agricultural farm.

The obtained results from the site are presented in the form of graphs which will providea visual depiction of the solar irradiation levels and average temperature variations.

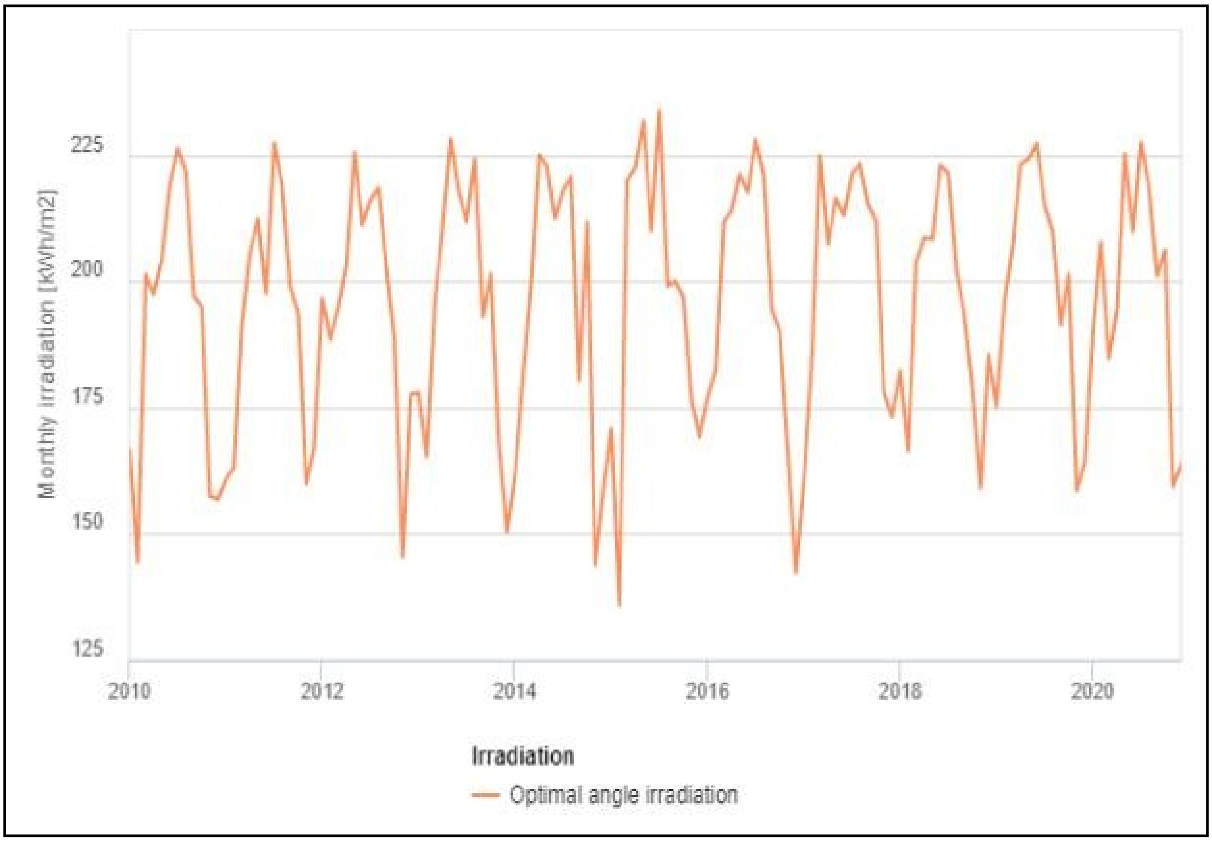


Figure II. 4 – Monthly solar irradiation between 2010 and 2020

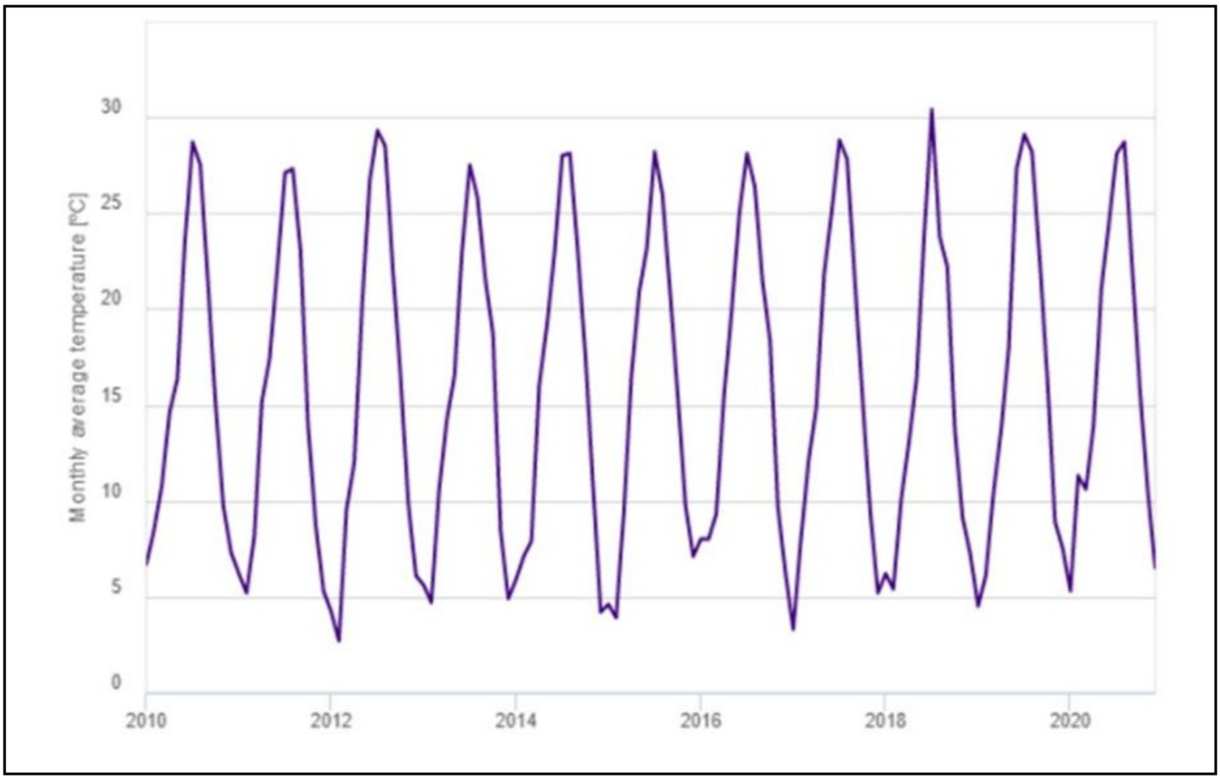


Figure II. 5 – Monthly average temperature between 2010 and 2020

Based on PV-gis, the solar irradiation levels at the study site were found to be 170 kWh/m² during the winter season and 230 kWh/m² during the summer season. These values represent the amount of solar radiation received per unit area. Additionally, the temperature ranges were observed to be between 1°C and 8°C during winter and between 18°C and 32°C during summer. Looking at these numbers we notice having relatively low temperature in comparison with the solar irradiation meaning that there's a good potential for energy production using solar pannels.

In regards to rainfall frequency, an illustrative figure is provided to depict the distribution of rainy days. The figure highlights a considerable number of rainy days, which holds significance when sizing solar pumping systems.

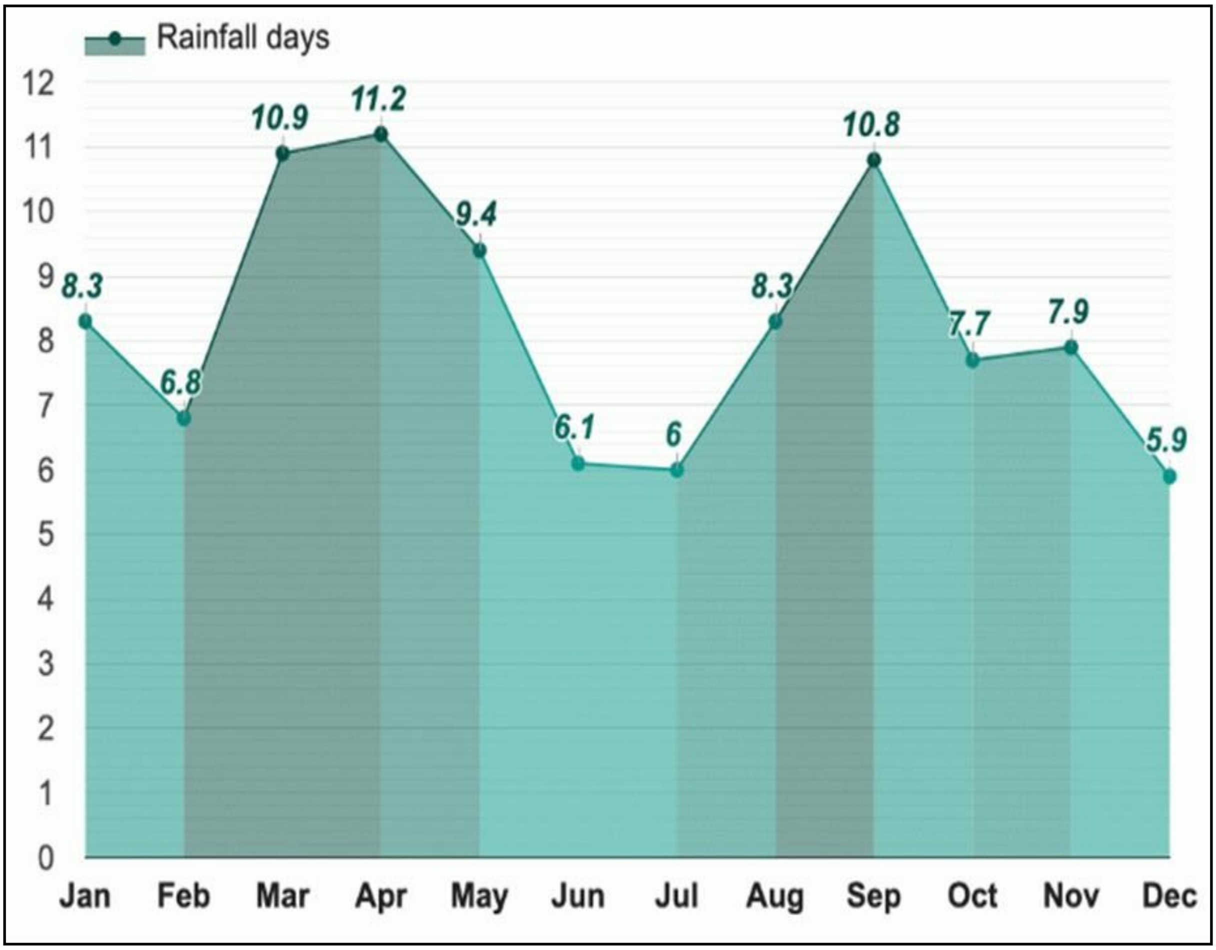


Figure II. 6 – Average rainfall days in El Djelfa, Algeria

II.3 Load

II.3.1 Electrical load

Understanding the electricity needs or energy load of a specific setting is essential for efficient energy management and resource allocation. In the case of our farm, we will be presenting the electrical load in the form of tables, providing a comprehensive overview of the electrical loads for each building individually.

