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Spécialité : Génie énergétique

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Centre d'Etudes Doctorales : Sciences et Techniques de l'Ingénieur

Titre de la thèse : Intégration des énergies renouvelables en agriculture au MAROC.

Nom et prénom du candidat : Abdel Ali Mana

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Résumé de la thèse

Le Maroc est fortement dépendant des sources d'énergie conventionnelles et des importations d'énergie qui accroissent son indépendance. À cet égard, nous pensons que les énergies renouvelables et leurs applications en agriculture entraîneront de nombreux avantages socio-économiques et environnementaux. Surtout, que le Maroc est doté de ressources abondantes et que les technologies du monde entier deviennent matures, fiables et rentables.

Dans cette optique, la thèse explore la possibilité d'intégrer des applications innovantes d'énergies durables au Maroc, ce qui pourrait contribuer à promouvoir la durabilité dans le secteur agricole. L'objectif général est d'identifier le nexus entre les préoccupations environnementales mondiales et le besoin pour l'agriculture de continuer à produire tout en consommant moins d'énergie sagement et produire de l'énergie propre.

Une étude approfondie a été menée, sur la gestion de l'eau en agriculture en optant pour des systèmes de pompage solaire. L'approche implique une perspective à plusieurs niveaux pour capturer les facteurs potentiels et les barrières du pompage solaire dans l'agriculture marocaine. Trois investigations sont menées : une analyse d'études de cas, une analyse comparative des coûts, et l'analyse détaillée (SWOT). L'approche projetée peut servir de référence pour les études d'évaluation de la gestion de l'eau au Maroc, en particulier pour des programmes de développement social et agro-économique ambitieux dans les zones reculées.

Ceci est suivi par l'étude de la biomasse agricole et valorisation des systèmes de cogénération. Les résultats de la performance dans la région de Sais, ont montré que seul avec les résidus d'olivier, les systèmes électriques inclus ont le potentiel de production d'électricité à 254 252 foyer. En effet, les centrales de cogénération offrent un LCOE de 15,03 cents/kWh respectivement, ce qui est exceptionnellement compétitif par rapport à la technologie solaire concentrée et aux ressources fossiles. Cette section se termine avec des études de sensibilité et paramétriques pour mettre en évidence des paramètres opérationnels et financiers clés ayant l'effet le plus influent sur les indices de performance de la technologie et son intégration à large échelle.

Finalement, ce travail aborde une approche transdisciplinaire qui relie l'agriculture, l'énergie, de l'intelligence Artificielle et de la durabilité, afin d'identifier les principales lignes directives vers une agriculture sécurisée.

Mots clés : Agriculture, Biomasse, Durabilité, Energie, Intelligence Artificielle, Renouvelable, Pompage.

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"Opportunities to Integrate renewable energies in agriculture, Morocco"

Morocco is highly dependent on conventional energy sources and imports, which increase its independence. In this regard, we believe that renewable energies and their applications in agriculture will bring many socio-economic and environmental benefits. Above all, that Morocco is endowed with abundant resources, and technologies are becoming mature, reliable, and profitable.

Thus, this thesis explores the possibility of integrating innovative applications of sustainable energies in Morocco, which could contribute to promoting sustainability in the agricultural sector. The overall goal is to identify the nexuses between global environmental concerns and the need for agriculture to continue producing while consuming less energy wisely and producing clean energy.

An in-depth study was carried out on water management in agriculture by opting for solar pumping systems. The approach involves a multi-level perspective to capture the potential drivers and barriers of solar pumping in Moroccan agriculture. Three investigations are carried out: an analysis of case studies, a comparative cost analysis, and the detailed analysis (SWOT). The proposed approach can serve as a reference for water management assessment studies in Morocco, in particular for ambitious social and agro-economic development programs in remote areas.

This is followed by the study of agricultural biomass and valuation of cogeneration systems. The results of the performance in the region of Sais, showed that alone with the olive tree residues, the included electrical systems have the potential to generate electricity at 254,252 households. Indeed, cogeneration plants offer an LCOE of 15.03 cents/kWh respectively, which is exceptionally competitive compared to concentrated solar technology and fossil resources. This section ends with sensitivity and parametric studies to better highlight operational and financial parameters. It is necessary to select the most influencing effect on the performance indices of the technology.

Finally, this work addresses a trans-disciplinary approach that links agriculture, energy, artificial intelligence and sustainability, in order to identify the main guidelines to a clean and secure agriculture.

Keywords: Agriculture, Artificial Intelligence, Biomass, Energy, Pumping, Renewable, Sustainability.

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To Sarati, my Mother and the Earth-mum.

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Acronyms

A.I: Artificial Intelligence,
ADEREE: Agency for the Development of Renewable Energy and Energy Efficiency
AfDB : African Development Bank
AI : Artificial Intelligence
ANN : Artificial neural network
CCHP : Combined Cooling, Heating and Power
CDER : Renewable Energy Development Centre
CHP : Combined Heat and Power
CIP : Inter ministerial Committee on Prices
CSP : Concentrating Solar Power
DC : Direct-coupled
DL : Deep Learning
EIB : European Investment Bank
ETP : Evapotranspiration
FDE : Energy Development Fund
GDP : Gross Domestic Product
IEA : International Energy Agency
IOT : Internet of Things
IPCC : Intergovernmental Panel on Climate Change
IPP : Independent Power Production
IRESEN : Institute for Renewable Energy Research and Development
IWR : Irrigation Water Requirement
LCOE : Levelized Cost of Electricity
LCOW : Levelized Cost of Water
M2M : Machine to Machine
MAGG : Ministry of General Affairs and Governance
MENA : Mediterranean Arab countries
ML : Machine Learning
NRTs: New Renewable Technologies
ONEE : National Electricity and Water Board
PA : Precision Agriculture
PMV : Green Morocco Plan
PNRC : National Plan to Combat Global Warming
PPP : Public and Private Partnerships
PR : Performance Ratio
RPAS :Remotely Piloted Aircraft System
SSSA :Secured Smart Sustainable Agriculture, 14
UAA : Useful Agricultural Area
UAV : Unmanned Aerial Vehicles
UNESCO : United Nations Educational, Science and Culture Organization
WB : World Bank

CHAPTER 1:

General Introduction

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I. Chapter

I. 1 Introduction

I.1.1 Background and motivation

Agriculture today faces serious challenges, including climate change, water scarcity and the dependence of production costs on fossil fuels [1]. In addition, the COVID-19 pandemic threatens the entire agricultural value chain [2]. At present, these confrontations are seen as an obvious reality. In fact, the impacts are strongly interlinked and agriculture is at the heart of this challenge. Agriculture is also the main global driver of global warming and, at the same time, the most affected by these changes [3].

However, it is agreed that energy is an important element of rural socio-economic development, and is therefore the mainstay of all services offered by the agricultural sphere, such as pumping for irrigation and drinking water, food preparation and drying and all daily activities. In general, the increase in the demand for energy (*in quantity as well as in quality*) is severely linked to socio-economic development.
However, rural populations in many developing countries have been excluded from most of the benefits of sustainable development and energy transition [4]. After the Kyoto Protocol and COP22, little seems to have changed; but the truth is that traditional energy sources (firewood, biomass waste, human and animal traction) remain the main and often the only energy resources available to millions of rural families [5].
Over the last decade, climate change has been the topic of interest. Currently, it is considered an evident reality and impacts greatly agriculture, water supply, and our ecological sphere [6] [7]. In fact, the impacts are strongly related and agriculture is situated at the heart of this challenge [8]. Agriculture is also the world largest driver of global warming [9] and, at the same time, the most affected by these changes [10]. Thus, a global agricultural transition is urgently needed to overcome the linearity of conventional evaluation methodologies which perceives farms as factories and counts plants and animals as industrial units [11]. This energetic transition is the key step to rely on energy efficiency and restores social metabolism [12]. The challenge is further complicated by the need not only to produce more, but also to sustain the entire food supply chain much more efficiently and reduce waste which has reached unacceptable proportions [13]. Intensive agriculture transforms landscapes, degrades biodiversity and boosts genetic erosion. It pollutes the air, hydraulic sources and puts human and animal health at peril [14], [15].

In this sense, sustainable agriculture is the result of a balanced solution to many productive, technological, environmental and economic problems [16]. Among these, improving energy efficiency and reducing greenhouse gas emissions are vital. As agriculture becomes an energy intensive consumer, an urgent call is needed to achieve a circular economy and sustainable goals [17]. Interestingly, agriculture has the unique potential to mitigate global warming and build the resilience of renewable solutions to the impacts of climate change. In addition, many organizations and initiatives are monitoring food security by creating the infrastructure for distinct groups of stakeholders to come together to address economic, social and environmental issues [18], [19]. For this to happen, agriculture must continue to produce while protecting the environment, and without depleting ecosystems. It is time to find new solutions and technologies to consume less fossil fuel and to use clean, renewable natural sources whose potential is almost infinite. On the one hand, agriculture is a favorableplatform for the use and integration of renewable energies on a large scale. On the
Other hand, farmers will have the opportunity to diversify their energy mix and relieve their bills. The renewable energies that can be developed in the countryside are numerous and diversified.

The overall objective of the thesis is therefore to identify the nexus between global environmental concerns and the need for agriculture to continue to produce while consuming less energy wisely and producing clean energy.

Could the primary agricultural sector be one of the precursors for the development of new energies in rural Morocco?

In this study the same focus is put on energy as a means and not as a usable end, with particular attention to the potential of renewable energy to be used for agricultural and rural development, especially for income generating activities, as a basis for sustainable rural development and a new societal perspective. Energy (*electricity*) and water have been identified as important drivers for Moroccan agriculture. The two forms of energy are also related through junction in their production and consumptionin agriculture known as the food-water-energy nexus [20].

I.1.2 Aims, Goals and novelty

The main objective of this study is to help to better understand the potential impact and the opportunity to integrate renewable energy for agriculture and rural and sustainable development, in particular agriculture in Morocco. The following researchtopics have been defined: Indeed, it is very important to determine the (potential) contribution of renewable energy systems to rural development, with the aim of generating greater economic and political engagement in favor of a successful agricultural metabolism.

- *What are the main applications of New Renewable Technologies (NRTs) now, particularly for revenue generating activities?*
- *What are the potential impacts of these systems?*
- *What are the advantages and disadvantages of these systems compared to other technologies?*
- *What can we learn from bibliography, key people and project reviews, maximizing the impact of NRTs systems on rural development?*

This study generates a framework based on the energy-water-food link in the development of agriculture and rural communities. Water management and the production of energy from biomass and agricultural waste can potentially reduce the economic and environmental impacts, thus meeting the water and energy needs of the rural population. In order to achieve this energy transition, the study aims to deepen knowledge of the following principles:

- Biomass systems can lead to rural socio-economic development specifically, the combined heat and power systems (*CHP*)are studied as a contribution to income-generating rural activities and as an instrument for the implementation of a high-value-added electricity, for the social benefits it entails.
- Various specific applications of PV systems for productive use can be widely replicated. But agriculture depends strongly on water, thus maturity of solar pumping systems is discussed and evaluated to face climate change and successive droughts.

- Artificial Intelligence (*A.I*) concerns for sustainable agriculture and renewable energies integration.

Aware of the absence of an integrated assessment of agricultural sustainability and these renewable systems in Morocco, this project aims to assess the technical economic and environmental issues of the multiple solutions of energy and water management in off-grid applications. Thus Scientists, researchers and farmers need to focus on modern techniques that will be cost-effective and more productive in dealing with the actual crisis. The point of view of this work is that the ecological transition and the digital transition can meet on the issue of sustainable agriculture. As well as, renewables energies have the potential to provide elements to improve agriculture and sustain the production. We also discuss the current challenges and limitations facing these technological systems, as well as their future perspectives for large-scale integration and achieving Secured Smart Sustainable Agriculture (*SSSA*). The main novelties of the research include:

- Development of scenarios for energy production, and management of irrigation water in agriculture; -agricultural sustainability assessment and water and energy supply scenarios for the studied region.

- A field survey on the possibility of integrating renewable energy for the production of heat and electricity in agricultural activities in Morocco.

- Technical economic viability and validation of reliable irrigation configurations for family farming.

- Technical economic analysis of electricity production by valuing olive tree waste.

- A survey review on the use of artificial intelligence in agriculture, and potentials solutions to achieve SSSA in morocco.

The choice of the area study is crucial. In this thesis is, the Fes-Meknes agro-pole (Sais region) is selected. This region has a wealth of favorable renewable resources resulting from both its geographical location and climatic conditions, but also from itswealth of resources from agricultural biomass.

The Fes-Meknes region occupies a strategic position. Overlooking Europe to the north and bordering Algeria to the east, this region is predestined to play the role of a crossroads for communication and exchanges in the Maghreb and Europe and to form a link between Africa and Europe. Thus, taking into account the favorable climatic conditions for most crops, the region of Fez-Meknes has a great diversity of plant and animal productions, in addition to the existence of an important the food industry. The agricultural plain of the Saïss, located in the Sebou basin, which covers 40,000 km ^{2} of surface area, representing 6% of the national territory, and contains 30% of Morocco's surface water resources [21]. This region thus presents itself as a witness to the possibilities of integrating renewable energies into agriculture and the limits that may exist to their implementation within a territory. Thus the transformation of the energy-intensive agricultural sector into an energy producer and the bearer of energy projects. This region is therefore a witness to the possibilities of integrating renewable energies into agriculture and the limits that may exist to their implementation within a territory. Thus the transformation of the energy intensive agricultural sector into an energy producer and energy project developer.