A. Main house

The electrical load for the main house, accommodating 5 occupants, is detailed in the table below. This information is crucial for ensuring the provision of sufficient energy for household needs.

Table II. 1 – Main house electrical load

Appliances	Energy consumption (Watts) "E"	Number of appliances "N"	E*N	Daily usage time (hours) "T"	E x N x T
Refrigerator	**50**	**1**	**50**	**24**	**1200**
LED lamps	**15**	**12**	**180**	**1**	**180**
Kitchen appliances	**1500**	**1**	**1500**	**1**	**1500**
Tv	**120**	**2**	**240**	**4**	**960**
Computer	**200**	**2**	**400**	**2**	**800**
Miscellaneous	**1000**	**1**	**1000**	**1**	**1000**
Total			**3370**		**5640**

B. Workers house

Understanding the electrical load of the workers' residence is essential for effective energy distribution and management. Given that they primarily spend their day outside tending to the farm, their energy consumption is relatively lower. The table below provides a breakdown of these loads.

Table II. 2 – Workers house electrical load

Appliances	Energy consumption (Watts) "E"	Number of appliances "N"	E x N	Daily usage time (hours) "T"	E x N x T
Refrigerator	**50**	**1**	**50**	**24**	**1200**
Tv	**100**	**1**	**100**	**4**	**400**
Fan	**50**	**2**	**100**	**8**	**800**
LED lamps	**10**	**5**	**50**	**4**	**200**
Miscellaneous	**500**	**1**	**500**	**1**	**500**
Total			**800**		**3100**

C. Poultry house

In our efforts to enhance self-sufficiency, we've incorporated specific electrical machines in the poultry house. The following table outlines the electrical loads associated with this section, including equipment for optimal operation.

Table II. 3 – Poultry house electrical load

Appliances	Energy consumption (Watts) "E"	Number of appliances "N"	E*N	Daily usage time (hours) "T"	E x N x T
LED lamps	**18**	**60**	**1080**	**6**	**6480**
Fan	**300**	**8**	**2400**	**24**	**57600**
Automatic feeder	**100**	**1**	**100**	**1**	**100**
			3580		**64180**

D. Cow barn

Accurate knowledge of the electrical load in the cow barn is vital for optimizing energy resources. The subsequent table illustrates the load distribution for this area, tailored to the needs of our 30 cows.

Table II. 4 – Cow barn electrical load

Appliances	Energy consumption (Watts) "E"	Number of appliances "N"	E x N	Daily usage time (hours) "T"	E x N x T
LED lamps	**18**	**8**	**144**	**2**	**288**
Water pump	**750**	**1**	**750**	**2**	**1500**
Fan	**150**	**6**	**900**	**8**	**7200**
Automatic feeder	**100**	**1**	**100**	**1**	**100**
			1894		**9088**

E. • Sheepfold

The electrical load of the sheepfold, designed for 120 sheep, is presented below. This information is fundamental for ensuring an adequate and stable energy supply to this part of the farm.

Table II. 5 – Sheepfold electrical load

Appliances	Energy consumption (Watts) "E"	Number of appliances "N"	E x N	Daily usage time (hours) "T"	E x N x T
LED lamps	15	6	90	2	180
Water pump	500	1	500	1	500
Total			590		680

II.3.2 Water needs

Efficient water management is paramount in ensuring sustainable practices and meeting the diverse water needs of a farm. To this end, we present a comprehensive overview of the water requirements for various areas within our farm.

A. Animals

Understanding the water needs of our livestock is paramount for their well-being. With 30 cows, 120 sheep, and 2000 chickens, we've calculated their daily water consumption, ensuring they receive adequate hydration. The table below provides a comprehensive overview.

Table II. 6 – Animals water needs

Species	Water Consumption per Animal (liters/day)	Number of Animals	Total Water Consumption (liters/day)	Total Water Consumption (m2/day)
Cows	40	30	1200	1.2
Sheep	5	120	600	0.6
Chickens	0.5	2000	1000	1
Horses	40	5	200	0.2
Total			3000	3

B. Agriculture

Effective water management is essential for successful agricultural operations. By considering the water needs per hour for specific crops and the total area under cultivation, we've calculated the daily water requirements. The table below details these vital figures, enabling precise irrigation practices for optimal crop growth.

Table II. 7 – Irrigation water needs

Crop	Water Needs per Hour (m2/day)	Area (hectares)	Total Water Needs (liters/day)	Total Water Consumption (m2/day)
Olive Trees	**35**	**1**	**35000**	**35**
Diverse Trees	**40**	**1**	**40000**	**40**
Herbaceous crops	**45**	**1**	**45000**	**45**
Total				**120**

- **For the main house with 5 people:**

70 liters per day per person = 350 liters per day

- **For the house of the 3 workers:**

40 liters per day per person = 120 liters per day

- **For the swimming pool:**

The swimming pool in question possesses a radius of 2.75 meters, and 1.8 meters in depth, resulting in a total volume of approximately 43 cubic meters. It should be noted that this initial fill volume is not taken into account for the purposes of subsequent calculations. However, the pool necessitates a daily replenishment of water due to evaporation, with an estimated loss of approximately 4 millimeters from the upper surface. Consequently, the daily water replacement requirement amounts to 96 liters.

The total water needs are **123.7 cubic meters per day**.

II.4 Softwares

II.4.1 HOMER Pro

HOMER-Pro is a highly sophisticated and versatile software tool that excels in optimizing energy systems for various applications. Developed by the National Renewable Energy Laboratory (NREL) in Colorado, USA, HOMER-Pro offers comprehensive capabilities for designing, analyzing, and optimizing energy systems.(Awan et al., 2022)

With HOMER-Pro, users can simulate, model, and optimize both standalone and grid-tied systems. It is renowned for its ability to evaluate multiple energy resources and find the most efficient configurations to meet energy demands.(Shahzad et al., 2017)

HOMER-Pro integrates meteorological data provided by the National Aeronautics and Space Administration (NASA), allowing for accurate assessment of renewable resource potential at any location. By leveraging this data, users can make informed decisions about system design and resource utilization. (Awan et al. 2022).

The software operates through a series of steps that facilitate the design process. Users input site-specific data, including available resources, load profiles, and system components. HOMER-Pro then performs advanced simulations and optimizations, taking into account various sensitive variables.

The results provide detailed information on financial parameters, system performance, and optimal sizing, empowering users to make informed decisions.

II.4.2 PVsyst

PVsyst is widely recognized as a leading simulation software used in the industry. Created by Swiss scientist Andre Mermaid & Co., it has gained popularity among engineers worldwide due to its fast and efficient results. This software conducts thorough analyses on various factors that impact system efficiency, providing comprehensive insights. Moreover, PVsyst excels in performing regular estimations and generating detailed reports. Its precision closely aligns with real-world values, enhancing its reliability. Additionally, PVsyst incorporates user-friendly features like color-coding to indicate error messages and warnings.(Shrivastava et al., 2023).

II.5 Optimization of the systems

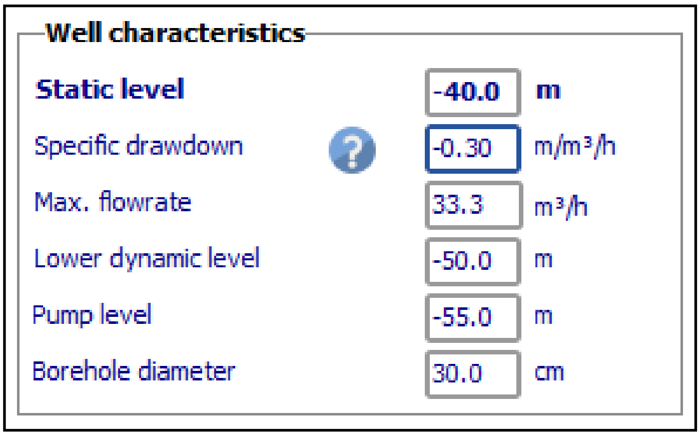
II.5.1 Water Pumping

The water pumping system employed for fulfilling the water requirements on the farm involved the utilization of a direct photovoltaic (PV) system. To determine the appropriate sizing of the system, the software tool PVsyst was utilized.

The water requirements amount to 123.7 cubic meters. To address this demand, a tank with a capacity of 150 cubic meters was employed. The tank is positioned at an elevation of 5 meters above the ground level and possesses a height of 5 meters.

Figure II. 7 – Water tank

A. Well characteristics



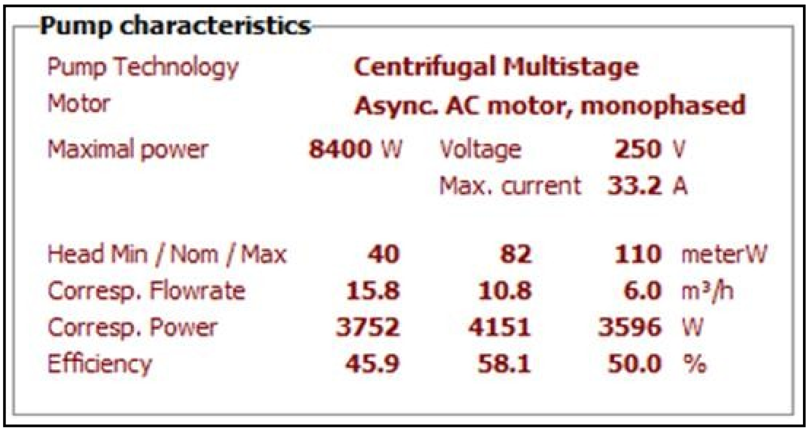
Well characteristics

Static level	**-40.0**	**m**
Specific drawdown	-0.30	m/m³/h
Max. flowrate	33.3	m³/h
Lower dynamic level	-50.0	m
Pump level	-55.0	m
Borehole diameter	30.0	cm

Figure II. 8 – Well characteristics captured from PVsyst software

B. Equipement choice

The selected pump for the system is an AC centrifugal pump from the manufacturer Lowara, specifically a 3.6 kW pump, possessing the following characteristics:



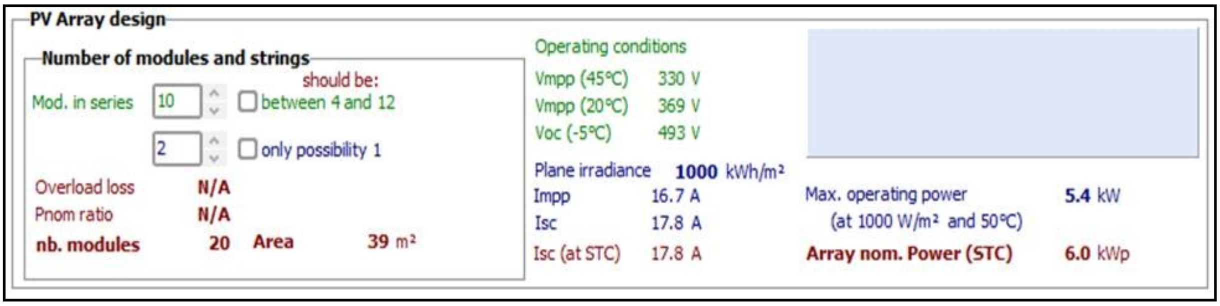
Pump characteristics

Pump Technology: **Centrifugal Multistage**
Motor: **Async. AC motor, monophased**
Maximal power **8400** W
Voltage **250** V
Max. current **33.2** A

Head Min / Nom / Max	**40**	**82**	**110**	meterW
Corresp. Flowrate	**15.8**	**10.8**	**6.0**	m^3/h
Corresp. Power	**3752**	**4151**	**3596**	W
Efficiency	**45.9**	**58.1**	**50.0**	%

Figure II. 9 – Pump characteristics captured from PVsyst software

To complete the system, an MPPT (Maximum Power Point Tracking) converter is integrated. As well as 300 w Polycristallin panels were used. These panels feature the following parameters illustrated in the figure



PV Array design

Number of modules and strings

Mod. in series: 10 ☐ should be: between 4 and 12
2 ☐ only possibility 1

Overload loss **N/A**
Pnom ratio **N/A**
nb. modules **20** **Area** **39** m^2

Operating conditions
Vmpp (45°C) 330 V
Vmpp (20°C) 369 V
Voc (-5°C) 493 V

Plane irradiance **1000** kWh/m^2
Impp 16.7 A
Isc 17.8 A
Isc (at STC) 17.8 A

Max. operating power (at 1000 W/m^2 and 50°C) **5.4** kW
Array nom. Power (STC) **6.0** kWp

Figure II. 10 – PV array designe

II.5.2 Water heaters sizing

Solar water heater sizing for residential application involves determining the appropriate system capacity to meet the hot water demand of the household. In the case of our farm, which accommodates 8 people, the desired hot water temperature is set at 45°C, with an estimated consumption rate of 50 liters per person.

$$B_j = 8*50 = 400 \text{ liters}$$

For safety purposes, it is recommended to have a hot water storage capacity that is 1.3 to 1.7 times the daily consumption of domestic hot water. In our case, we will choose a factor of 1.4.

$$C_{(j\,)} = B_j * 1.4 = 560 \text{ liters}$$

We start by calculating the daily energy input (Qj) required to heat the hot water using the formula:

$$Qj = Cj * 0.00116 * (Tf- \ Tc)$$

Where:

Qj: is the daily energy input required (in kWh per day).

Cj: is the daily consumption of domestic hot water (in liters per day)..

Tc: is the desired hot water temperature (in °C).
Tf: is the average ambient temperature (in °C).
0.00116: the conversion factor for the specific heat capacity of water (kWh/(kg·K)).

We take Tc = 20°C for the cold water temperature and Tf = 45°C as the recommended temperature for hot water in the context of domestic hot water systems.

- **Application:**

$$Qj = 560 * 0.00116 (45-20) = 16.24 \text{ KWh/day}$$

The annual energy input (Qa) can be calculated by multiplying the daily energy input by the number of days in a year (365):

$$Qa = Qj * 365$$

In our case the annual energy input would be:

$$Qa = 19.49 \ * 365 = 5927.6 \text{ kWh/year}$$

To determine the energy contribution from the solar collectors (Qcoll), we multiply the annual energy input (Qa) by the solar coverage percentage (Cs), solar coverage refers to the percentage of domestic hot water that will actually be produced using solar energy on average throughout the year. Typically, the optimal solar coverage falls within the range of 50% to 60%. This range ensures a balance between maximizing the utilization of solar energy and managing the cost of the installation.

We take **cs=0.6**

$$\mathbf{Qcoll = Qa*(Cs / 100) = 7112.85*0.6=3556.56\ Kwh/year}$$

$$\boldsymbol{\eta}\mathbf{inst = Qcoll / (Sth * Esol)}$$

Where:

- **Hinst:** Installation efficiency.
- **Qcoll:** Energy contribution from the solar collectors.
- **Sth:** Theoretical collector surface area.
- **Esol:** Solar irradiance received on an inclined surface of a thermal solar collector.

The conversion efficiency of solar collectors is approximately 50%, Considering the overall system efficiency, which takes into account factors such as heat exchanger efficiency and losses from piping, the total system efficiency (ηinst) is estimated to be 35% . (Pambudi et al., 2023)

According to PVGIS **Esol=2371.37kwh/ m²** per year in the site of study

$$\mathbf{Sth = Qcoll / (}\boldsymbol{\eta}\mathbf{inst * Esol)= 3556.56/(0.35*2371.37)= 4.28\ m^2}$$

The theoretical collector surface area (Sth) is defined for solar collectors that are installed facing due south and inclined at the latitude of the location. However, since the orientation and tilt of the collectors may not always be optimal throughout the year, it is necessary to consider correction factors for both the orientation (kor) and tilt (kti). By multiplying Stheorique by these correction factors, we obtain the effective surface area (Seff) of solar collectors to be installed (in square meters).

In summary:

$$\mathbf{Seff = Stheorique * kor * kti}$$

Where kor=1,09 and kti =1,04

$$\mathbf{Seff =4.28*1.09*1.04=4.85\ m^2}$$

II.6 Homer simulation

In the HOMER Pro simulation conducted for the integrated renewable energy system in El Djelfa, Algeria, a diverse range of renewable energy sources was incorporated. This comprehensive selection comprised PV panels, an electrolyser, a fuel cell, a wind turbine, biomass, batteries, and a diesel generator. The inclusion of these distinct renewable energy sources aimed to facilitate a comparative analysis of their individual performance within the integrated system. By evaluating the simulation results, the feasibility and suitability of employing each renewable energy source in the system can be assessed. This analysis not only enables a comprehensive understanding of their respective contributions but also provides valuable insights into their combined utilization for achieving energy self-sufficiency in the rural farm setting.

II.6.1 Proposed hybrid power system operating strategy

The proposed hybrid power system operating strategy encompasses various components and technologies to ensure efficient and reliable energy supply. The following figure represents the schematic of the total energy sources that we entered.

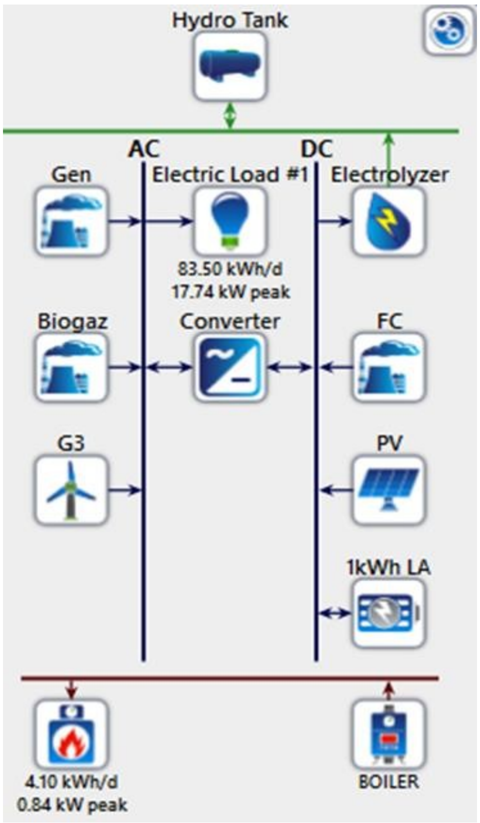
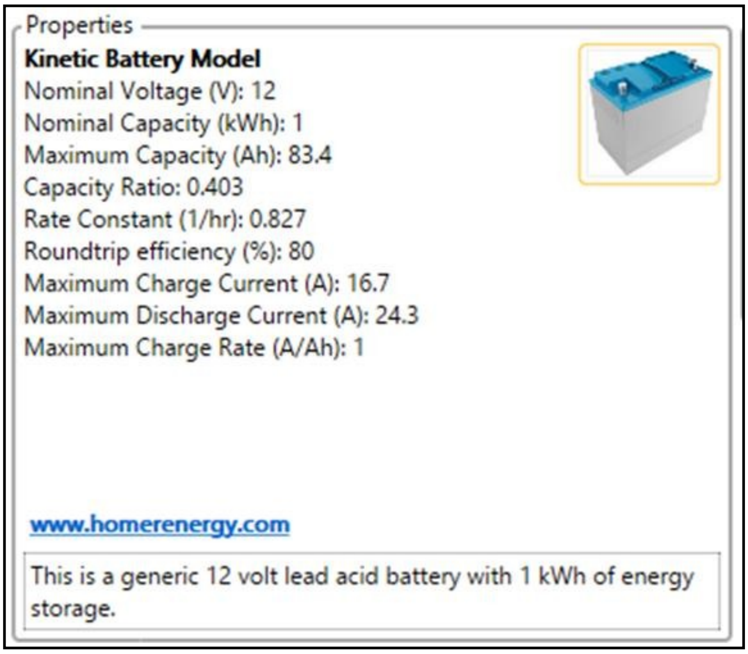


Figure II. 11 – Schematic of HOMER Pro system

The system includes an electrical load of 83.5 kWh/day, which serves as the basis for determining the power generation requirements. For this purpose, 300W PV panels are incorporated to harness solar energy and a 1 kWh lead-acid battery is utilized for energy storage with the following properties:



Properties

Kinetic Battery Model

Nominal Voltage (V): 12
Nominal Capacity (kWh): 1
Maximum Capacity (Ah): 83.4
Capacity Ratio: 0.403
Rate Constant (1/hr): 0.827
Roundtrip efficiency (%): 80
Maximum Charge Current (A): 16.7
Maximum Discharge Current (A): 24.3
Maximum Charge Rate (A/Ah): 1

www.homerenergy.com

This is a generic 12 volt lead acid battery with 1 kWh of energy storage.

Figure II. 12 – Battery propreties

To further enhance the system's capabilities, additional elements are introduced. A fuel cell and an electrolyzer are integrated to enable hydrogen production and storage in a dedicated tank. This enables the utilization of hydrogen as an energy source when required. Moreover, a biogas generator is implemented, utilizing biomass as a renewable energy source for power generation.

In addition to the solar and biogas components, wind turbines with a rated capacity of 3 kW are integrated into the system. This harnesses the power of wind to contribute to the overall energy generation. Furthermore, for comparison purposes, a diesel generator is also included in the system configuration.

It is important to note that alongside the electrical load, a thermal load and a boiler are incorporated into the system. However, their inclusion will not impact the overall results as they are present in all system configurations.By combining these various components and technologies, the proposed hybrid power system aims to optimize energy generation, storage, and utilization. The integration of renewable energy sources, along with backup options such as the diesel generator, ensures a reliable and sustainable power supply for the specified electrical load. The system's flexibility and adaptability make it well-suited for meeting the energy needs of the rural farm while minimizing reliance on non-renewable resources.

In the context of the proposed hybrid power system, it is important to note that HOMER Pro software is utilized for system simulation and optimization. HOMER Pro incorporates its own meteorological data for solar radiation, wind speed, and temperature. These data are derived from reliable sources, including NASA predictions and worldwide energy resources databases.

II.7 Conclusion

In summary, Chapter II forms the bedrock for realizing a Smart Farm with Zero Energy in El Djelfa, Algeria. Through a systematic approach, we've assessed the site, analyzed energy needs, and optimized systems. By considering farm layout, weather data, and using specialized software like HOMER Pro and PVsyst, we've laid a solid groundwork for sustainable energy integration. This chapter marks a pivotal step towards a greener future in agriculture, showcasing the potential of renewable energy systems.