I.1.3 Contribution to a dynamic process in Moroccan transition

Ever since 2015 (COP21) Morocco is actively seeking to mitigate climate change and reduce greenhouse gas emissions by 13% in 2030. Since then, Morocco has set an example towards clean development; it is ranked 38th worldwide by environmental contribution, and leader in Africa in hosting the COP22 climate negotiations (2016). It is committed from the outset, to inclusive green growth in the endorsement of the sustainable development goals. Although Morocco has a small contribution to global greenhouse gas emissions, but the country is heavily impacted by climate change. The effects of these changes can be seen on the reduction of water resources and the worsening of desertification; in particular, on agriculture, a reduction in cereal land and the disappearance of certain crops and biodiversity.

In order to break with this situation, Morocco has adopted an energy policy that promotes the introduction of renewable energies at the national level by developing hydroelectric power, energy wind and solar power. This choice is motivated by the deposits important resources available to Morocco in terms of primary resources. The objectives set by Morocco for this regard are spread over two levels: the first stage 2020 where the share of renewable energies will represent 42% as a contribution to total energy production and the second in stage 2030 to bring this 52% stake.

In this context, this document should therefore contribute to this important challenge. In addition, the approaches highlighted aims to support the country's initiatives in the preparation of the carbon strategy. Thus serving the technical and academic actors to strengthen the energy mix, without forgetting to re-enter the agricultural sphere and to integrate renewable energies in order to establish a rural urban metabolism towards a green and sustainable economy it is hoped through this modest work to Give New Impetus to National Strategies to Achieve Sustainable Agriculture.

I.1.4 Research Limitations

The strategies examined in this thesis for deepening sustainable agriculture focus on reducing the consumption of fossil fuels on farms. It also includes reducing the consumption of chemical fertilizers, using biodiversity practices, improving water efficiency and, most importantly, assessing opportunities for energy production in the agricultural sector. However, the structural integration of sustainability in agriculture depends on several variables that change from country to country, and even within the same country and region it changes from farm to farm. In addition, the calculation of agricultural energy inputs is more complex because it differs on several variables.

The skilled workforce is also a big obstacle since the installation and maintenance of renewable installations requires highly skilled labor, especially in rural areas. The Moroccan education system has not integrated completely professional training in a context where technological breakthroughs are increasing and where the current working population has received little initial training. Morocco is therefore in lack qualified technical Manpower.

The most pointed challenge throughout the research has been that CHP and A.I. are new domains in morocco, and their promotion is variable. In addition, the present subject is rather large and requires interdisciplinary approaches. Which portray the use of different approaches. Faced with limitations related to time and resources certain aspects are not studied. The production of biogas is not sufficiently developed, see thatthe CHP systems are prevailed in rural areas, and the biogas production facilities present several unmanaged risks. Secondly, the use of heat alone is not studied, taking into account the primary need of farms for electricity. Third, environmental studies are not deep enough and the context scan focuses on national policy and not organizations.

Despite the fact that some issues could not be discussed in detail, or were retrenched,the author believes that the research outlines very comprehensive approaches, problems, and opportunities for Moroccan agriculture to achieve more sustainability.

I.1.5 Methodology

The methodology used in this document was developed as a step-by-step approach to help identify which of the many agro-food climate technologies and practices should be prioritized based on mitigation potential under existing conditions, in light of several important criteria like technical parameters, financial/economic feasibility and sustainability considerations. In addition, it seeks to identify barriers that may hinder renewables energies integration in agriculture and suggests solutions that maydeserve greater attention to stimulate energetic transition. The methodology is organized in four steps, with each intended to help the assessor answer specific questions:

- Step 1: **Which are the most relevant agricultural activities in terms of GHG emissions and energy consumption?**

- Step 2: **How can renewable technologies perform energy consumption in agriculture based on techno economic parameters?**

Step 3: **What are the relevant potentials in terms of resources availability and sustainability viability when advocating green technologies in agricultural field?**

Step 4**: Which are the main opportunities and barriers and how they can be addressed?**

There are three main points to be considered when interpreting the results obtained through the application of this methodology. Firstly, the methodology has been developed as a measurement tool; a mix of data sources is used depending on the availability in Morocco, with a quantification of energy, climate and environmental inputs in the agricultural sub-sector and renewable energies evaluated. However, the approach can be adapted to a more in-depth exercise such as biotechnology, which involves the collection of primary data depending on resources and time.

The study mainly used official national and international data as well as industrial sources, territorial investigations and information from the scientific world. It is therefore subject to the quality of these sources and the availability of data. The analysis was carried out by a team of international and local experts in close collaboration with country officials.

Secondly, the number of technologies considered and the techno economic analysis can be approached for promising technologies as required. Indeed, future work should take into consideration more technologies and the socio-rural context as these are two dynamic and rapidly changing elements.

In addition, the technical analysis may need to be deepened in order to facilitate the reliability and viability of the integration of green technologies. Within this framework (figure *I.1*), the analysis seeks to define the key activities to be renewed, in order to ensure a favorable follow-up to the agricultural sector reform solutions. Thirdly, the methodology has been designed as a replicable exercise. In principle, it can be applied recurrently in the future, at appropriate time intervals, assuming that most of the data sources have been identified. This will allow territories and local authorities to monitor the adoption of renewable energies in their practices and proposals at regional and national level. The integration of specific renewable energies can also meet the requirements of international environmental policy, and inspire other nations for more sustainable energy scenarios.

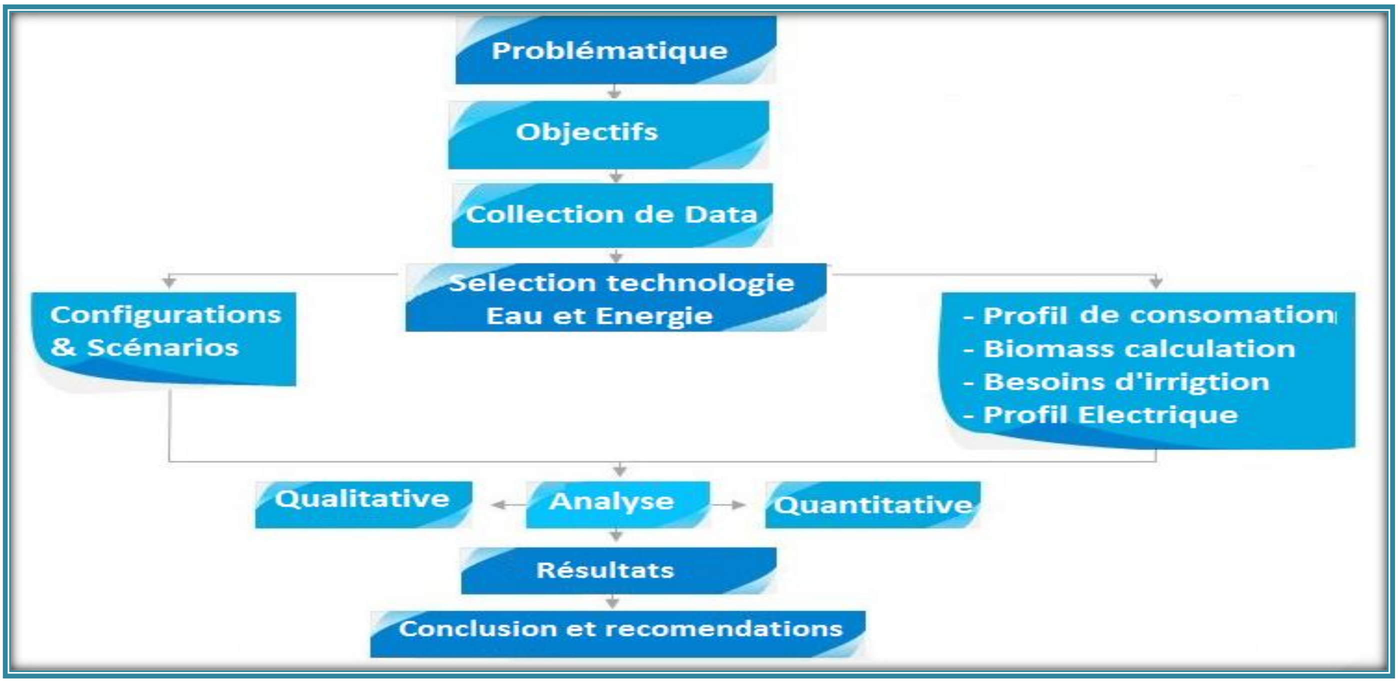

Figure I.1: Analytical framework methodology of Research.

I.1.6 Structure of the thesis

After the transitory introduction to the research approach, the following section underline the Moroccan current state and renewable energies share on energy sector.

Therefore, this thesis is presented as a compilation of articles related adapted, into the dissertation. The author is the main contributor and the firstauthor of all articles.

Chapter 2: presents a comprehensive study on water management in agriculture by opting for solar pumping systems.

This is followed by the assessment and upgrading of agricultural biomass by CHP systems in chapter 3.

Chapter 4: Opportunities for AI to promote the Energy-water-food Nexus, and NRTs.

Finally, Chapter 5 provides general conclusions and recommendations for future work.

I.2 Overview of the Moroccan context

I.2.1 Context and dictum

Faced with the overall economic and environmental situation, all the countries of our mother-earth, whether developed or developing, are looking for sustainable alternatives for energy efficiency and food security. In a global context, Energy savings, renewable resources and renewable energies become solutions to be considered and to be multiplied by the developing countries. States like Morocco find these solutions in the reduction of greenhouse gases, respect for the environment, renewable energies, laws, rules and principles to improve the quality of life. In this first chapter, it seems opportune to define the Moroccan national context before getting to the heart of the subject related to renewable energies.

This section examines the sociopolitical economic situation of Morocco in a context linked to the global energy problem and to climate change. Structural analysis reveals economic inertia, linked to unstable agriculture and a weak economy. This non-circular economy is weighed down by a strong dependence on fossil imports, which presents a very high energy bill. While the Moroccan structural transformation aims for a green economy that offers growth in agricultural productivity, as a means of increasing income as well as new possibilities for renewable energies for energy independence.

This structural transformation must necessarily go through a well-reasoned and integrated energy transition. The need to invest in renewable energy and human capital has also been stressed to deal with the current alarm situations. Market flexibility, the level of inflation, the rural poverty rate and the financial system represent a major obstacle to improving sustainability and the integration of NRTs into agriculture in Morocco and other sectors. Of course, countries all tend to diversify their economies even though far from agriculture and natural resources. Developed countries have succeeded in achieving an economic model capable of improving productivity, labor and capital. On the other hand, economies now considered less developed have remained trapped in low and middle incomes. Both, the preservation of water sources and increasing agricultural productivity is a major asset for the economic development, which achieves and maintains a higher standard of living of agricultural countries. The processes needed to achieve this include the use of reasonable technologies, green technologies, and investment in human capital and, above all, a robust financial plan that facilitates the integration of NRTs in agriculture and agro-industry. When this process is successful and sustained over the decades, it leads to sustainable agriculture.

Morocco, officially the Kingdom of Morocco, is a country in the Maghreb region of North Africa. Its eastern border is with Algeria and a relatively narrow body of water separates it from Spain to the north. Studies on predicting climate change and global warming have shown that Morocco is among the countries most likely to be threatened by climate change [22].

The country has a very important coastline stretching 3,500 km. According to the World Bank the Moroccan population is 36,029,138 in 2018 with (40.63%) rural population growth of 1%. Morocco is divided into 16 regions, which are themselves subdivided into 44 provinces and 24 prefectures. Each region has local community status. The total area of the country is (710,000 km^2)[1].

Agriculture is the main pillar of the Moroccan economy; it is highly dependent on the weather, typical of third world countries. In 2008, the Moroccan government published a new agricultural strategy, called the Green Morocco Plan (PMV)". In addition to the objective of "aggressively" promoting agricultural productivity, it also addresses climate change, overexploitation of groundwater and poverty reduction[2].

1.2.2 Socioeconomic aspect

The Kingdom of Morocco is located in northwest Africa, with coastlines on the Mediterranean Sea and the Atlantic Ocean. Thanks to its location, Morocco has for century's maintained very close economic and cultural nexus with Europe, Africa and MENA countries. This economic side of the relationship has been developed significantly since the country's running industrialization process in the 1970s.

Morocco's capital is Rabat. The political regime is well founded on the separation, balance and collaboration of powers, as well as on citizen and participatorydemocracy, and the principles of good governance and the correlation between responsibility and accountability. Since 1999, Morocco has been engaged in the political, economic and social modernization of the country, which was accelerated by the regional context in spring 2011.Other economic problems mobilize society and affect the government. As the rise in prices and the fall in purchasing power, are at theorigin of a major boycott campaign of the companies Central DANONE (milk), Sidi Ali (mineral water) and Afriquia (fuels), launched on the networks social on April 20, 2018.Critics highlight the collision between the economic and political spheres, leading to a conflict in the unity of government.

[1] Plan Maroc vert: Premières perspectives sur la stratégie agricole, ⟨www.vulgarization.net/plan maroc vert.pdf⟩;

[2] MAPM : Ministère de l'agriculture et pêche maritime : http://www.agriculture.gov.ma/

The protest movements in the Rif (started in October 2016) and in the Oriental (started in December 2017) also explain the difficulties in rural areas. Trials of Hirak Rif activists have raised criticism in Moroccan opinion for their political character.
However, to deal with this situation, Morocco has made sustainable development a national priority. Recently in 2018, an urgent call was lunched for the "reassessment of the national development model" towards a new economic strategy.

The social impacts are strongly related to economic and energetic situation. Morocco relies on imports for almost all of its energy requirements, in the form of oil, natural gas and coal. Such heavy reliance on fossil fuel imports has prompted a strong drive by the government to reduce imports, switch to renewable energy sources and to launch energy efficiency policies in the face of higher demand in a growing economy.

As portrayed for Morocco (figure *I.2*), the share of value added in the three sectors remained stagnant at about 12%, 25% and 51% respectively for the agricultural, industrial and services sectors. The sharing of agriculture always depends on fluctuations in rainfall. The industry has been able to provide real momentum to the labor market, representing about 12% of the employed workforce. Although the services sector, which accounts for about 40% of jobs (67% of total creation), appears to be expanding, most jobs are concentrated in traditional low skilled services.

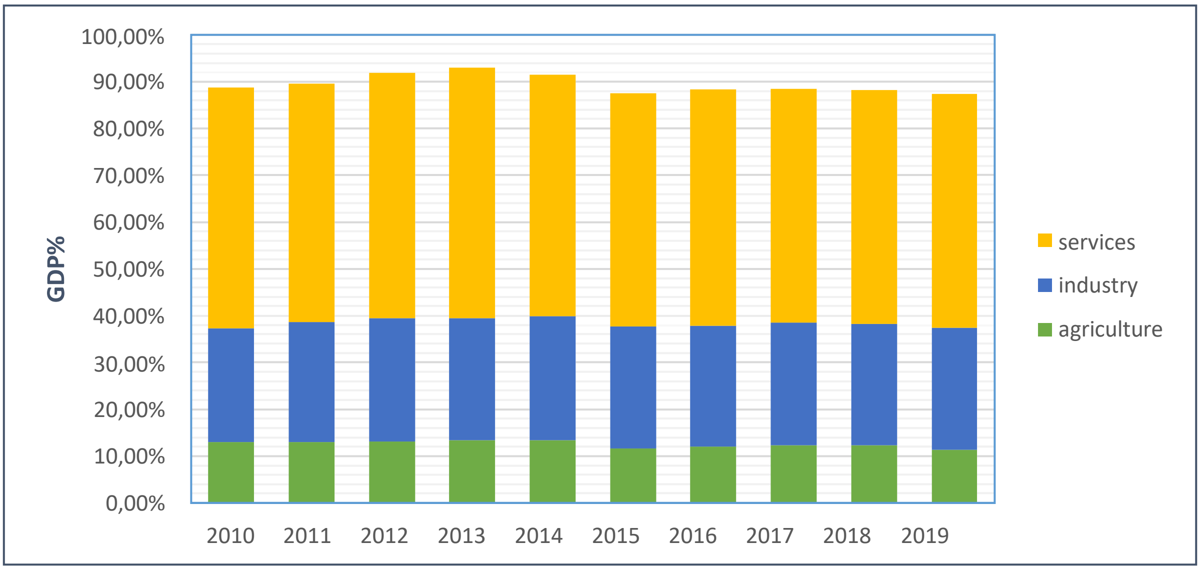

Figure I.2: Distribution of gross domestic product (GDP) across economic sectors (2010 to 2019)[23].

Indeed, the increase in added value has largely stagnated. The agricultural sector presents irregularities in production, which strongly influences the overall performance of the economy, especially since the sector absorbs the majority of the working population, with around 40% of total employment. This is due to the size of the agricultural sector, relatively to the rest of the economy limits, the rate of labor migrationto non-agricultural jobs and other services.

In an economy dependent mainly on agriculture, the relative share of agricultural employment will slowly decline compared to employment in industry and services which is very high.

Agricultural development has been achieved much more through intensification, than through the development of vertical productivity. In addition to the use of new technologies and selection of seeds and fertilizers, the agricultural sector is confronted with the cultivation of virgin and fertile lands such as forest areas and rangelands, as well as the imbalance between irrigated and no irrigated areas. The slow pace of structural transformation in Morocco is also reflected in the difficulty of the industrialization process. In 2018, the industry's contribution to GDP was around 26%. The decrease in the total share of this sector in total employment, from 42% to 37% between 2000 and 2018, is explained, among other things, by the transformations of the Moroccan industrial sector, in particular the decrease in importance of traditional activities as a result of the modernization of production methods of certain activities and the emergence of new industries. Likewise, the improvement of labor productivity in the industrial sector is insufficient, this situation being explained by the fact that Morocco has a structure which evolves in two opposite directions. On the other hand, very dynamic activities carried out by leading companies which have taken advantage of the country's policy of openness to develop competitive export strategies. On the other hand, there are traditional sectors with a large number of companies losing performance. Morocco's economy is heavily dependent on the primary sector "agriculture", which accounts for about 12 % of (GDP), but occupies more than 50% ofthe workforce. Growth in non-agricultural activities is relatively high in contrast to thatof the agricultural sector, which tends to decline over the years.

Morocco has returned to economic growth since the early 2000s, but this remains correlated with the agricultural sector and global economic conditions. After a year of declining growth in 2016 (1.6%) due to drought, the rate has risen to 4% in 2017.
Morocco is experiencing a slowdown in its economic growth, to 3% in 2018[3]. Due to Covid-19, the PIB continue to fall in 2020 at (- 6.7%), as seen in (figure I.3).

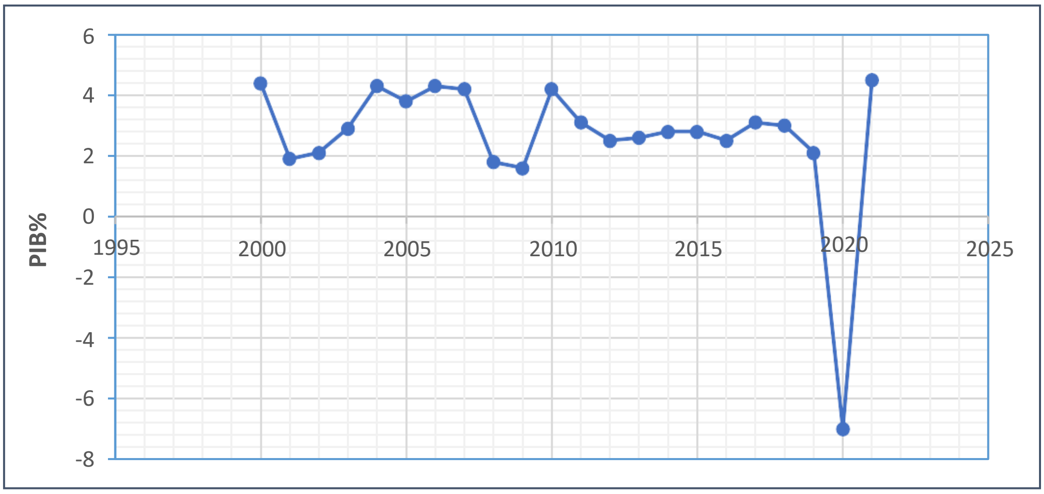

Figure I.3: PIB progression (2000-2020). [4]

The country strives to promote a better resilience of the Moroccan economy to agricultural fluctuations. In this sense, important reforms have thus emerged as part of a sector diversification. The adoption of these reforms has been facilitated by favorable external conditions (*lower oil prices, good rainfall, and resumption of European activity*). This reform plan has not jeopardized the efforts of successive governments toredress fiscal and external accounts. The budget deficit has steadily narrowed over thepast five years to reach 3.7% of GDP in 2018. Public debt reaches 84% of GDP in 2018.While debt has reached a high level, particularly due to the sharp rise in the debt of so-called soles, the own risk is offset by active management (78% of internal outstanding, average cost of 4.3% and maturity at more than 6 years).

Despite these encouraging indicators, the unemployment rate is struggling to fall, affecting 9.8% of the working population in 2018. It mainly affects young people (26%of 15-24 year olds).

[3] Source: Central Bank of Morocco
[4] Source : FMI - World Economic Outlook Database

Highlighting the shortcomings of Morocco's development model for inclusion, the World Banks monitoring report on Moroccan economic situation in April 2018 recommends that the Kingdom move towards an economic model based on private sector as a promoter of growth and employment.

The government regularly insists on the ambition to make Morocco an emerging and pioneering country on the continent. To this end, Morocco has decided to supplement its free zones (Tangier) and sectorial development plans (*agriculture, tourism, fisheries, competitiveness clusters*) with a regional development dynamic towards sub-Saharan Africa, in order to find new sources of growth, and energy sources.

I.2.3 Environnemental aspect

Morocco is distinguished by four types of climate: humid, sub humid, semi-arid and arid. In recent years, climate observations in Morocco show that the semi-arid climate is progressing towards the north of the country, which poses a great threat to socio-economic development and to the lives of the population. Indeed, people's lives are very much linked to climate. The economy is highly dependent on water, agriculture, and the coastline. The natural vulnerabilities to which Morocco is constrained are water stress, fragility of vegetation cover, desertification and seismicity. Climate data from the country indicate significant warming during the 20th century, estimated at more than 1°C with a significant increase in the frequency and intensity ofextreme events such as droughts and floods. The estimate of the likely warming of the region during the 21st century is in the range of 1 to 5 degrees Celsius compared to the20th century [24]. Rainfall varies from more than 2 m per year on the northern reliefs ofthe country to less than 25 mm per year in the southern desert plains. There has been an overall decrease in rainfall in recent decades, ranging from 3% to 30% depending on the region. This reduction can reach 60% by the end of the 21st century compared to the 1961-1990 period. Throughout the 21st century, Morocco will therefore face severe watershortages if no action is taken today. Climate aridity is also a cause of desertification, endangering the entire vegetation cover and increasing the susceptibility of forests to fires (United Nations Educational, Science and Culture Organization *UNESCO*).

During the decade 2006-2016, total energy related CO2 emissions have increased by more than a third by 55.3 MtCO2 and by 181% since 1990. In 2016, oil was responsible for 64% and coal was responsible for 31% of total emissions, with the rest from natural gas and other sources. As, shown in (figure*I.4*), CO2 emissions for Morocco has reached 73.9 million tons in 2019 [25]. Oil is consumed in many sectors, while emissions from coal use come from electricity generation. Electricity generation and transport account for the majority of energy related CO2 emissions in Morocco. In 2016, the electricity sector emitted 39% and the transport sector 31% of the total emissions. The rest came from industry (13%), residential and commercial buildings (12%) agriculture (5%). Emissions have increased rapidly in all sectors over the past decade, with the exception of industry, which has remained relatively stable. Between 2006 and 2016, emissions increased by 31% in energy production, by 63%in transport, by 1.5% in industry, 58% in the residential and commercial sectors and 58% in agriculture.

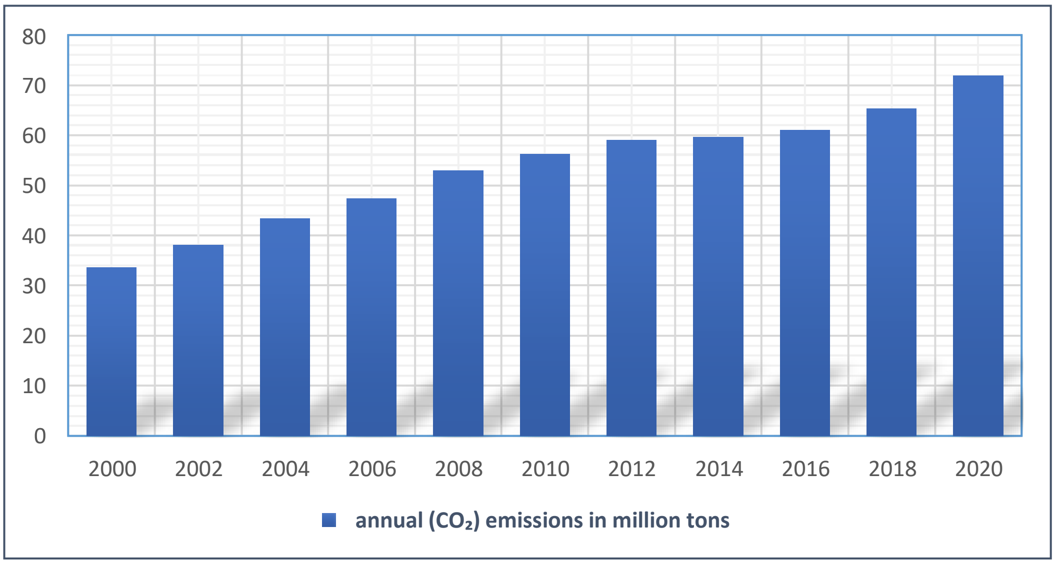

Figure I.4: Annual CO2 emissions in Morocco.

I.2.4 Energetic context

The national energy environment is marked by high external dependence and a very significant increase in energy demand. Between 93% and 97% of energy is imported in the form of petroleum products, coal and electricity. Only hydroelectric, wind and solar energy are produced locally. As the state moves to stimulate investment in renewable energy, provide access to electricity for almost all of its rural population and end most energy subsidies fossil fuels. But, despite the positive efforts, you have to know that Morocco's primary energy consumption still relies almost 90% on fossil fuels: 62% on oil, 21.7% on coal and 5% on natural gas according to the latest data from the Agency covering 2018.

Morocco relies heavily on imports. Energy demand is expected to reach 42 million toe to meet 2030; 21.6 million toe, was recorded in 2019 [26]. The following illustration (figure *I.5*) show the evolution of primary energy imported from 1990 to 2019.