Chapter III: Results and Discussion of Integrated Renewable Energy System Optimization

III.1 Introduction

In this chapter, the results and analysis of the HOMER simulation, as well as the solar pumping results using PVsyst, are presented. These simulations provide comprehensive insights into the performance, feasibility, and optimization of the integrated renewable energy system in the context of the rural farm.

The HOMER simulation results reveal the energy production potential and system efficiency of various configurations. The analysis considers different factors, such as the sizing of solar panels, wind turbines, and energy storage systems, to maximize energy self-sufficiency and minimize costs. The simulations enable a thorough evaluation of the system's ability to meet the specific energy demands of the rural farm, including the powering of irrigation systems, livestock management, and other agricultural activities.

Moreover, the cost analysis provides a comprehensive assessment of the economic viability of the integrated renewable energy system. It considers the initial investment costs, operation and maintenance expenses, and potential long-term cost savings associated with the utilization of renewable energy sources. These findings contribute to informed decision-making regarding the financial feasibility and long-term sustainability of the system.

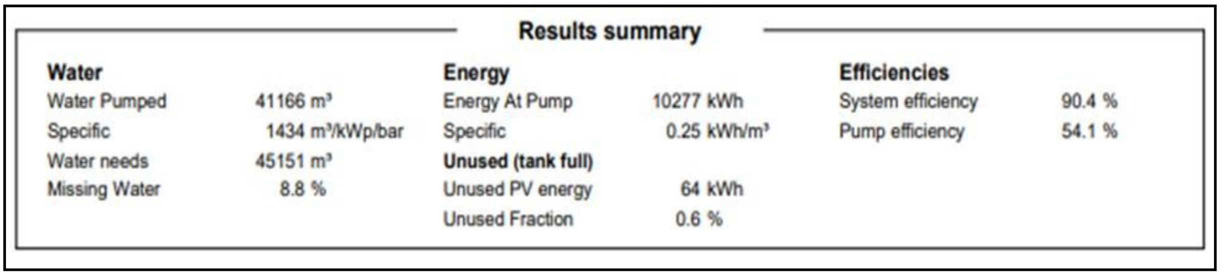
In addition to the HOMER simulation, the solar pumping results using PVsyst are discussed. These results provide valuable insights into the performance and efficiency of the solar pumping system. The analysis considers parameters such as solar irradiation, panel tilt angle, and pump specifications to optimize the pumping process and ensure the continuous supply of water to meet the farm's needs.

By examining both the HOMER simulation and the solar pumping results using PVsyst, a comprehensive evaluation of the integrated renewable energy system's performance, efficiency, and sustainability is achieved. These findings serve as a basis for further optimization and implementation, ultimately contributing to energy self-sufficiency, cost-effectiveness, and environmental sustainability in the rural farm setting

III.2 Interpretation of PVsyst simulation

After conducting the simulation using PVsyst software, we will start with a result summary. The detailed report generated by PVsyst provides comprehensive insights and analysis, serving as a valuable resource for evaluating the performance of the integrated renewable energy system. The result summary offers a concise overview of key findings, including solar photovoltaic performance, energy production and system efficiency.

This summary serves as a starting point for further analysis and discussion of the results obtained.



Results summary

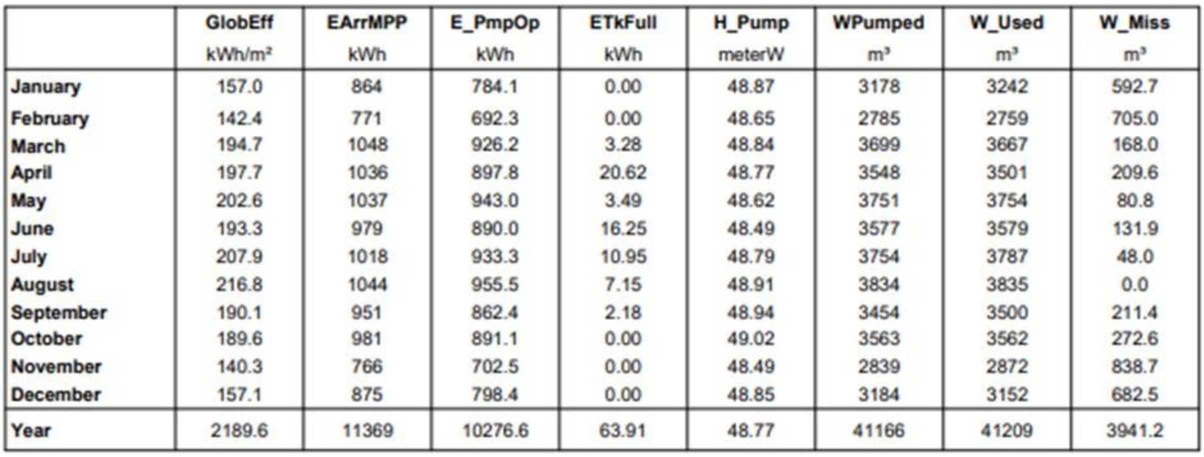
Water		**Energy**		**Efficiencies**	
Water Pumped	41166 m³	Energy At Pump	10277 kWh	System efficiency	90.4 %
Specific	1434 m³/kWp/bar	Specific	0.25 kWh/m³	Pump efficiency	54.1 %
Water needs	45151 m³	**Unused (tank full)**			
Missing Water	8.8 %	Unused PV energy	64 kWh		
		Unused Fraction	0.6 %		

Figure III. 1 – Results summary

III.2.1 Missed water

The following table presents the main results obtained throughout the year, with a specific focus on the last column indicating the missed power. This column reflects the instances where the integrated renewable energy system was unable to meet the energy demand of the farm. The missed power serves as an important indicator of system performance and highlights the areas that require further optimization. By analyzing the missed power values, we can identify periods of high energy demand and assess the effectiveness of the system in meeting those demands.

Table III. 1 – Balances and main results



	GlobEff kWh/m²	EArrMPP kWh	E_PmpOp kWh	ETkFull kWh	H_Pump meterW	WPumped m³	W_Used m³	W_Miss m³
January	157.0	864	784.1	0.00	48.87	3178	3242	592.7
February	142.4	771	692.3	0.00	48.65	2785	2759	705.0
March	194.7	1048	926.2	3.28	48.84	3699	3667	168.0
April	197.7	1036	897.8	20.62	48.77	3548	3501	209.6
May	202.6	1037	943.0	3.49	48.62	3751	3754	80.8
June	193.3	979	890.0	16.25	48.49	3577	3579	131.9
July	207.9	1018	933.3	10.95	48.79	3754	3787	48.0
August	216.8	1044	955.5	7.15	48.91	3834	3835	0.0
September	190.1	951	862.4	2.18	48.94	3454	3500	211.4
October	189.6	981	891.1	0.00	49.02	3563	3562	272.6
November	140.3	766	702.5	0.00	48.49	2839	2872	838.7
December	157.1	875	798.4	0.00	48.85	3184	3152	682.5
Year	2189.6	11369	10276.6	63.91	48.77	41166	41209	3941.2

Upon careful analysis, it is evident that the month of November experiences a relatively higher amount of missed water, which can reach up to 800 m². However, it is worth noting that this discrepancy in power supply does not pose a significant problem. As previously mentioned, the region of El Djelfa, Algeria, receives relatively high rainfall rates, particularly during winter months. This abundant rainfall acts as a supplementary source of energy, compensating for the insufficient energy during the month of November.

Furthermore, it is important to emphasize that our integrated renewable energy system is designed to ensure the necessary water quantity during the summer months. Whilethere may be a slight shortfall in power supply during the summer, it does not hinder the system's ability to meet the water requirements of the farm. The resilience and reliability of oursystem enable us to maintain a consistent water supply, supporting the agricultural operations even during periods of higher energy demand.

By considering the local climatic conditions and implementing appropriate measures, such as utilizing rainwater harvesting systems, our integrated renewable energy system offers a sustainable and robust solution for addressing energy and water needs throughout the year. This holistic approach ensures the farm's self-sufficiency, mitigates potential energy shortfalls, and maintains an uninterrupted water supply for successful agricultural activities

III.2.2 Loss diagram

The loss diagram provides valuable insights into the energy lost throughout the entire conversion process. However, for our specific analysis, we are primarily concerned with the final result.

It indicates that we have successfully supplied 91.3 percent of the water needs. This achievement is significant, considering the rainfall patterns in El Djelfa. By optimizing our integrated renewable energy system, we have found the best option that allows us to economize costs while precisely meeting the farm's water requirements.

Taking into account the relatively high rainfall in El Djelfa, our system's performance aligns with the goal of sustainability and efficiency. By leveraging renewable energy sources and optimizing their utilization, we strike a balance between cost-effectiveness and providing the farm with the necessary water supply. This approach ensures that the farm's operations can thrive while minimizing energy losses and maximizing resource utilization.

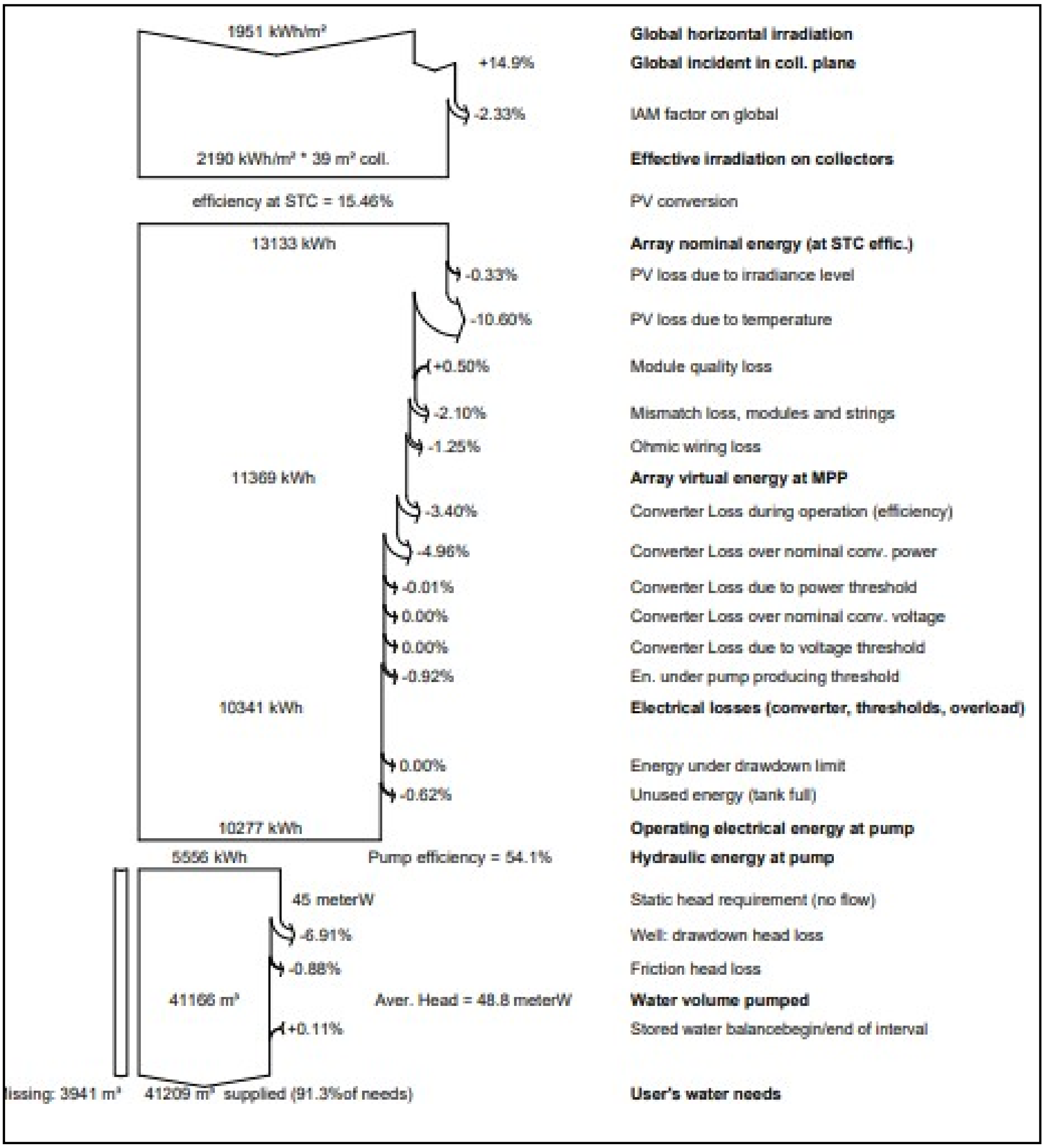


Figure III. 2 – Loss diagram from PVsyst report

Over all, the results demonstrate the effectiveness of our integrated renewable energy system in meeting the water needs of the farm. The careful consideration of local conditions, including rainfall patterns, allows us to strike an optimal balance between resource availability and consumption. This achievement not only supports the farm's sustainability goals but also showcases the potential for similar systems to be implemented in other agricultural settings.