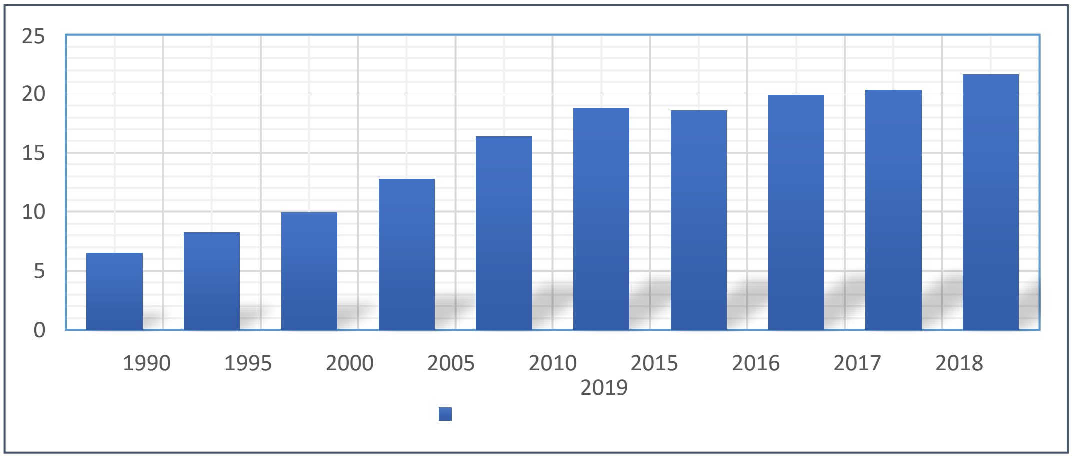

Figure I.5: Primary energy imported from 1990 to 2019 in Morocco.

I.2.4.1 Electricity in Morocco

Moroccan electricity generation is an example of traditional production (figure*I.6*). Single public sector, although private production through concessions also exists, to some extent. The National Electricity and Water Board (*ONEE*) is responsible for much of the electricity generation, is the sole transport operator and is responsible for the purchase of fuel. The activity of the ONEE, the main purchaser of fuel and distributor of power plants in the country, is directly affected by fluctuations in oil prices. Since the traditional single public service system is still widespread in many countries, our approach and considerations can be useful in similar contexts.

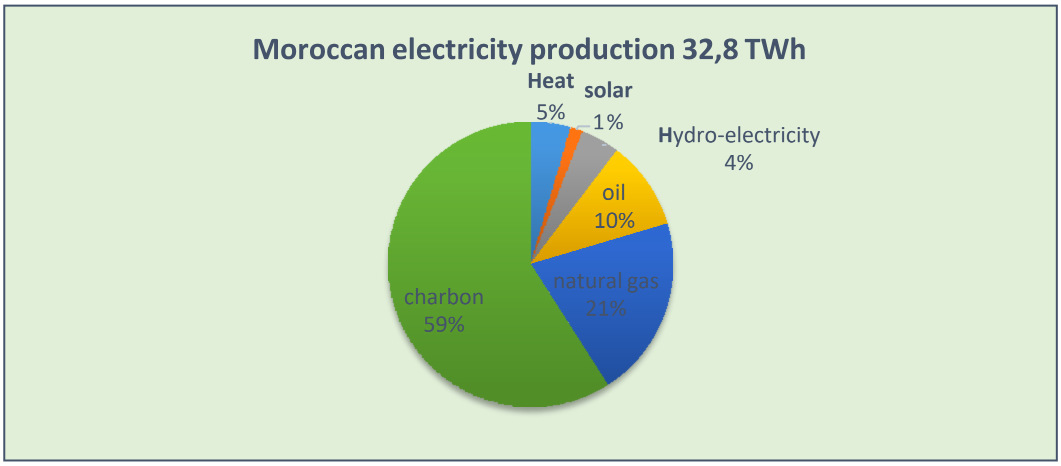

Figure I.6: Moroccan electricity production.[5]

[5] IEA : Energy Policies beyond IEA Countries: Morocco 2019, IEA, May 2019.

Electricity tariffs in Morocco are regulated by the Inter Ministerial Committee on Prices (*CIP*) chaired by the Ministry of General Affairs and Governance (*MAGG*). Electricity rates vary depending on the type of use (residential, commercial, agricultural and municipal), voltage level and the time of use of the day. The Moroccan electricity market is managed by the (*ONEE*). This state-owned company manages the production, distribution, transmission and supply of electricity in Morocco. However, production is open to competition, especially for renewables. Morocco applies a progressive pricing with a VAT of 14% on the price of electricity (table*I.1*).

Table I.1: Fixed cost of electricity in Morocco.

Monthly consumption	Price per kWh in $
0 to 100 kWh	0,090
101 to 1200 kWh	0,100
201 to 300 kWh	0,109
301 to 500 kWh	0,129
500 kWh	0,149

The high progressivity of this price per kWh slightly lower than the French price encourages consumers to be energy efficient. These rates are valid in October 2015. Consumption 960 kWh per person, in 2017. The following figure *1.7,* illustrates the evolution of electricity consumption between 1960 and 2017.

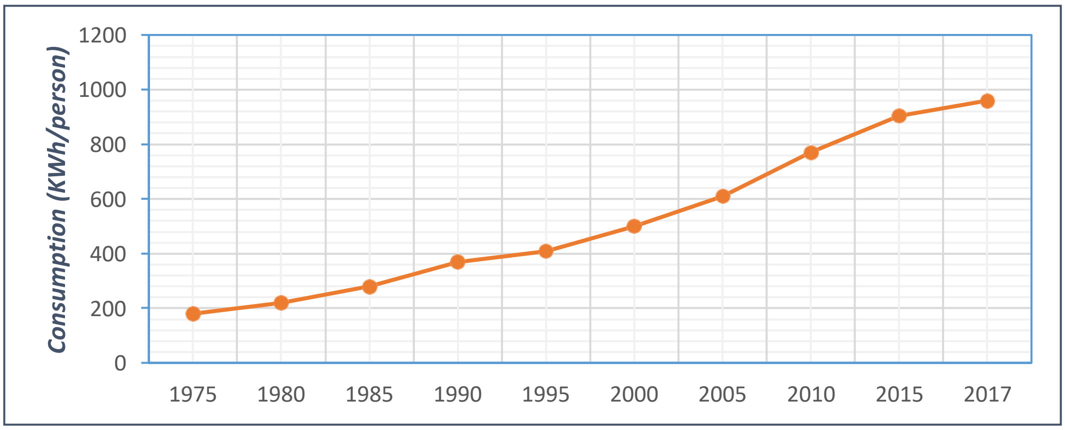

Figure I.7: Electricity consumption (KWh/person)[6].

[6] Source banque mondiale

I.2.4.2 Electricity for agricultural use in Morocco

It should be noted that there is a specific electricity tariff for professionals in the agriculture sector in Morocco, called the green tariff. This tariff is intended for individual customers or companies engaged in an agricultural activity recognized by a certificate issued by the competent services of the Ministry of Agriculture. The green Rate includes three options tailored to the annual duration of use and seasonal variation (double winter/summer seasonality). It offers the advantage of an exemption from the subscription of powers.

In addition, the electric bill is optimized by shifting consumption from peak hours to normal hours (table 1.2). Farm customers can benefit, as an option, from the "green tariff" under three tariff options (table 1.3).

Table I.2: The hourly positions in rural areas.

	winter	**Summer**
Peak hours	5 p.m. to 10 p.m.	6 p.m. to 11 p.m.
Normal hours	10 p.m. to 5 p.m.	11 p.m. to 6 p.m.

Table I.3: COE for Agricultural activities.

Tariff options	**Fixed $/KVA**	**Prices in $/kWh**			
		Peak hours		Normal hours	
		winter	Summer	winter	Summer
TLU	284,41	0.06	0.06	0,06	0,05
Mu	127,98	0,13	0,07	0,10	0,06
Cu	56,88	0,20	0,09	0,14	0,07

I.2.5 Energy transition in Morocco

Morocco's ambition is to strongly develop renewable energy in the electricity generation sector: in 2009, it adopted an ambitious energy strategy aimed at the development of large-scale renewable energy and to promote energy efficiency. This strategy is based on five main strategic objectives :

- Energy security and diversification, particularly in the electricity sector.
- Development of renewable sources, particularly solar and wind.
- Improved energy efficiency.
- Supply of energy to all segments of the population at competitive prices;
- Regional energy integration in the Euro Mediterranean and African markets.

The new national energy strategy has set a target of increasing the share of these sectors to 42% by 2020 in the total installed capacity of the Moroccan electricity fleet.

This transition is designed to ensure Morocco's energy security, reduce dependence on petroleum products and enable the country's energy transition to sustainable energy. Itplaces renewable energy and energy efficiency at the focus of the national priority, which is to reduce the country's energy dependence while paving the way for the export of green electricity. Morocco has since specified that renewable energy will have to count more than 52% of the country's electricity capacity by 2030. To do this, the country relies on the various renewable sectors: wind (9.5% of electricity production in 2017), hydroelectricity (4%), solar (1.3%) including thermodynamic power plants, etc.

It is also recommended that energy efficiency be made a national priority with the implementation of a major strategy dedicated to 2030, with financial resources. Morocco's primary energy consumption increased by 32% between 2007 and 2017 (reaching 20.5 Mtoe that year). The growth in electricity demand is even stronger and could continue at an average rate of 5% per year by 2021, according to the International Energy Agency (*IEA*).

As a reminder, Morocco - which hosted COP22 in Marrakech at the end of 2016 - has committed under the Paris Agreements to reduce its greenhouse gas emissions by 42% by 2030 compared to a *"business-as-usual"* scenario at this time; "substantial *support from the international* community" (without this external support, the target is limited to a 17% reduction in emissions by 2030).

This strategy was supported by a comprehensive legal, institutional and regulatory reform framework that included:

- A specific Renewable Energy Development Act (No. 13-09) (2009);
- A specific energy efficiency law (No. 47-09) (2009);
- the creation of Masen 9: Moroccan Agency for Solar Energy, responsible for the development of the global solar program (2010);
- the creation of (*ADEREE*): Agency for the Development of Renewable Energy and Energy Efficiency (2010);
- the creation of (*IRESEN*): Institute for Renewable Energy Research and Development (2011);
- the creation of (*EIS*): a public energy investment company for the development of ER and EA projects through public and private partnerships (*PPP*) in 2010;

- The creation of a US$1 billion energy development fund (*FDE*) to finance ER and EI projects through direct financial incentives or equity investments by EIS (2009).

Law 13-09 was recently amended and supplemented by Law 58-1513. The provisions of this new law recommend:

- Opening the electricity market to low-voltage renewable energy sources, to enable the large-scale development and use of PV in residential and tertiary power connected in low voltage.
- Increasing the installed capacity threshold from 12 to 30 MW for hydroelectric power generation projects.
- The possibility of selling the surplus of production that is not used by the operator.

The decrees on how to access electricity from renewable sources to the low voltage network and the decrees on the terms of the sale of the surplus of self-producers to the grid are being validated.

I.2.6 Renewable energy potential in Morocco

Faced with the alarming situation, as well as the climate decline; it is essential to seek alternative energy resources for the world's nations. Renewable energies would significantly reduce future greenhouse gas emissions. Rising energy prices, global warming and the depletion of primary energy sources require that renewable energy will be properly managed and used to support economic development. In addition, renewable energy is sometimes a vital strategic decision for countries, especially those with limited fossil energy resourcesand dependent on other energy importing countries. The worst situation is when a country relies on a country for their energy imports [27].
Meantime, Morocco has several continuous renewable energy projects. Moroccan Solar Plan is one of the world's largest solar energy projects, and it is estimated that it will cost ($8.4 billion). Moroccan energy efficiency projects, solar and wind programs have been supported and funded by the African Development Bank (A*fDB*), the World Bank (*WB*), and the European Investment Bank (*EIB*)[28]. Morocco has begun to take an interest in ERs. This was manifested by the creation of the Renewable Energy Development Centre (*CDER*) in 1982 (now the National Agency for the Development of Renewable Energy and Energy Efficiency in 2010 (ADEREE), a public institution under the MEMEE's tutelage. However, little was done until 2009 when major projects were planned under the new energy policy and the National Plan to Combat Global Warming (*PNRC*).
Morocco has great potential for renewable energy production, thanks to the largewind power and solar resources. Renewable energy accounted for 34.5% of installed capacity in 2017.

The government is on track to meet its target of 42% for the share of installed capacity by here2020 and has increased the ambition to at least 52% by 2030(table *I.4*). The recent growth in wind and solar energy has increased the share of renewable energy sources to almost 16% of total electricity generation; wind power remains the iconic energy with 59% (figure *I.8*).

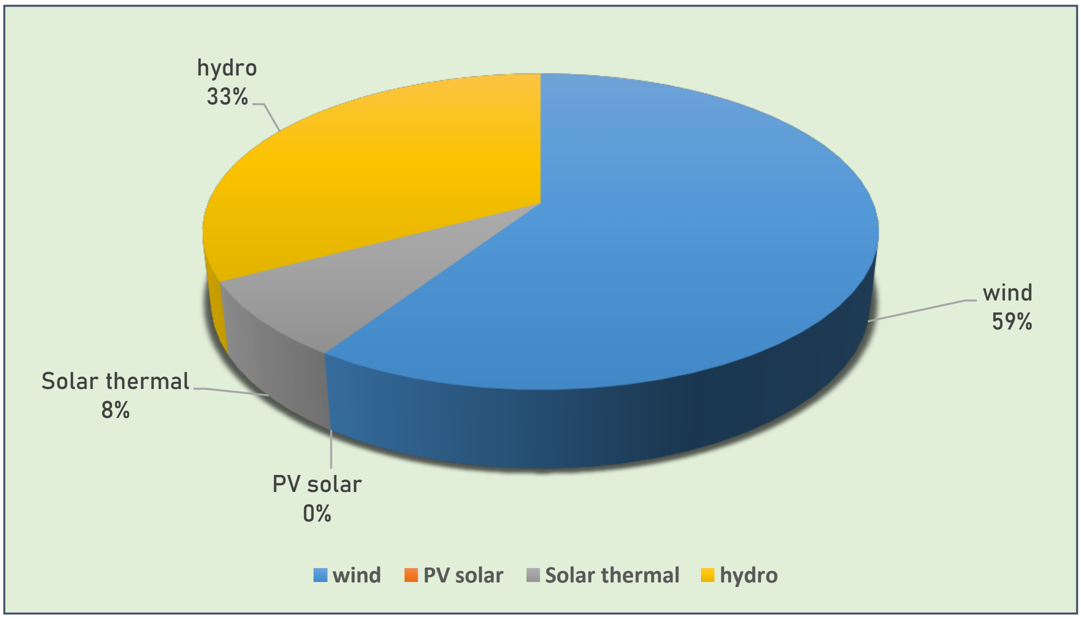

Figure I.8: Share of sources in renewable electricity generation (GWh).

Table I.4: Moroccan renewable energy state and targets for 2030 [29][30].

Energy source	Current state	Potential target in 2030
Wind	500 / 1500 MW under construction	4200 MW
hydro	1770 / 1625MW	3100 MW
solar	20 / 500MW	4560 MW
biomass	5 Mw	950 MW
Geothermal	0	5 Mw

In the Moroccan situation, the growing involvement of renewable energy in the energy package would solve both environmental problems and energy security items. As an effect, expansion of energy security could also aid in understanding the interlinkage among energetic security, sustainable development, and climate change [31].

Today, Morocco is implementing several large-scale renewable energy projects. To achieve an even more ambitious target, 52% of Morocco's energy production by 2030 will be from renewable sources, with efforts focusing mainly on solar and wind energy once again.

I.2.6.1 Solar energy

Solar is very important in Morocco. It is the most important source of renewable energy in the country. As shown (figure I.9) average incident solar radiation ranges from 4.7 to 5.6 kWh per day and per square, which represents between 2,800 hours of sunshine per year for the least advantaged regions and more than 3,400 hours per year for the most [31]. The exploitation of solar resources is well suited to cope with the limitations of current patterns of energy generation and consumption and to complement existing energy production systems.

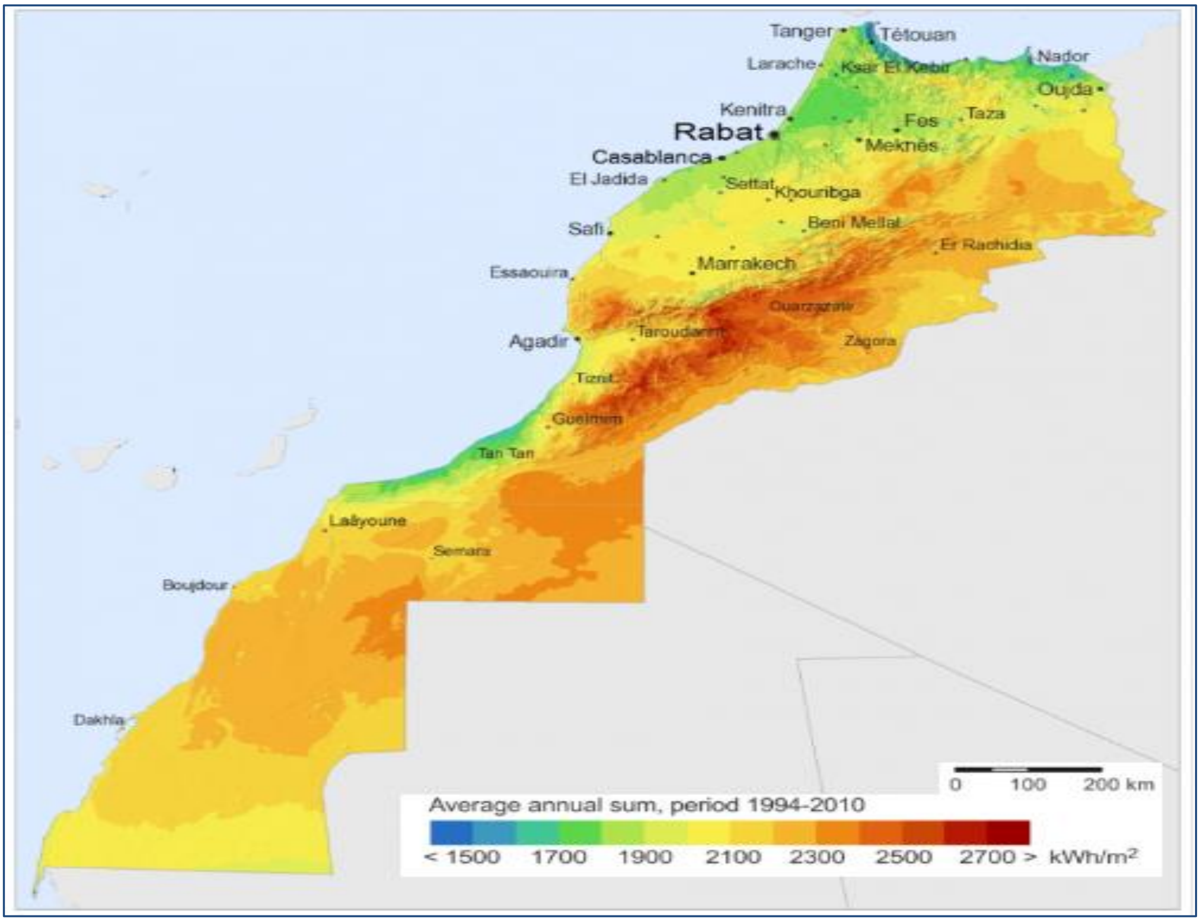

Figure I.9: Moroccan solar potential (World Bank).

Solar technologies convert the solar radiations into electrical energy and it can be classified into two main groups, i.e. photovoltaic technology and concentrating solar power (*CSP*)[32]. Photovoltaic technologies involve the direct conversion of solar energy to electricity (as opposed to indirect conversions, such as when solar-heated steam is used to drive a turbine).

As the photovoltaic technology is maturing and cost of PV systems is decreasing, the demand of this renewable energy technology in developing countries is increasing exponentially [33].

Two types of PV technology are currently available in the market:

- Crystalline silicon based PV cells.
- Thin film technologies made out of a range of different semiconductor materials, including amorphous silicon cadmium telluride.

Usually two types of PV systems are installed: grid connected or centralized systemsand off grid or decentralized systems. Decentralized systems are more common forsmall power stations, which operate as local centralized systems.

Morocco has great potential for the production of solar energy, applying both photovoltaic and solar thermal technologies [34]. In Morocco, the recent large-scale solar PV projects are already competitive with thermal generation: the cost of electricity generated by the NOOR Ouarzazate IV plant will be less than 5 USD cents/kWh. The average production cost at the NOOR Ouarzazate site (CSP) is 14 USD cents/kWh, but it largely competes with diesel fuel and special fuel for gas turbines at peak times, and further cost reductions can be expected due to the current trends in prices and the excellent natural conditions in Morocco. Therefore, the competitiveness of solar power with fossil fuels might complete a determinant role in the future, as perceived in the figure *I.10*.

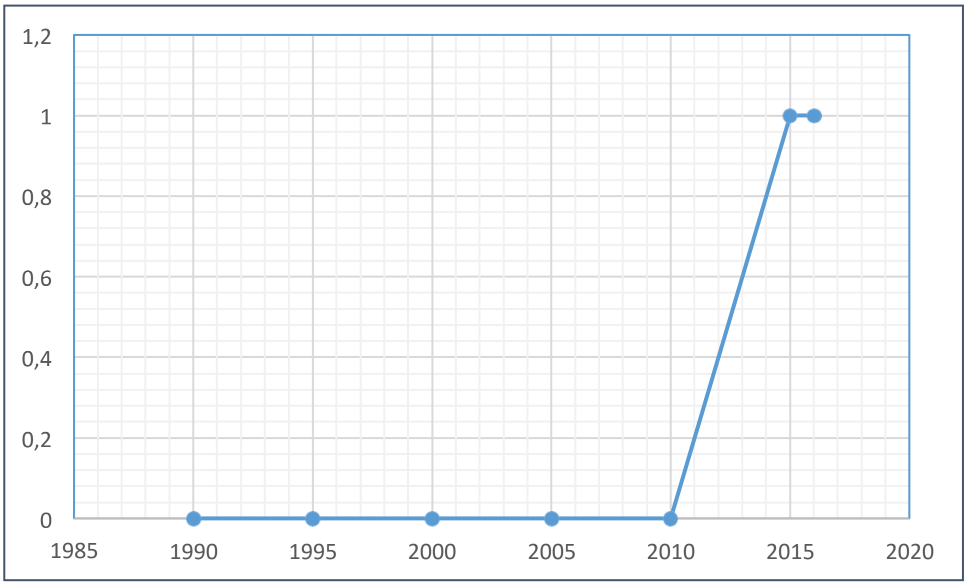

Figure I.10: Solar PV electricity generation in GWh.

I.2.6.2 Wind energy

Human society has harnessed wind power for almost five thousand years [35], mainly in rural activities and pumping water [36]. Even longer, civilizations have used the wind as a driving force for sailboats [37]. Locally, Morocco has an important deposit in its coastal areas, which cover 3,500 km with wind speeds of more than 6.5 m/s and up to 11 m/s. Essaouira, Tangier and Tetouan are especially impressive with average wind speeds between 9.5-11 (m/s). Tarfaya, Taza and Dakhla record wind speeds between 7.5-9.5 m/s. The total wind potential is 7.9 TWh/year while technical wind potential stands at 4.8 TWh/year and exploitable potential is judged to be at 25 GW, of which 6 GW couldbe installed by 2030 [38]. Exploitation of these wind sources will go through two periods, before and after Law 13-09 on renewable energy, allowing auto-production of energy with access to VHV/HV/MV networks. More specifically, this means that it is now possible to generate electricity from renewable energy sources for one's own use and, if necessary, to export it if there is a surplus. Over the period 1999-2019, in addition to the wind farms developed by ONEE, Independent Power Production (*IPP*) farms were set up, also called IPP-ONEE farms, whose characteristic is to be at the origin of private farms, held jointly by a foreign holding company and a Moroccan holding company. Finally, what characterizes this sector is that nearly 60% of its production concerns the southern provinces (figure *I.11*). Thus, this South/South sector will be treated separately [39].

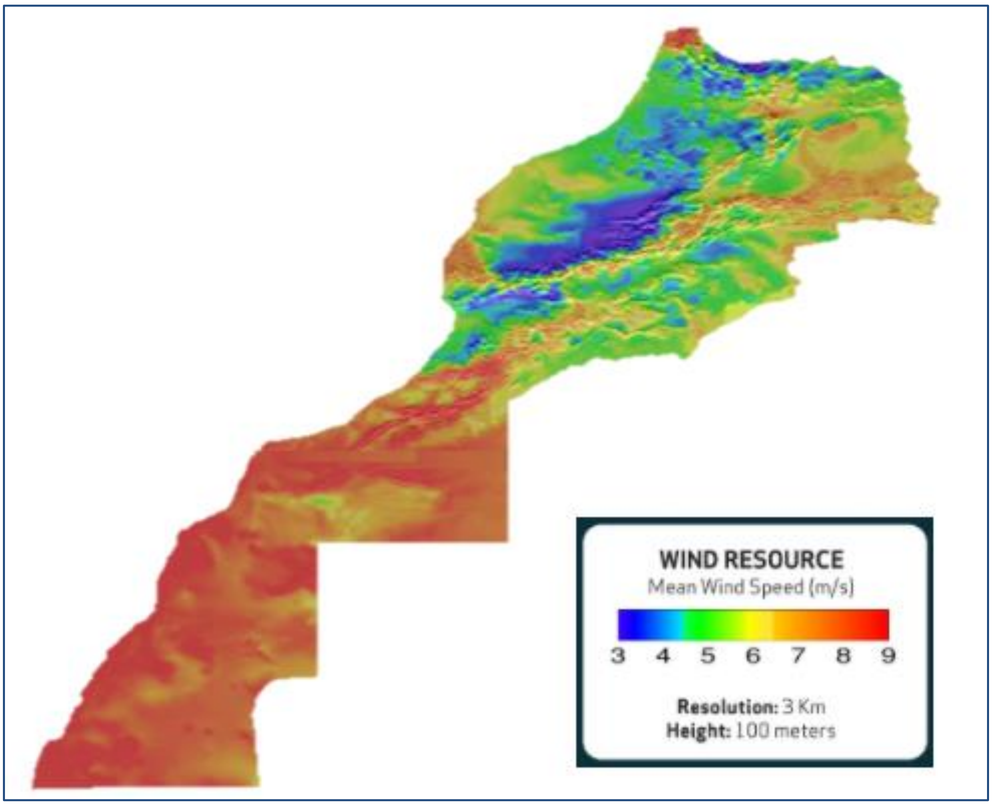

Figure I.11: Wind energy map.

As part of Morocco's Integrated Wind Energy Project, ONEE has tendered for the construction of many wind farms of a continuous total installing capacity (figure I.12). A total capacity of 850 MW at the following locations: Tanger II 150 MW; Midelt 100 MW; Jbel Lahdid (Essaouira) 200 MW; Tiskrad (Laayoune) 300 MW; and Boujdour 100 MW. The developer will design, finance, construct, operate and maintain the wind farms as IPPs. In addition, the developer and turbine supplier will also be required to extend the 50 MW Koudia al-Baida Al II wind farm to a total capacity of 200 MW. ONEE is also tendering a 150 MW wind farm at Taza, northern Morocco (Table I.5).