III.3 Interpretation of HOMER Pro Simulation

The interpretation of the HOMER Pro simulation for the integrated renewable energy system in El Djelfa, Algeria provides valuable insights into the performance and feasibility of the proposed system. By analyzing the simulation results, based on Cost-Benefit Analysis, payback period, a Comparative Analysis of the First and Tenth Systems Proposed by HOMER as well as The Carbon Emissions and the Impact on the environment. Additionally, the interpretation of these results allows for an evaluation of the system's ability to achieve energy self-sufficiency and its reliability in meeting the energy demands of the rural farm. Through a detailed examination of the simulation outcomes, this section aims to uncover the strengths and limitations of the integrated renewable energy system design, as well as identify potential areas for further optimization. The interpretation of the HOMER Pro simulation results serves as a foundation for the subsequent comparison of different system configurations and the formulation of informed recommendations for the rural farm in El Djelfa, Algeria.

III.3.1 Homer pro results

The HOMER simulation has provided valuable insights into the optimization and evaluation of different system configurations for the integrated renewable energy system. The objective of this analysis is to identify the most efficient, cost-effective, and sustainable solutions for achieving energy self-sufficiency in the rural farm setting.

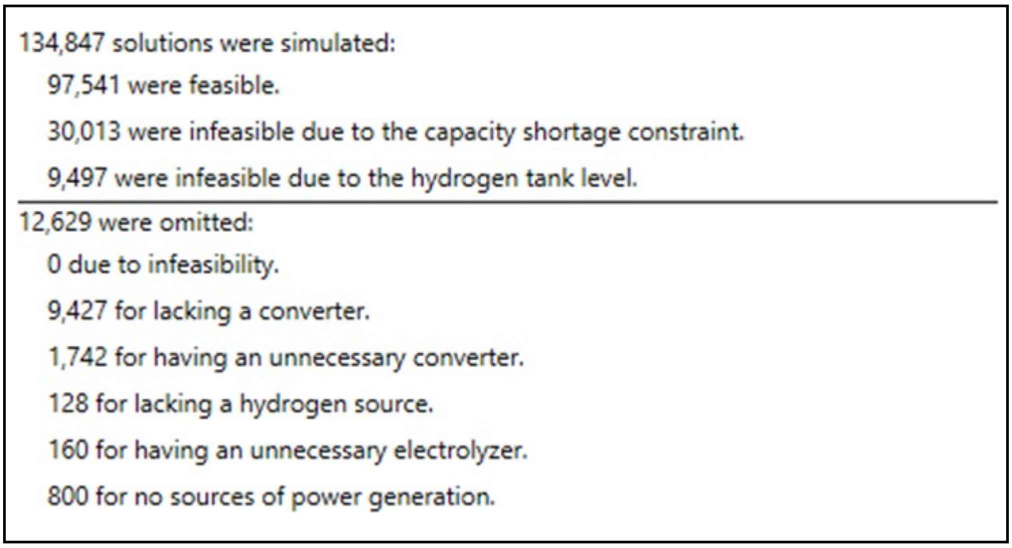
In this section, we present an overview of the different system configurations proposed by HOMER, which encompass a range of renewable energy sources, energy storage options, and backup power alternatives. Each system configuration has been carefully designed to meet the specific energy demands of the farm while considering factors such as resource availability, system reliability, and economic feasibility.

Through a thorough analysis and comparison of these proposed systems, we can evaluate their performance in terms of energy production, cost-effectiveness, and environmental sustainability. This will provide valuable insights and inform decision-making processes regarding the selection and implementation of the most suitable system configuration for achieving energy self-sufficiency in the rural farm.

In the following sections, we will present the different system configurations proposed by HOMER, highlighting their key components, energy generation capabilities, and economic considerations. By examining the results and analysis of these system configurations, we can gain a deeper understanding of the potential solutions that can pave the way towards a sustainable and self-sufficient energy future for the rural farm in El Djelfa, Algeria.

- **Calculation report**

We will begin by presenting the calculation report, which involved the simulation of an extensive number of system configurations. A total of 134,847 solutions were simulated to evaluate their feasibility and performance within the context of the integrated renewable energy system. It is noteworthy that out of these solutions, 97,541 were deemed feasible and met the specified criteria, as illustrated in the figure provided within the calculation report.



134,847 solutions were simulated:
  97,541 were feasible.
  30,013 were infeasible due to the capacity shortage constraint.
  9,497 were infeasible due to the hydrogen tank level.

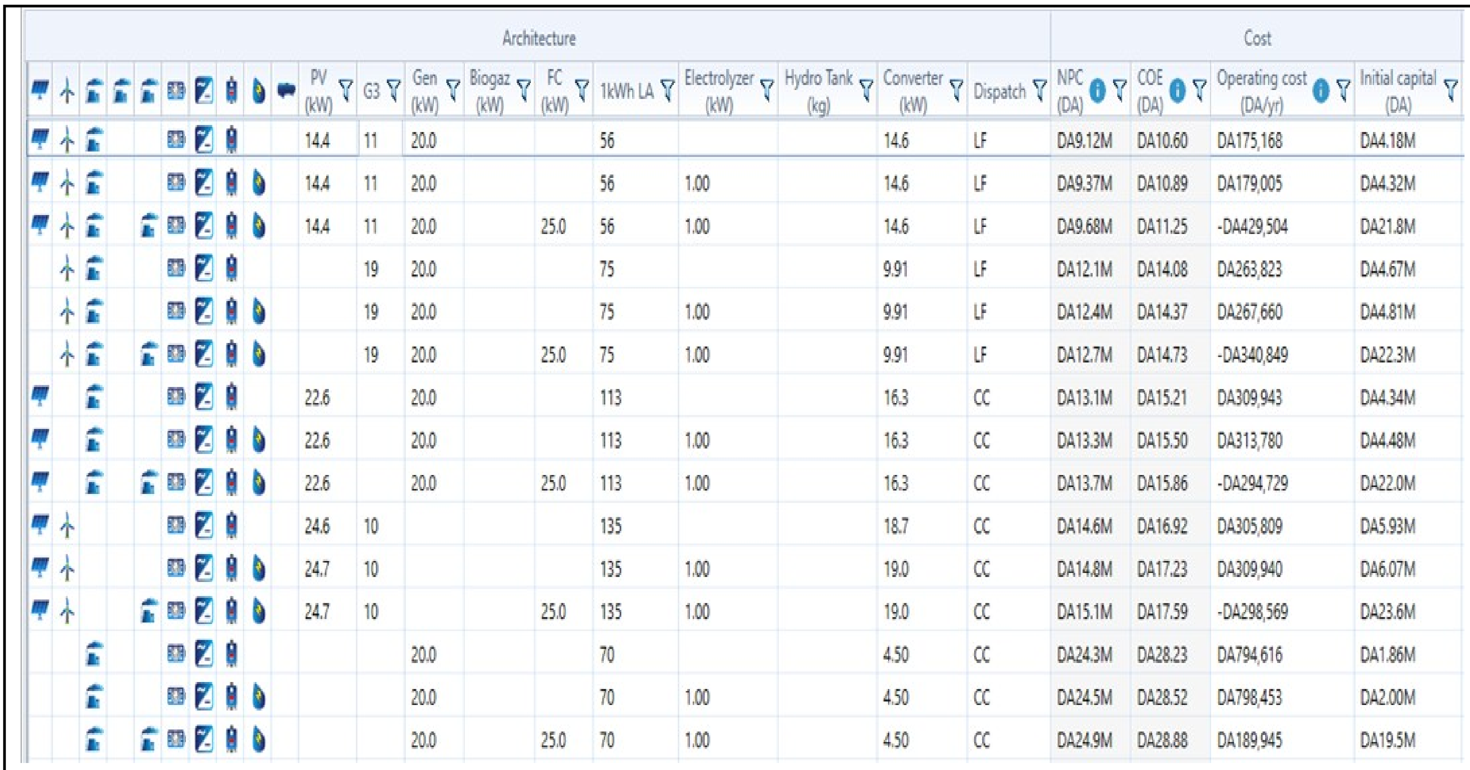
12,629 were omitted:
  0 due to infeasibility.
  9,427 for lacking a converter.
  1,742 for having an unnecessary converter.
  128 for lacking a hydrogen source.
  160 for having an unnecessary electrolyzer.
  800 for no sources of power generation.

Figure III. 3 – HOMER Pro calculation report

The calculation report serves as a comprehensive analysis of the system configurations generated through the simulation process. It explores a wide range of possibilities, accounting for different combinations of renewable energy sources, energy storage options, and backup power alternatives. By considering numerous parameters and constraints, the report identifies viable solutions that align with the objectives of achieving energy self-sufficiency and optimizing system performance.

- **Feasible configurations**

The following figure provides a visual representation of the simulated solutions and highlights the feasible configurations. It offers a clear overview of the possibilities explored within the simulation, emphasizing the breadth of the analysis conducted. The visualization helps to discern the diversity and complexity of the system configurations considered and serves as a starting point for further examination and evaluation. The first 15 feasible simulations, sorted in ascending order based on the cost of electricity, are presented below. These simulations represent system configurations that have met the specified criteria and are economically viable options for achieving energy self-sufficiency in the rural farm setting.