Table I.5: Wind Energy projects in Morocco [40].

Planned projects	Location	Potential level of production	Investment cost
Taza	Taza	Capacity: 150 MW Annual production: 430 GWh	3 billion DH ($310.2 million)
Boujdour	Boujdour	Capacity: 100 MW Annual production: 325 GWh	
JbedLahid	Essaouira	Capacity: 200 MW	850 MW integrated
Tiskarad:	Tarfaya	Capacity: 300 MW Annual production: 1000 GWh	28.5 billion DH ($2.9 billion)
Midelt	Midelt	Capacity: 150 MW	
Tanger II	Tanger	Capacity: 10 MW	
Tarfaya	Tarfaya	Capacity: 300 MW	450 million euros ($485.1 million)
KoudiaLbaida	Tetouan	Capacity: 300 MW	
Jbel Khaladi	Tanger	Capacity: 120 MW	1.9 billion DH ($196.44 million)
Akhfenir II	Tantan	Capacity: 100 MW	

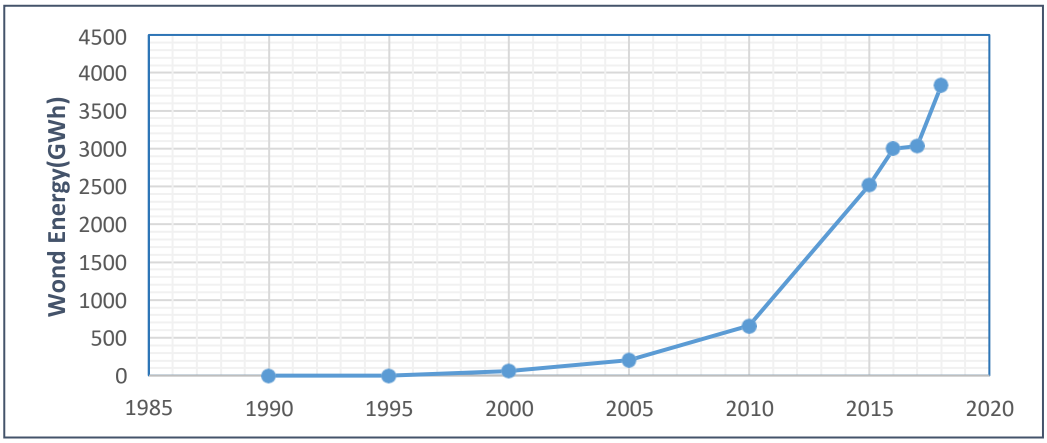

Figure I.12: Wind Enegy production in Morocco.

Unfortunately, while wind farms are technically feasible, they are not economically viable. However, the increased costs associated with higher wiring and maintenance costs. Furthermore, the increase of wind power capacity in Morocco will then pose several challenges to the stability of the electricity system [41]. These challenges are intensified by a weak electricity grid, limited hydraulic power plants and lower electricity exchange with Spain and Algeria, which fail to deliver necessary conditions for a larger penetration of wind energy. Therefore, to take advantage of Morocco's wind energy potential, it is necessary to boost the present transmission system and connection capacity with Algeria and Spain [42].

I.2.6.3 Biomass energy

In general, biomass energy has great potential. However, this resource should be used with caution, especially when it comes to forest biomass. Biomass presents all organics (vegetables and animals) derived from the process of photosynthesis. It includes biodegradable organic material originating from plants, animals and micro-organisms. This includes also products, byproducts, residues and waste from agriculture and industries. This energy source accounts for over 10% of global primaryenergy supply and is the world's fourth largest source of energy (following oil, coal, andnatural gas. Indeed, biomass energy accounts for almost one third of the Moroccan total energy consumption resulting in a loss of 30,000 ha of forest per year.

Forest resources that can be exploited are numerous: forest undergrowth, wood chips from the wood and sawmill industry, alfat rills, and wood-cut arboriculture and viticulture. The residual biomass of municipalities, the agricultural sector and industry represents a good potential for energy production reaching 950 MW. The predominant use of biomass in Morocco is traditional fuels for cooking and heating. Forested areas are estimated at 9 million hectares, although annual consumption is estimated to be 30,000 ha. An additional 400 MW of co-generation potential is available in the country (see next page table *I.6*).

Total solid bio-energy potential is estimated at 12,568 GW h/year, with a further 13,055 GW h/year from biogas and biofuels. Biogas sector presents a total installed capacity of 33,800 m^2, with an annual production of about 21.6 million m^3[30].

Table I.6: Moroccan potentialities in biomass/biogas sector[7].

Origin	Characteristics
Agricultural biomass	- Total agricultural area of 9 million ha - 7 million large livestock units, with more than 500,000 farms
Household waste	- 5.5 million T/year (2010) - The theoretical potential: 4700 million m^3 of biogas/year; 4.2 MW h/an
Waste water	- The theoretical potential: 230 million m^3 de biogas/year; 1.376 million MW h/year - The technical potential (Medium term): 31 million m^3 biogas/year; 185.463 MW h/year
Forest	- Moroccan forestry area: near to 9 million hectares - Afforestation rate: 8%

I.2.6.4 Hydro power

Hydropower is very popular due to its flexible technology. It can provide energy for a single home, and at its largest it can supply industry and the public needs with renewable electricity on a national scale. Four hydro power technologies exist[8]:

- Run-of-river hydropower provides a continuous supply with some flexibility of operation for daily fluctuations in demand.

- Storage hydropower is typically a large system that uses a dam to store water in a reservoir. It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks or even months.

- Pumped-storage hydropower provides peak-load supply, harnessing water that is cycled between a lower and upper reservoir by pumps that use surplus energy from the system at times of low demand.

[7] Agence Marocaine pour le Développement des Energies Renouvelables et de l'Efficacité Energétique. ⟨http://www.aderee.ma/⟩.

[8] International Hydropower Association (IHA), 2019. Hydropower projects test draft climate resilience guide. https://www.hydropower.org/news/hydropower-projects-test-draft-climate-resilience-guide

- Offshore hydropower is a less established but growing group of technologies that use tidal currents or the power of waves to generate electricity from seawater.

Morocco, fortified by its important renewable energy resources, was among the first countries in the Middle East and North Africa to cut fossil fuel subsidies. It has significant potential to increase hydropower storage capacity and reinforce its green energy production.

Morocco has low potential in hydropower. This is partly due to the country's water shortage, particularly in the southern regions. Hydropower is provided mainly by dams. The country’s total installed capacity is 8,262 MW of which 1,770 MW is accounted for by hydropower. This power will be developed by 2020 to 2,700 MW by building new dams and pumping power transfer stations [43]. With 3,500 km of coastline, Morocco has potential for the development of pumped storage projects which could be coupled with other renewable energy facilities to provide a viable solution to the intermittency of variable renewables such as both solar and wind energy.

The office ONEE is the main player in the power sector. ONEE is implementing an environmental and social management system at the Al Wahada and Afourer hydropower plants. Moreover, the Ministry of Energy in cooperation with the German government is undertaking a study to assess the viability of seawater pumped storage [44]. ONEE is the fourth largest operator in the Spanish electricity market with the Morocco-Spain interconnection, which has an exchange capacity of 2,400 MW. Another interconnection between Mauritania and Morocco is also being assessed. In 2017 ONEE announced construction of two new pumped storage stations with a total capacity of 600 MW. The first, the El Menzel II station, will be located in the upper Sebou, and the second, the Ifahsa station, will be built on the right bank of Oued Laou. These projects will each have an installed capacity of 300 MW. Ifasha is scheduled to be completed by 2025. The completion of the Abdelmoumen pumped storage project (350 MW) located about 7km north-east of Agadir will support the Aferer project (464 MW). Abdelmoumen will become operational in 2020 and will add 350 MW of capacity to the country.

In addition, construction of the Khénifra hydropower plant (128 MW) has begun together with several small hydropower plans: Bar Ouender (30 MW) in Taounate Boutferda (18 MW) in Azilal, Tillouguit aval (26 MW), Tillouguit amont (8 MW) and Tamejout (30 MW) in Benin Mellal [45]. As perceived (figure *I.13*), portrays hydro power generation in Morocco.

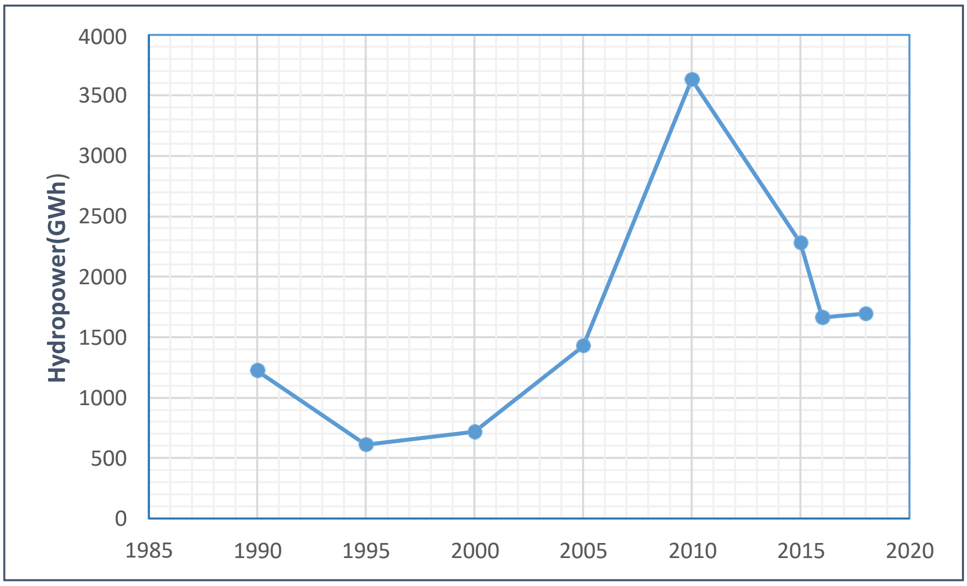

Figure I.13: Hydropower generation in Morocco.

I.2.7 Agriculture Promotion in Morocco

In recent years, Moroccan agriculture has grown considerably in terms of the extension of cultivated land, modernization and mechanization of the sector, diversification of agricultural products, profitability or an increase in the number of farmers.

The agricultural sector is now one of the pillars of the Moroccan economy: its contribution to Gross Domestic Product (*GDP*) is considered important, as the growth rate in Morocco is closely linked to the rate of agricultural production.

The issue of water is crucial for the development of agriculture in Morocco. It is linked to the network of dams that are spread throughout Morocco. Since the 1960s, Morocco has gained a great deal of experience in the construction of dams that have generated significant gains for the agricultural sector. The agricultural sector is, in many respects, a highly strategic sector for the socio-economic development of Morocco.

According to the annual rainfall, this sector accounts for between 12% and 18% of national GDP,11% of exports and 37% of jobs supporting more than 9 million rural people.

Agriculture is thus of strategic importance in terms of jobs. As such, it has always enjoyed sustained government support as a highly strategic sector for the country's development and food security. The majority of rural populations are poor and socially vulnerable. It lags far behind cities in terms of social development, particularlymeasured by high rates of illiteracy, poverty and mortality.

With its various aspects of modernity, infrastructure, public services and opportunities for social change, the urban environment arouses the covetousness of rural people.
This poses an immanent problem of rural exodus, overcrowding of cities and the creation of marginalized peripheral areas. Agriculture offers rural people the security of economic and social anchoring and thus helps to limit rural exodus and the risk of urban instability. Beyond its contribution to GDP, the activities of the agricultural sector have always had a decisive impact on the national economy and in particular on Morocco's GDP. This is due to the induced effect of rural income and expenditure, which make up 40% of the Moroccan population, on the national economy. In fact, efforts to date to modernize the agriculture sector and diversify the national economy, while important, have failed to decouple economic growth from the level of rainfall and performance of the agricultural sector.

Obviously, the growth rate of total GDP and the poverty rate are correlated. In 2018, the agricultural sector achieved satisfactory results for the second year in a row benefiting from favorable climatic conditions characterized by a good rainfall distribution. The 2017/2018 crop year resulted in cereal production of about 103 million quintals, an increase of 7.3% over 2017. This good performance drove up GDP of agriculture by 2.4%. The livestock sector has also consolidated, benefiting from improved pasture and forage supplies. Indeed, the agricultural value added in the 2017-2018 season has reached nearly 125 billion DH. Since its launch, the Green Morocco Plan has given great importance to the diversification and conversion of traditional crops, vulnerable to climatic vagaries and the impacts of free trade agreements, into competitive and high-rise crops. Value added. This arsenal of measures has transformed the structure of GDPA characterized by the reduction of THE sensitivity of GDPA to fluctuating cereal production and strengthened the resilience of our agriculture. Between 2008 and 2018, the weight of GDPA in GDP ranged from 12% to 14% with an average of 12.8%. As a result, the agricultural sector's contribution to economic growth increased significantly from 7.3% to almost 17.3%.

To meet the challenges of rural development and improving the productivity of the agricultural sector, Morocco implemented in 2008 an ambitious strategy for equitable and sustainable development of the agricultural sector in the Green Morocco Plan (PMV). The Green Morocco Plan aims to establish the agricultural sector as a real lever for socio-economic development in Morocco by accelerating the growth of the sector's capital gains, improving farmers' incomes and reducing poverty in rural areas, with the ultimate goal of transitioning to modern, inclusive and sustainable agriculture**.**

On the operational side, the PMV has set itself the objectives of: to print a harmonious, balanced and evolutionary dynamic for the agricultural sector that takes into account its specificities; to exploit the margins of progress and to make the best use of Potentialities; Addressing new challenges while maintaining social and economic balances; to support the profound transformation of the global agro-food system. To do this, the national agricultural strategy focuses on a comprehensive approach to include all the farmers' fringes in their diversity, according to their means and their development objectives. Thus, the design of the PMV is based on two distinct but complementary pillars:

– **Pillar I:** focuses on the development of modern, high-value-added/high-productivity agriculture, meeting the rules of the market by relying on private investments;

–**Pillar II**: concerns the solidarity support of small-scale agriculture, through the improvement of the incomes of the most insecure farmers, especially in landlocked areas. The mid-term results, recently presented by the Minister of Agriculture, show that the LMP's objectives have been largely achieved and that the LMP is now an international benchmark for a successful sustainable inclusive development of agriculture in developing and emerging countries.

I I.3 Conclusion

The agricultural sector accounts for a significant share of national energy consumption, concentrated mainly in irrigation equipment, tractors and motors, dryers and livestock buildings (milking blocks in cattle farming, air conditioning and heating in poultry farming, feeding equipment). In addition, indirect energy consumption resulting from the use of inputs (fertilizers, feed) and the energy impact of investments in buildings and equipment. In addition to its impact on the environmental quality of the rural area, energy consumption has a significant impact on the economic competitiveness of the Moroccan agricultural sector, severely burdening the operating costs of producers.
Agricultural.
In order to support the agricultural sector in reducing its energy bill and carbon footprint, the country intervenes at the level to control energy consumption by developing alternative energies; through a program dedicated to promoting solar pumping, and reducing energy consumption, through a program to optimize the energy performance of farms.
Farm Energy Performance Optimization Program Launched in partnership with the *Credit Agricole Group of Morocco* the farm energy performance optimization program is intended to support producers in actions aimed at reducing their energy bills, optimizing their consumption and encouraging the use of renewable energy. The objectives of this program are: Assessing the potential for energy saving and renewable energy production. Improving the competitiveness of the agricultural sector, through lower operating expenses by reducing the bills.

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CHAPTER 2:

II

Solar energy for water management and use efficiency in agriculture

Contents

II.1 Introduction

Over the last decade, climate change has been the topic of interest. Currently, it is considered an evident reality and impacts greatly agriculture, water supply, and our ecological sphere. In fact, the impacts are strongly related and agriculture is situated at the heart of this challenge. Agriculture is also the world largest driver of global warming and, at the same time, the most affected by these changes. Thus, a global agricultural transition is urgently needed to overcome the linearity of conventional evaluation methodologies which perceives farms as factories and counts plants and animals as industrial units. This energetic transition is the key step to rely on energy efficiency and restores social metabolism. The challenge is further complicated by the need not only to produce more, but also to sustain the entire food supply chain much more efficiently and reduce waste which has reached unacceptable proportions (estimated at 30% by FAO).

Generally, recent studies reveal that intensive agriculture transforms landscapes, degrades biodiversity and boosts genetic erosion. It pollutes the air, hydraulic sources and puts human and animal health at peril. In this sense, sustainable agriculture is the result of an equilibrated solution of many productive, technological, environmental, and economic issues. Among these, improving energy efficiency and reducing greenhouse gas emissions are vital. As agriculture becomes an energy-intensive consumer, an emergency call must be launched to attain a circular economy and sustainable goals [17].

Interestingly, sustainable agriculture has the unique potential to mitigate global warming and fortify the resilience of renewable solutions to face the impacts of climate change. Furthermore, several international organizations and initiatives are monitoring food security by creating the infrastructure for separate groups of stakeholders to come together to address economic, social and environmental synergies.

Agriculture in developing countries depend strongly on rain and negatively affected if water is insufficient. Thus, to improve water management, groundwater is pumped to reduce this dependency. Irrigation and rural water supply mainly use classic pumping systems; however, the unavailability or erroneous supply and high cost of diesel pumping remain the main problems that require special attention [46]. Closely, water use efficiency in agriculture will require an increase in crop water productivity and a reduction in water losses and pollution [47]. Many favorable policies for obtaining water use efficiency are available.

These include suitable integrated water management practices such an efficient recycling of agricultural wastewater, bio-fertilizers, and solar irrigation [48]. Farmers can choose many habits to progress their sustainability by local resources to guarantee long-term farm effectiveness, environmental management and improved quality of life [49]. Water conservation has become an important part of agricultural stewardship [50]. Solar pumping systems can be the most profitable answer when they are designed and sized accurately [51]. Moreover, they can be easily installed without needing long pipelines, and they are highly environmentally friendly [52]. Despite this fact, solar photovoltaic water pumping systems currently have a shorter life cycle cost compared to diesel systems [53].

Solar water pumps are often viewed as an expensive technology, unable to pump enough water and sustainably throughout the year. In Morocco, photovoltaic systems are the symbol of renewable energies and play a driving role in the energy transition. In 2020, renewable energies are expected to account for 42% of the energy consumed in Morocco and 52% in 2030. However, agriculture remains the biggest forgotten part of this transition since COP22. It depends largely on the rains and is affected by successive droughts. Poverty, famines and power shortages remain the major problem in remote areas of the country. Subsidized butane water pumping systems is used mostly in Morocco for irrigation and pumping groundwater.

In the same context, the use of fossil based irrigation methods infects and overexploits the groundwater in an abusive manner, which explains the unavailability of water in this country. The accelerated socio-economic development has resulted in increasing pressure on resources in water. Following the unprecedented increase in water needs in the agricultural sector, creating regional disparities and the emergence of acute pollution problems of water. Although some researchers in the Mediterranean Arab countries (*MENA*) have focused on solar irrigation and underlined SPVWP as an appropriate solution for a sustainable agriculture sector, but few examinations have been carried out under Moroccan context for the development of SPVWP.

To fill this research gap, the study seeks to examine the potential of a local area under regional meteorological conditions to integrate SPVWP. However, pumping of photovoltaic water wins' importance in recent years compared to conventional pumping systems. In addition, the pumping of water usually depends on conventional electricity or electricity produced with diesel and especially in African countries [54]. Solar water pumping minimizes reliance on costly and polluting conventional sources. Solar pumping systems are environmentally friendly and reduces maintenance costs and increasing fuel costs [55]. Thus, the use of SPVWP can be able to contribute to the socio-economic development [56].

The cited systems before, conserves electricity by reducing the usage of conventional methods and conserves water by reducing water losses [20]. The proposed model ensures to work forsmall and medium irrigation needs to take advantage of the power produced by the system. Optimizing this type of PV irrigation involves considering both PV subsystemsand irrigation requirements [57].

To sum up, a conceptual framework is proposed to figure out the most adapted SPVWP system for poor farmers and small and medium scales applications. Therefore, the purpose of this article is to introduce a detailed approach for the design, technical and economic evaluation of SPVWP systems and to give a guideline to local installers and decision-makers for integrating renewable sources in Moroccan agriculture. A first case study dealing with the irrigation of tomatoes and their water supply, to consolidate family agriculture is investigated. In addition, a second case study focuses on the irrigation of medium-sized crops (6 ha in olive trees) using the drip method to improve the performance of SPVWP systems. A complete performance analysis based on dynamic simulations is developed to highlight the most viable coupling configuration for local irrigation. In this regard, we adopted a SWOT approach to investigate the internal strengths and weaknesses, as well as the external opportunities and threats for PV solar pumps development in Morocco.

This new advanced regional study will make a decisive contribution to the economic and social development of the country, through the enhancement of water potential and resources, the mobilization of various local actors, and participation in the development and implementation of structuring projects, and the strengthening of agricultural attractiveness.”

Finally, based on the obtained results and according to available energy resources, this work revealed a significant contribution in the selected region to hold more than 17000 solar pumps with capacities between 0.6 up to 40 kW, and the possibility to convert more than 80% of existing butane-powered pumps to PVWP. This proves that solar pumping must be widely considered as the most suitable solution to manage water and reduce almost agricultural CO_2 emissions.

II.1.1 Solar Photovoltaic Water Pumping System

Several works affirm that PV pumping system has some leads of saving operating costs and reducing CO_2 emissions in comparison to conventional methods. Also, the investment payback period is found to be 4–6 years [58], when the energy is from the sunlight. Apparently, photovoltaic is one of the main applications of the autonomous pumping systems [59]. It consists of a water pump driven by an electric DC motor and powered directly by solar panels through an MPPT system. PV pumping systems are widely used in areas for agricultural purposes. However, there are many disadvantages of PV systems [60]. They have high costs, unreliable operation and maintenance which are considerably higher if the batteries are used [61],[62],[63]. Recent works have focused on system modeling for an optimum management of energy to store the monthly irrigation needs [64]. SPVWP systems can include a water tank [65], or electrical storage of energy [66], [67]. Most of the studies dealt with remote-controlled water storage [68]. In these studies, valid areas for the implementation of SPVWP wereevaluated through the processing of local spatial datasets. Many kinds of research on the sizing of the photovoltaic pumping system have been published [69], [70]. These studies are centered on the simulation of the functioning of each component of these SPVWP systems. However, the design of any cost-effective solar energy system requires experimental data that are not willingly available. The widely proposed system consists of the use of the directly coupled system to produce electricity. For more flexible irrigation planning, the system can supply water to a reservoir or a collection basin, and thenwater runs from the basin to the crops through a drip irrigation facility. The direct coupled solar water pumping system to supply water for drip irrigation is shown in (Figure *II.1)* [71].

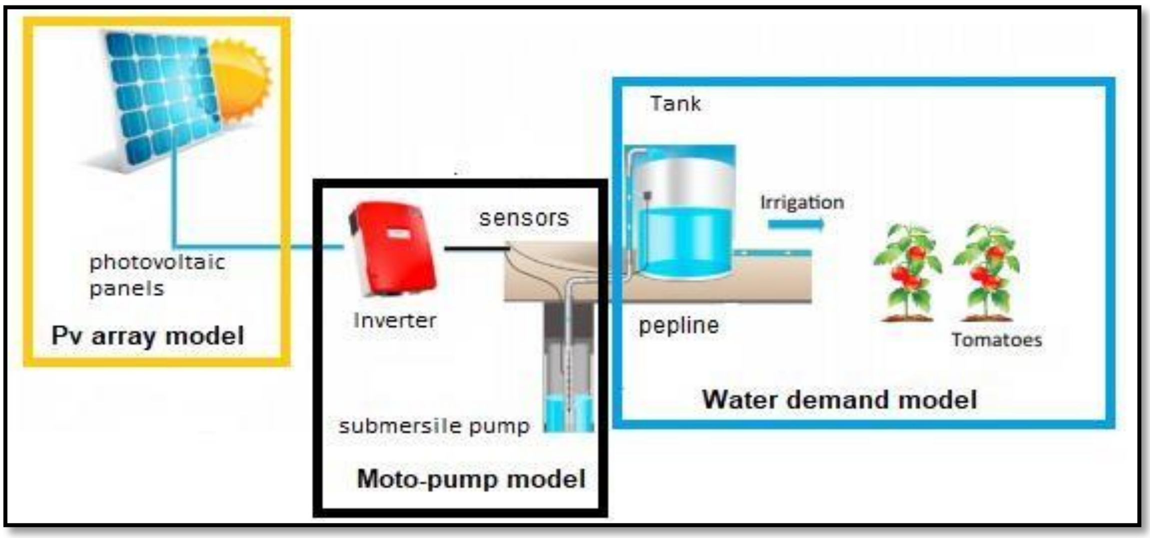

Figure II.1: Schematic diagram of PV water pumping.

The PV modules are linked in series and parallel for the working of a pump motor sub-system that will demand power to generate a certain total of pressure and water flow. The pump speed depends strongly to the solar radiation received by the PV generator. One should state that, if an MPPT is used, the electrical energy delivered to the motor is nearly stable. DC or AC motors generally use the centrifugal pumps in PV pumping systems, which have generally a long-term reliability and hydraulic efficiency differing from 25% to 35% [72]. Direct coupled (*DC*) solar pumps are simple and consistent [73], but cannot run at the maximum power point of the PV generator as the solar radiation varies during the day [74]. It is increasingly evident that SPVWPs are a key criterion for water efficiency. Many researchers have investigated those systems in the MENA and sub-Saharan region, but little literature analyzed the case of Morocco. To review more subsequent literature, Table *II.1* gives a summary of regional investigations.

Table II.1: Summary of SPVWP performance investigation in MENA and sub-Saharan region.

Ref.	**Location**	**System specifications**	**outcome**
[75]	Nigeria	Pumping rate: 2.6m³/h Pv array :1.6 kW$_p$ Borehole:30m	- Solar pumps can replace conventional AC pumps. - Solar pumps can meet the water demand of 20 m³/day at 5 kWh /m2/day.
[76]	Africa	39 cases studied Medium Heads: 50 m Power range :0.7 to 4 kW$_p$	- Due to their technical ability and their cost-effectiveness, solar PVP system can replace the diesel engines for drinking water supply system and irrigation in Africa and rural areas. - Average price 30cents/m³
[77]	Algeria	Pv array : 2.4 kW$_p$ Pumping head: 0 to 120 m Flow rate: 0 to 30 m3/h	Multistage centrifugal solar PV pumps coupled to DC motors show significant efficiency for high head applications (40~70 m)
[78]	Algeria	Pumping head: 12.5~13.5 m Tomato needs: 1012 mm/day	PVWP used efficiently for water pumping in agricultural sectors.
[79]	Tunisia	Pv array: 85 m² (100Wc, 24V) Pump system efficiency: 45(%) Water pumped: 40 m³ /ha/day	- Studied the economic viability of SPVWPS to satisfy water requirement in Tunisia desert. - Cost of water :0.18 $/m³
[80]	Egypt	water head=40, 80, 120 m water flow:15m³/feddan/day (for drip irrigation).	- The cost of the water unit pumped by PV systems (0.11~0.33$/m³) is much less than that pumped using diesel systems (0.51~0.94$/m³). - The water cost is more sensitive to the PV cell's prices than the life-time periods.
[81]	S.Arabia	Batteries: two batteries of 12 V Pv: 2 panels (35 V generated)	This study presents the usage of photovoltaic electricity in an automated irrigation system, which optimize water requirement.
[82]	Algeria	Pv array: 1.5 kW$_p$ Pump capacity: 80 l/min Head : 33 m Moto-pump efficiency: 30%	- The system runs without battery and complex electronic control, as a result the initial cost is low and Maintenance, costs are saved - Directly coupled photovoltaic water pumping systems are suitable for low head applications.
[83]	Algeria	______	- Proposed intelligent control method for MPPT of PV systems, to ensure high flexibility.