Architecture										Cost			
PV (kW)	G3	Gen (kW)	Biogaz (kW)	FC (kW)	1kWh LA	Electrolyzer (kW)	Hydro Tank (kg)	Converter (kW)	Dispatch	NPC (DA)	COE (DA)	Operating cost (DA/yr)	Initial capital (DA)
14.4	11	20.0			56			14.6	LF	DA9.12M	DA10.60	DA175,168	DA4.18M
14.4	11	20.0			56	1.00		14.6	LF	DA9.37M	DA10.89	DA179,005	DA4.32M
14.4	11	20.0		25.0	56	1.00		14.6	LF	DA9.68M	DA11.25	-DA429,504	DA21.8M
	19	20.0			75			9.91	LF	DA12.1M	DA14.08	DA263,823	DA4.67M
	19	20.0			75	1.00		9.91	LF	DA12.4M	DA14.37	DA267,660	DA4.81M
	19	20.0		25.0	75	1.00		9.91	LF	DA12.7M	DA14.73	-DA340,849	DA22.3M
22.6		20.0			113			16.3	CC	DA13.1M	DA15.21	DA309,943	DA4.34M
22.6		20.0			113	1.00		16.3	CC	DA13.3M	DA15.50	DA313,780	DA4.48M
22.6		20.0		25.0	113	1.00		16.3	CC	DA13.7M	DA15.86	-DA294,729	DA22.0M
24.6	10				135			18.7	CC	DA14.6M	DA16.92	DA305,809	DA5.93M
24.7	10				135	1.00		19.0	CC	DA14.8M	DA17.23	DA309,940	DA6.07M
24.7	10			25.0	135	1.00		19.0	CC	DA15.1M	DA17.59	-DA298,569	DA23.6M
		20.0			70			4.50	CC	DA24.3M	DA28.23	DA794,616	DA1.86M
		20.0			70	1.00		4.50	CC	DA24.5M	DA28.52	DA798,453	DA2.00M
		20.0		25.0	70	1.00		4.50	CC	DA24.9M	DA28.88	DA189,945	DA19.5M

Figure III. 4 – HOMER Pro results

III.3.2 Systems analyse

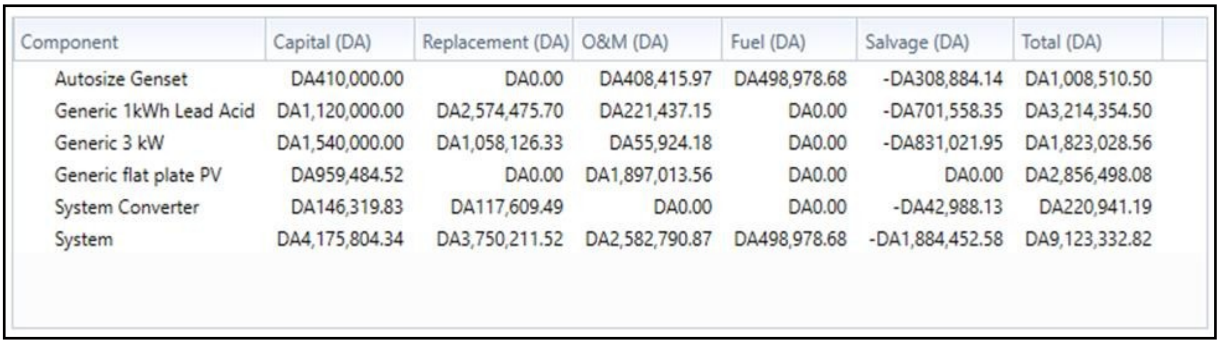
a) Simulation 1

Simulation 1 presents a system configuration that combines 14.4 kW of solar PV panels and11 wind turbines as the primary sources of renewable energy. The system is designed to meet the energy demands of the rural farm while incorporating a storage component of 56 kWh battery bank to store excess energy.

In order to ensure a reliable power supply, Simulation 1 includes a 20 kW diesel generatoras a backup option. This backup generator serves as a supplementary power source during periods of low renewable energy generation or when the battery bank is depleted, ensuring uninterrupted electricity supply.

One notable aspect of Simulation 1 is that it does not rely entirely on renewable energy sources. Despite this, it stands out as the most cost-effective option among the simulations. Thismay be attributed to the relatively low fuel prices in Algeria, making the cost of electricity in this system competitive compared to systems that solely rely on renewable energies.

A detailed cost summary table is provided to analyze the financial aspects of Simulation 1. This table breaks down the various costs associated with the system, including initial investment costs, maintenance expenses, and fuel costs for the diesel generator. It offers a comprehensiveview of the economic feasibility of the integrated system, providing valuable insights into the overall cost-effectiveness and potential long-term savings.



Component	Capital (DA)	Replacement (DA)	O&M (DA)	Fuel (DA)	Salvage (DA)	Total (DA)
Autosize Genset	DA410,000.00	DA0.00	DA408,415.97	DA498,978.68	-DA308,884.14	DA1,008,510.50
Generic 1kWh Lead Acid	DA1,120,000.00	DA2,574,475.70	DA221,437.15	DA0.00	-DA701,558.35	DA3,214,354.50
Generic 3 kW	DA1,540,000.00	DA1,058,126.33	DA55,924.18	DA0.00	-DA831,021.95	DA1,823,028.56
Generic flat plate PV	DA959,484.52	DA0.00	DA1,897,013.56	DA0.00	DA0.00	DA2,856,498.08
System Converter	DA146,319.83	DA117,609.49	DA0.00	DA0.00	-DA42,988.13	DA220,941.19
System	DA4,175,804.34	DA3,750,211.52	DA2,582,790.87	DA498,978.68	-DA1,884,452.58	DA9,123,332.82

Figure III. 5 – Cost summary of system 1

Overall, Simulation 1 represents a cost-effective solution that combines renewable energy sources with a backup diesel generator. While it may not achieve complete reliance onrenewable energies, its affordability makes it an attractive option for achieving energy self- sufficiency in the rural farm. The detailed cost summary table further supports the economic viability of this system and contributes to a comprehensive analysis of its financial implications.

b) Simulation 2 to 9

Simulations 2 to 9 showcase similar system configurations with the inclusion of a diesel generator, batteries, and a converter. The main distinction among these simulations lies in the balance between different renewable energy sources, such as solar PV panels, wind turbines, and the integration of a fuel cell and electrolyser. Each system exhibits a slight increase in cost compared to the previous simulation.

While these systems offer variations in the combination and proportion of renewable energy sources, none of them present a unique or distinctive feature that sets them apart significantly.The focus primarily remains on achieving the desired energy self-sufficiency and minimizing the reliance on conventional energy sources.

It is worth noting that the absence of a standout characteristic does not diminish the importance of these simulations. Each configuration contributes to the exploration of potentialsystem designs and aids in evaluating the performance, feasibility, and cost-effectiveness of the integrated renewable energy systems.

The analysis of Simulations 2 to 9 allows for a comprehensive comparison between different combinations of renewable energy sources. The slight price increase in each system reflects the additional benefits and capabilities provided by incorporating specific renewable energy technologies. These simulations collectively contribute to the understanding of optimalsystem configurations in terms of cost and renewable energy utilization.

Overall, while none of the simulations possess a distinct advantage, the cumulative analysisof Simulations 2 to 9 provides valuable insights into the effectiveness and viability of integrating renewable energy sources in achieving energy self-sufficiency for the rural farm.

c) Simulation 10

Simulation 10 introduces the first system configuration consisting solely of renewable energy sources. It comprises 24.6 kW of solar PV panels, 10 wind turbines, and a battery bankwith a capacity of 135 kWh using lead-acid batteries. The cost of electricity for this system is estimated to be 16.92 Algerian dinars (DA) per kilowatt-hour (kWh).

One of the most significant advantages of Simulation 10 is its zero emissions characteristic.By relying entirely on renewable energy sources, this system ensures a clean and sustainable power supply for the rural farm. This aligns with the goal of reducing carbon footprint and promoting environmental sustainability.

The cash flow chart for Simulation 10 provides a comprehensive overview of the financial aspects associated with the system. It illustrates the capital investment required for the initial setup, which may be relatively high due to the inclusion of renewable energy technologies. However, once established, the annual cost deposition is remarkably low, indicating minimal ongoing expenses except for periodic replacements, typically occurring every 10 years.

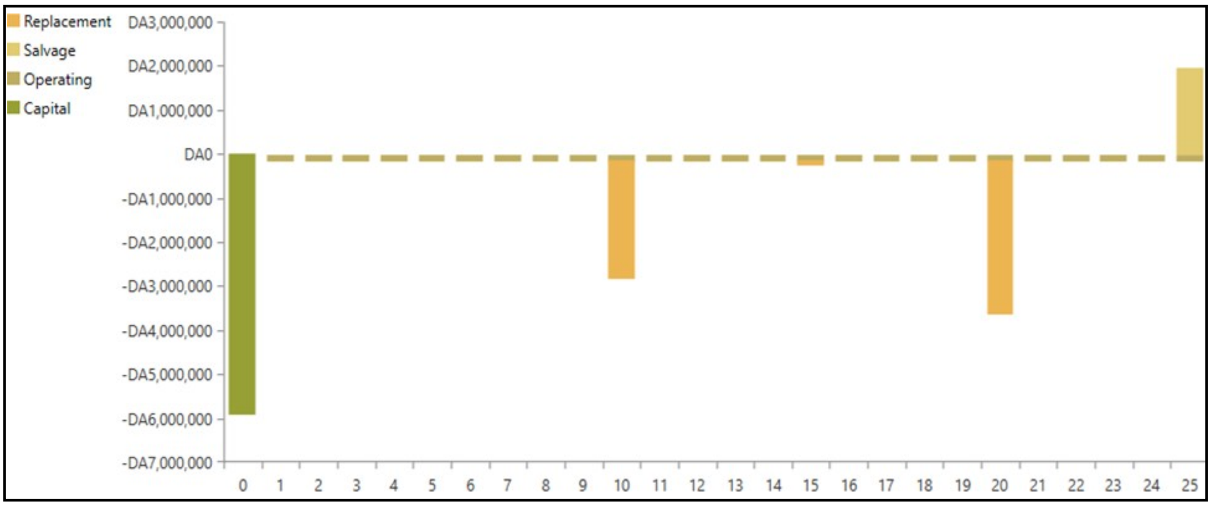


Figure III. 6 – Cash flow chart

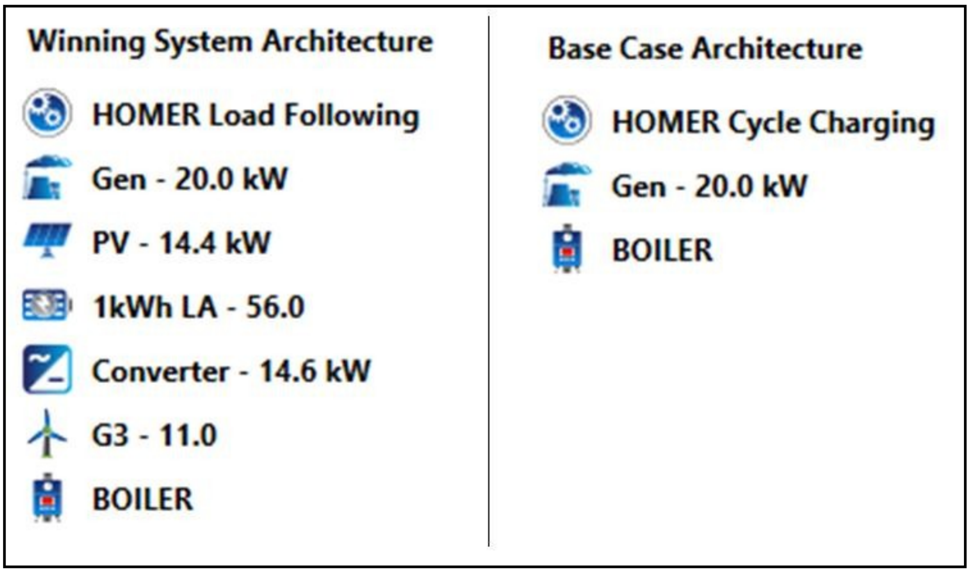
This cash flow pattern reflects the long-term cost benefits of implementing a renewable energy system. While the initial capital investment may be higher compared to conventional energy systems, the low annual cost deposition and extended lifespan of the components contribute to significant cost savings in the long run.

Simulation 10 exemplifies the potential of renewable energy systems to achieve energy self-sufficiency while minimizing environmental impact. The absence of emissions ensures a cleaner and healthier environment, and the cashflow analysis highlights the financial benefits of adopting renewable energy technologies over time.

Overall, Simulation 10 serves as a notable example of a renewable energy system that offers both environmental sustainability and long-term cost advantages for the rural farm.

III.3.3 Cost-Benefit Analysis of the Base Case Architecture and Proposed Renewable Energy System

This section presents a detailed cost-benefit analysis comparing the base case architecture, comprising a diesel generator and a boiler for thermal load, with the proposed renewable energy system recommended by the HOMER software. The objective is to assess the economic feasibility and long-term financial performance of both systems within the context of the ruralfarm in El Djelfa, Algeria.



Winning System Architecture

HOMER Load Following
Gen - 20.0 kW
PV - 14.4 kW
1kWh LA - 56.0
Converter - 14.6 kW
G3 - 11.0
BOILER

Base Case Architecture

HOMER Cycle Charging
Gen - 20.0 kW
BOILER

Figure III. 7 – Winning system architecture and the base case architecture

As demonstrated in the figure below, the initial system cost analysis reveals that the base case architecture has a lower upfront investment compared to the renewable energy system.

However, when interpreting the results, it is important to consider the long-term financial implications and potential cost savings offered by the renewable energy system.

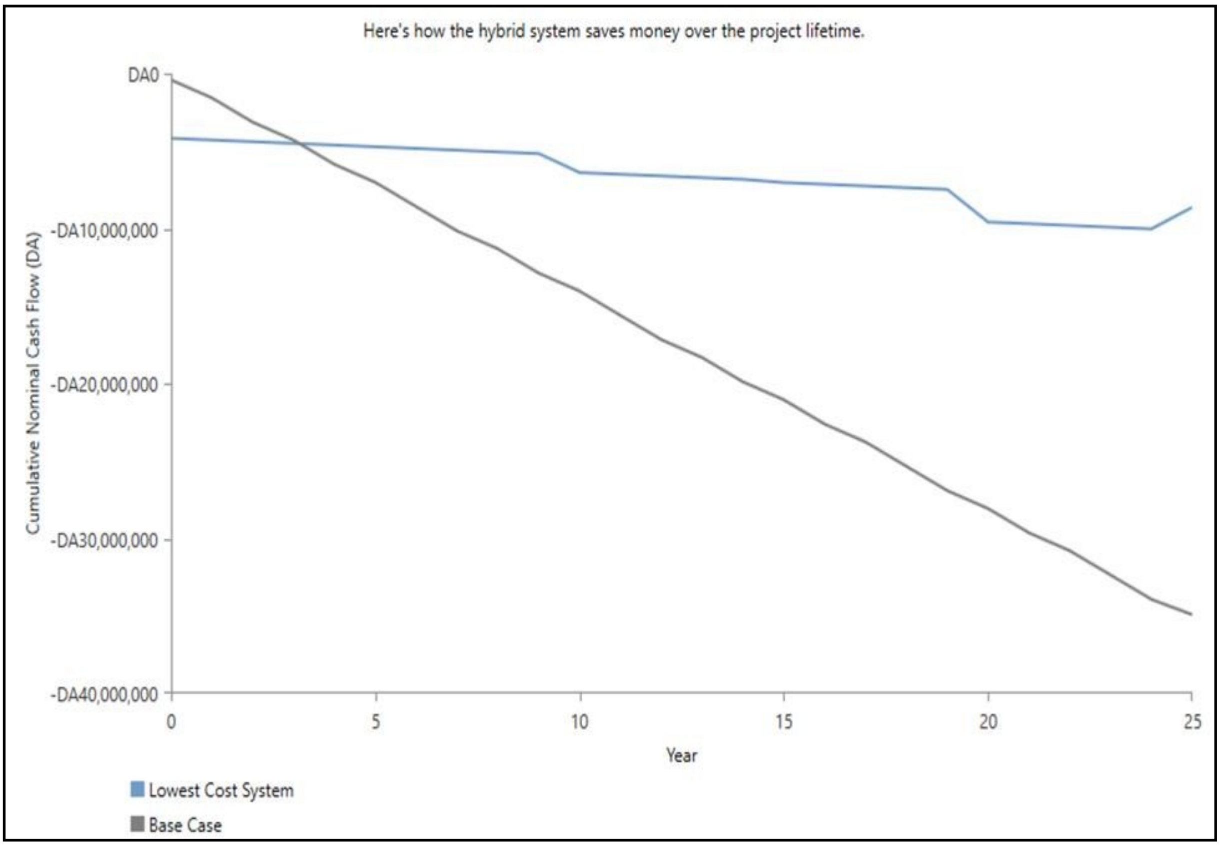
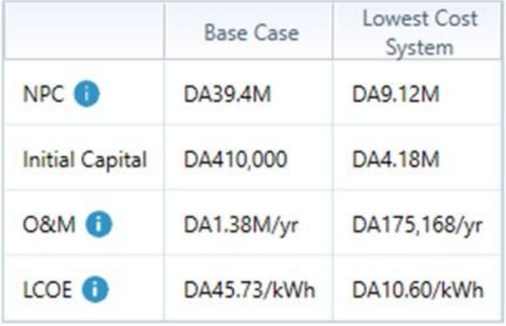


Figure III. 8 – Cost comparison between the base case and the optimized system on the courseof 25 years

The payback period analysis indicates that the renewable energy system is projected to recoup its initial investments within a relatively short period of 3.1 years. This findingdemonstrates the system's efficiency in generating energy and reducing reliance on external sources. Over a 25-year timeframe, the renewable energy system is expected to achieve significant cost savings of over 25,000,000 Algerian dinars compared to the base case.

To provide a comprehensive overview of the economic comparison between the base case architecture and the proposed renewable energy system, a cost summary table is presented below. This table outlines the key cost components, including initial investment, operational and maintenance costs, The net present cost (or life-cycle cost) ,and LCOE which is is the average cost per kWh of useful electrical energy produced by the system., for both the base case and the renewable energy system over a 25-year timeframe.

Table III. 2 – Cost summary



	Base Case	Lowest Cost System
NPC	DA39.4M	DA9.12M
Initial Capital	DA410,000	DA4.18M
O&M	DA1.38M/yr	DA175,168/yr
LCOE	DA45.73/kWh	DA10.60/kWh

The superior cost-effectiveness of the renewable energy system can be attributed to its utilization of abundant renewable energy sources, such as solar panels, wind turbines, and biomass, along with energy storage capabilities provided by batteries. This integration enablesthe system to operate with a higher level of self-sufficiency, reduced dependence on fossil fuels,and improved resilience to price fluctuations.

In addition to the cost factors, the analysis takes into account operational and maintenance costs, fuel expenses, and potential environmental benefits, such as reduced greenhouse gas emissions associated with the renewable energy system.

The interpretation of the cost-benefit analysis results suggests that while the base case architecture initially incurs lower costs, the renewable energy system proves to be more financially advantageous in the long run. Its ability to recoup investments within a short periodand generate substantial cost savings over a 25-year timeframe underscores its superiorfinancial performance and viability for the rural farm in El Djelfa, Algeria. These findings highlight the importance of considering long-term economic benefits and sustainability when making energy system decisions in rural areas.

By interpreting the results of the cost-benefit analysis, it becomes evident that the proposed renewable energy system offers significant economic advantages and represents a promising solution for achieving energy self-sufficiency in the rural farm in El Djelfa, Algeria.

III.3.4 Comparative Analysis of the base case system and Tenth System Proposed by HOMER

The comparative analysis between the base case system, which relies solely on fossil fuels, and the Tenth System proposed by HOMER, which utilizes only renewable energies, reveals distinct differences in terms of cost and economic viability, an illustrative figure is included.

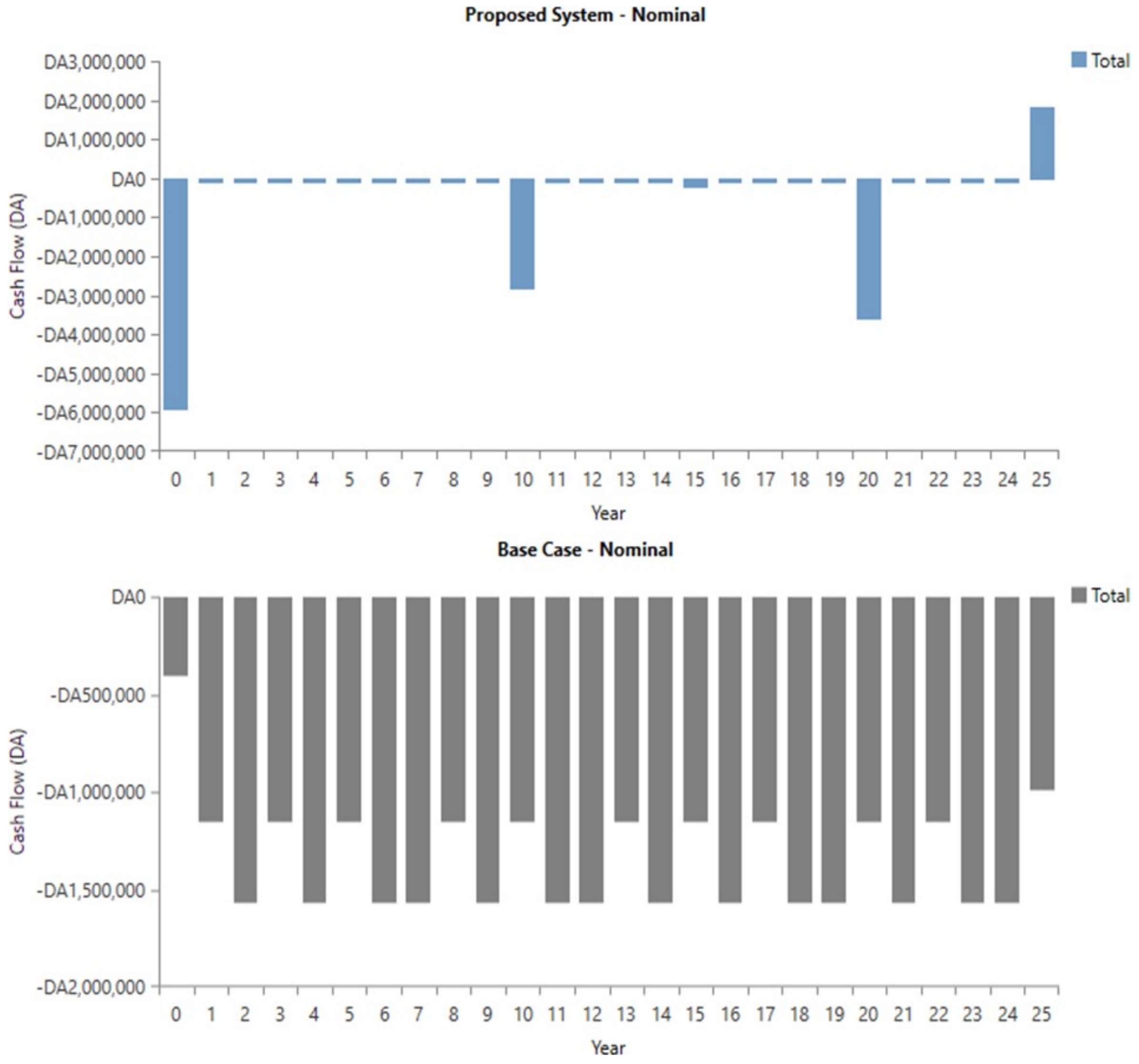


Figure III. 9 – Economics comparisson between fossil fuel system and renewable energy system

The base case system initially presents a lower investment cost, primarily due to the relianceon conventional fossil fuels. However, as time progresses, the accumulation of fuel prices becomes a significant factor, resulting in higher operational costs throughout the year. This ongoing expense can impact the financial sustainability of the base case system, as fuel prices are subject to fluctuations and potential increases in the future.

In contrast, the Tenth System, based on renewable energies, incurs a higher initial investment cost. This is primarily attributed to the incorporation of renewable energy technologies and the necessary infrastructure. However, once the system is established, the operational costs become minimal, with no recurring fuel expenses. Instead, the system requires periodic replacements, typically occurring twice during its projected lifespan of 25 years. These replacements account for the majority of the cost, but they are spread out over an extended period, resulting in lower annual costs compared to the base case system.

The economic comparison is visualized through charts that illustrate the economics of both systems. These charts provide a comprehensive understanding of the cost dynamics, considering factors such as initial investment, operational expenses, and replacements. They highlight the long-term cost advantages of the renewable energy system, as well as the potential cost volatility associated with fossil fuel-based systems.

Overall, the comparative analysis underscores the economic benefits of transitioning from the base case system, reliant on fossil fuels, to the Tenth System based on renewable energies.While the initial investment cost may be higher, the absence of fuel expenses and the lower annual costs contribute to long-term financial sustainability. Moreover, the reliance on renewable energies ensures a more stable and environmentally friendly energy supply, reducingthe dependence on fossil fuels and mitigating the associated risks of price fluctuations and environmental impact.

III.3.5 Comparative Analysis of the First and Tenth Systems Proposedby HOMER

In the comparative analysis between the first systems proposed by HOMER Pro, incorporating a combination of renewable energy sources, and the base case architecture relyingsolely on a diesel generator, notable differences were observed in terms of cost and environmental impact. A side by side representation of the 2 systems will offer a clear perspective on their architecture and cost.

Architecture											Cost			
PV (kW)	G3	Gen (kW)	Biogaz (kW)	FC (kW)	1kWh LA	Electrolyzer (kW)	Hydro Tank (kg)	Converter (kW)	Dispatch	NPC (DA)	COE (DA)	Operating cost (DA/yr)	Initial capital (DA)
14.4	11	20.0			56			14.6	LF	DA9.12M	DA10.60	DA175,168	DA4.18M
24.6	10				135			18.7	CC	DA14.6M	DA16.92	DA305,809	

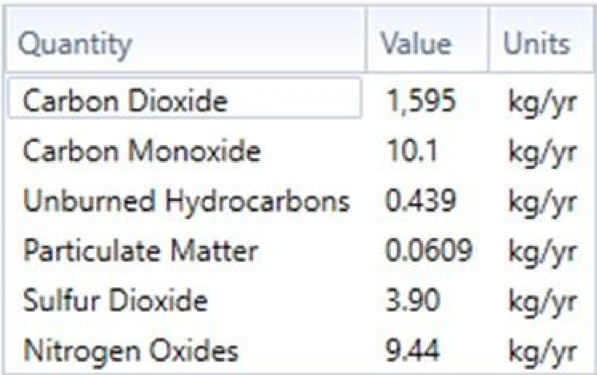
Figure III. 9 – Optimized homer system and all renewable energy system

The renewable energy system, as per the simulation results, exhibited a cost of 16.92 Algerian dinars per kilowatt-hour (16.92 DZD/kWh). In contrast, the first system proposed byHOMER Pro showcased a lower cost of 10.6 Algerian dinars per kilowatt-hour (10.6 DZD/kWh). This cost disparity between the two systems amounted to 6.32 Algerian dinars per kilowatt-hour (6.32 DZD/kWh).

However, it is crucial to consider the environmental implications alongside the cost analysis. While the renewable energy system achieved zero emissions, the base case architecture relyingon the diesel generator emitted approximately 1.595 kilograms of carbon dioxide per, in addition to other emissions. This significant difference in carbon emissions underscores the favorable environmental impact of the renewable energy system, contributing to the reductionof carbon footprint and fostering a cleaner and more sustainable environment.

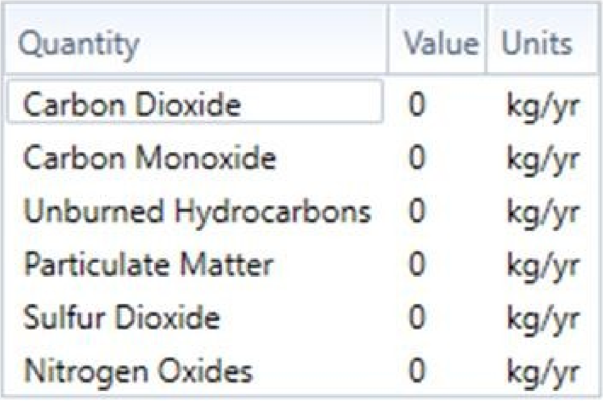
Two figures are presented below. These figures enable a side-by-side comparison, visually illustrating the emissions of each system.

Table III. 3 – Emissions of HOMER optimized system



Quantity	Value	Units
Carbon Dioxide	1,595	kg/yr
Carbon Monoxide	10.1	kg/yr
Unburned Hydrocarbons	0.439	kg/yr
Particulate Matter	0.0609	kg/yr
Sulfur Dioxide	3.90	kg/yr
Nitrogen Oxides	9.44	kg/yr

Table III. 4 – Emission of the all renewable energies system



Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

Taking into account both the cost and environmental aspects, the renewable energy system emerges as a more compelling choice, despite the higher cost per kilowatt-hour. The ability ofthe renewable energy system to mitigate carbon emissions aligns with the growing global emphasis on transitioning to cleaner energy alternatives and sustainable practices. The findings of this comparative analysis highlight the importance of considering both economic and environmental factors when evaluating energy system options.

III.3.6 Interpretation of Renewable Energy System with Biomass: Leveraging Animal Waste for Sustainable Energy Generation

In addition to the previously discussed systems, the interpretation of a renewable energy system with biomass offers further insights into its economic viability and potential benefits. The system incorporates a biogas generator that converts biogas derived from animal waste into electricity. However, it is important to note that the biogas generator contributes to the higher cost of the biomass system, which is estimated at 64.26 Algerian dinars per kilowatt (64.26 DZD/kW).

Comparing the biomass system with the previously examined renewable energy systems,it becomes evident that it carries a higher cost due to the expenses associated with the biogas generator. While the higher cost may initially seem prohibitive, it is essential to consider the availability and cost of alternative energy sources for heating and cooking.

In this context, the utilization of animal waste for biogas production represents a significant advantage. Animal waste, readily available in rural farms, serves as a free and abundant resource for biogas generation. By relying on animal waste for the production of biogas used in heating and cooking, the biomass system can offer substantial cost savings in terms of fuel expenses.

The integration of animal waste as a renewable energy source contributes to a circular economy approach, where organic waste is transformed into useful energy, reducing environmental impacts and promoting sustainability. Additionally, by replacing traditional fossil fuel-based sources, such as wood or charcoal, with biogas for heating and cooking, the biomass system enables a cleaner and healthier living environment.

While the biomass system may involve higher upfront costs due to the biogas generator, the utilization of animal waste for biogas production brings long-term economic benefits and enhanced sustainability. The cost savings achieved by utilizing free and readily available resources for heating and cooking purposes can outweigh the initial investment.

III.3.7 Conclusion

The simulations conducted using PVsyst have demonstrated a commendable level of sufficiency in meeting our water intake requirements. With the integrated renewable energy system in place, we can confidently assert that the optimal system has been achieved. The combination of renewable energy sources, complemented by natural replenishment from rain and the substantial storage capacity of our water tank, ensures that we consistently meet our water needs. This integrated approach allows us to effectively manage our resources, especially during periods of varying weather conditions.

In considering the Homer Pro simulation, the first system, while being a combination of renewable and non-renewable energies, presents a dilemma. It emerges as the most cost-effective option but carries a significant environmental cost due to its polluting nature. The slight difference in cost between this option and the all-renewable energy system is overshadowed by the substantial difference in emissions. Consequently, the decision to adopt the all-renewable energy system becomes evident. It not only minimizes our environmental impact but also offers a more sustainable path forward for our farm. This choice not only aligns with our commitment to responsible energy practices but also represents a prudent financial investment, with the marginal increase in cost being far outweighed by the reduction in emissions

General Conclusion: The Future of Renewable Energy in Rural Algeria

In conclusion, the implementation of an integrated renewable energy system in a rural farm in El Djelfa, Algeria holds tremendous promise for achieving energy self- sufficiency and promoting sustainable development. The findings derived from the HOMER Pro simulation have provided invaluable insights into the cost-effectiveness and environmental benefits of renewable energy systems when compared to conventional diesel generators.

Although the initial system cost for the base case architecture, incorporating a diesel generator and a boiler for thermal load, may appear more economical, a closer examination reveals that the renewable energy system has a compelling payback period.Within a relatively short period of 3.1 years, the renewable energy system is projected to recoup its initial investments. Moreover, over the course of 25 years, it is estimated to generate substantial cost savings exceeding 25,000,000 Algerian dinars compared to the base case. This long-term economic advantage firmly establishes the superiority of the renewable energy system in terms of cost-effectiveness and financial viability.

Beyond economic considerations, the renewable energy system offers notable environmental benefits. By replacing fossil fuel-based energy sources with renewable alternatives, such as solar panels, wind turbines, and biomass, the system achieves a significant reduction in carbon emissions. The comparison between the renewable energy system and the base case architecture reveals that while the renewable energy system emits zero carbon dioxide and other harmful emissions, the base case architecture emits a considerable amount of carbon dioxide along with other pollutants.This stark contrast underscores the positive environmental impact and the potential for carbon footprint reduction through the adoption of renewable energy systems.

The integration of renewable energy systems in rural areas, particularly in Algeria,holds immense potential for enhancing energy security, reducing dependence on imported fossil fuels, and promoting sustainable development. The findings from this study provide a compelling case for the wider adoption of renewable energy systems inrural farms and communities. By leveraging abundant renewable resources and implementing effective system design and optimization, rural areas in Algeria can achieve energy self-sufficiency, reduce greenhouse gas emissions, and foster a cleaner and more sustainable future.

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