It has been concluded that SPVWP systems can be used efficiently for irrigation in agriculture and rural areas. The price of the water pumped by those systems is muchless classic methods. Conventionally, almost all studies related to solar pumping systems reported positive impacts about their widespread integration.

II.1.2 National background and target area

Morocco is situated in the Maghreb region of North Africa, separates by the Mediterranean Sea from Spain to the north. Recent global warming studies confirmed that Morocco is among the countries more menaced by climatic change [84]; in 2008 the Moroccan government announced an agricultural strategy called "Plan Maroc Vert" [85]. The objective of this strategy is to promote the productivity of agriculture by addressing as well as climate change, over-exploitation of groundwater, and poverty [30]. In Morocco, irrigation is very water-intensive; it is estimated that about 83% of available resources are used by agriculture with an efficiency of less than 50%.

Morocco is a dependent nation on agriculture as it is responsible for 20 % of the Gross Domestic Product. This sector plays an important role in food security and sustainable development. According to Ministry of Agriculture and Maritime Fisheries data , the total area of Morocco is 71.085 million hectares. Agricultural, pastoral and forest lands represent 38.7 million hectares or 54.4% of the total area. The useful agricultural area (*UAA*) lands cover almost 9 million hectares, forest occupies 5.8 million, and rangelands represent 21 million hectares. Irrigated agriculture in Morocco occupies only 19% of the UAA, as illustrated in Figure.*II.2*.

Figure II.2: Part of irrigated agriculture in Morocco.[9]

[9] according to annual reports of the Ministry for agriculture(http://www.agriculture.gov.ma/)

The agricultural activity is exemplified in the Sebou River, which is responsible for half of Morocco's sugar production, as well as most of the country's olive production. The most fertile part of the Sebou is the Saiss Basin (Figure *II.3*).

It holds about a quarter of Morocco's arable land but only uses a little of the national water reserve. Moreover, this water is often overexploited and poorly managed. The potential region under investigation Saiss (Fez-Meknes) have a strategic geographical position. Given the beneficial climatic conditions for most crops, the region of Fez-Meknes knows a great diversity of plant and animal production, in addition to the existence of a significant activity of the food industry. Fortunately, the Fes-Meknes Region, covers an area of 40,075 km², representing 5.7% of the Kingdom's surface area (i.e.14% of soluble soils). The land use is relatively varied with a dominance of cereals (60%), the rest is occupied by fruit plants (14.4%), legumes (6.6%), industrial crops, beet and sugar (4.2%), oilseed crops (3.6%), vegetable crops (3.1%), and fodder crops (1.7%).

Figure II.3: Boundaries of Saiss region and selected case study.

II.1.3 Objectives and Key inputs

The objective of this work is to present a low-cost solution and assess the performance of photovoltaic pumping to power small-scale activities to consolidate familial agriculture in Morocco. The solar radiation data were collected from local databases, and then imported to PVsys software database using its meteorological tool [86]. The Irrigation water requirements were evaluated using the software Cropwat [87]. It is designed as a useful tool for carrying out estimations of reference evapotranspiration, crop water, and more explicitly the design and management of irrigation. Calculations of crop water requirements and irrigation needs are generated with dynamic inputs, (climate data, crops, soils, local geographic data…).

Calculations of crop water requirements and irrigation needs are generated with dynamic inputs, (climate data, crops, soils, local geographic data…). To better provides recommendations for improving irrigation practices, it is necessary to consider planning irrigationschedules under changing water supply conditions and valuing production under scarcity of rainfall [88].

This paper represents the theoretical design and computer simulations analysis, as a method for optimizing direct coupling systems and evaluating their performance. The life-cycle cost analysis is also carried out. Generally, Optimal sizing methods use ‘’the worst month’’ or average values. Consequently, systems can be oversized or undersized. In analytical methods, mathematical equations used for sizing of the system, but those methods are limited and less exact. In contrast, numerical methods are most applied due to their accurate dynamic simulations.

A new contribution of this work includes an assessment of configurations according to the system of regulator of the installation of pumping:

- Direct coupling.
- MPPT DC-DC regulation.

In this study two systems in different locations were considered to deliver a daily needof 36 and 134 m ^{3}/day with well depth in the range of 20 to 50 meters. For external environmental data, it must be used as input during water needs calculation as well as SPVWP design.

Thus, the work follows an observation of regional meteorological data before the use of METEONORM [89]. The Saiss region is characterized by the diversity of its soils where three main types of soils can be identified. It should be noted that Saiss is characterized by rich soils and is full of important agricultural potentialities.

In terms of precipitations, the region is characterized by a continental climate in the north, cold and humid in the mountains, and a semi-arid climate in the Missourian highlands. This variability of climate leads to a diversity of cultures that adapt better to the specificities of this region. The average annual precipitation is 520 mm, which places the zone in the favorable market.

It should be noted, however, those inter-annual variations can be very important. The rainy period extends from November to April. The biologically dry period lasts five months (May to September) as shown in Figure II.4.

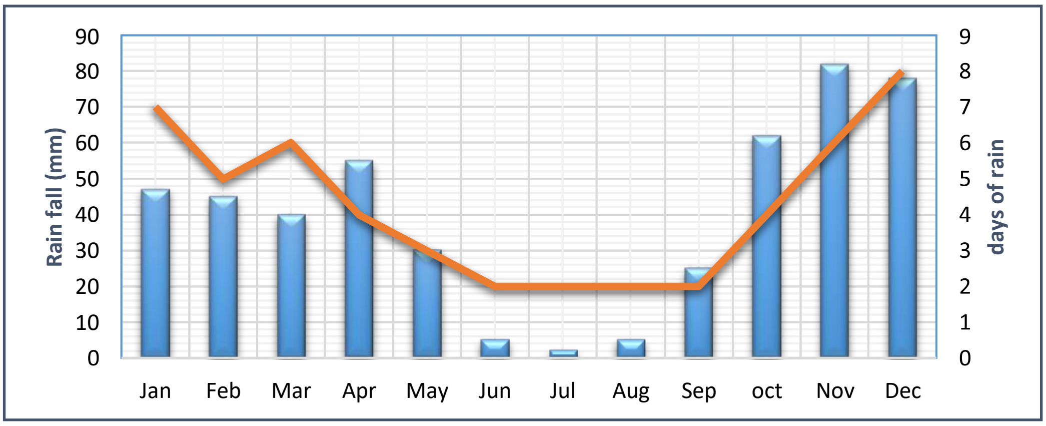

Figure II.4: Rainfall in Saiss region. 2000-2018, 4% uncertainty of yearly values.

While Figures II.5 –II.6 shows the temperature profile observed in the period 2000-2018 with the uncertainty of yearly values T=0.3°C. Locally, the average annual temperature is 18°C. The annual averages of minimum and maximum temperatures are 11.3 °C and 26.5 °C respectively. The coldest month is January, followed by December and February. The average temperature of the coldest month is 11 °C and the minimum temperature is 5.5 °C. The hottest month is August, followed by July. The mean exceptionally temperature of the warmest month is 38.5 °C. It coincides with the high radiation registered in the region. Figure 6 shows the monthly distribution of global irradiance, the global solar radiation is maximum during the dry season (May to August) and distributed from 9 to 16 am of the day, which particularly fits the irrigation period.

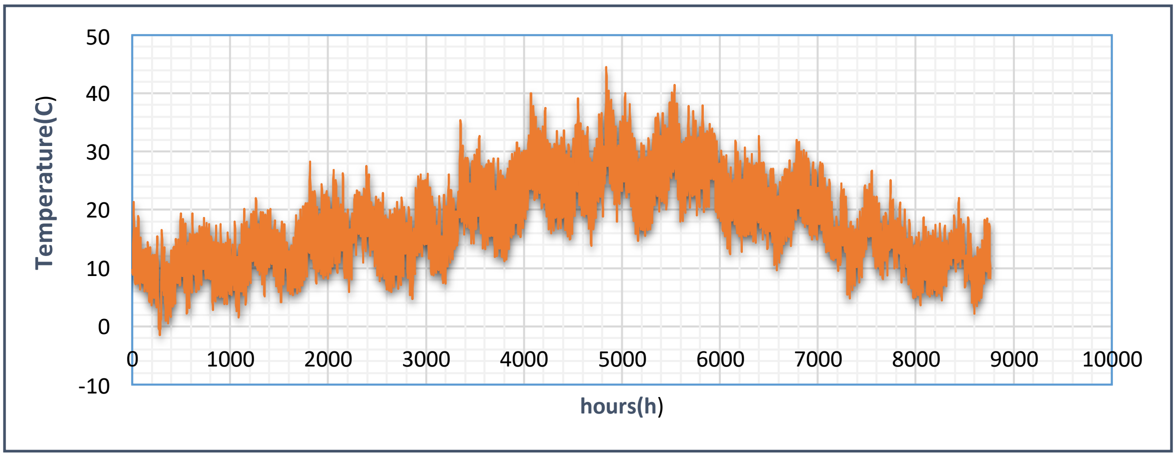

Figure II.5: Annual temperature profile.

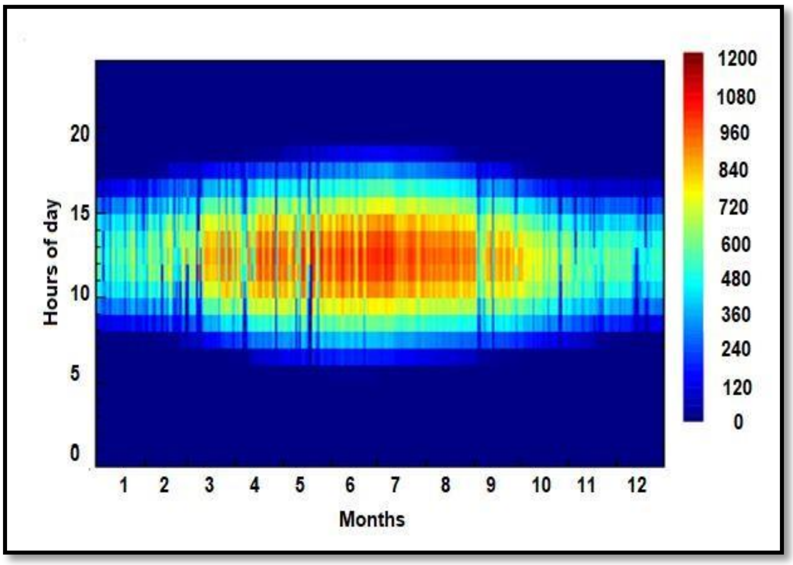

Figure II.6: Annual temperature profile.

To summarize observations during the year 2016, Table II.2 gives an overlook on climatic parameters that can influence directly or indirectly solar pumping systems. It provides illustrations of detailed weather data for the area of Fes-Meknes temperature, the predictable number of sunny days, evapotranspiration and rainfalls status to lead more researches in this region. The literal data for water pumping requirements were examined, measured, then compared and presented in results section.

Table II.2: Monthly Climate parameters in Saiss region[10].

Month	T_{max} (°C)	Humidity (%)	Wind (km/day)	Sun (Hours)	ETo (mm/day)
January	20.0	74	233	6.7	2.06
February	18.0	67	311	7.3	2.74
March	19.0	64	294	8.0	3.35
April	23.0	67	302	8.9	4.23
May	27.0	64	294	9.6	5.27
June	33.0	52	328	12.1	7.52
July	38.0	49	294	12.1	8.37
August	38.0	50	302	11.9	8.23
September	33.0	58	277	10.7	6.09
October	29.0	62	294	8.9	4.58
November	20.0	66	302	7.7	2.80
December	18.0	72	233	6.8	1.87

I I.2 Conceptual framework

In this section, a brief description of sizing process and conventional mathematicalmodel are reported. The performance and economic indices are also carried out.

II.2.1 Sizing procedure

- **Water requirements**

The assessment of crop water requirements is a critical step to sizing every irrigation system since it depends on climatic and crop parameters [90]. In theory, the water requirements are precisely defined as the difference between the amount of rainfall and the Cultural Evapotranspiration (*ETP*) [91].

Theoretical methods can be used (e.g. the Blaney-Criddle method) to determine the reference crop evapotranspiration (ET_o) [92], especially under "extreme “conditions, the ET_o is undervalued (up to 60%), while in calm, humid, clouded areas, the ET_o is overrated (up to 40%) [93].There are many other equations more or less simple, in our case, evapotranspiration can be estimated from several years weather data from the nearest meteorological station or through the maximum temperature (T_{max}) using the regression following equation, [94] :

$$ET_o = 0.16\ T_{max} + 0.14 \qquad (1)$$

The evapotranspiration is calculated from ET_o taking into consideration a specific cultural coefficient K_c dependent on the type of crop and growing phase [95].

$$ET_c = ET_o \,.\, K_c \qquad (2)$$

The net requirement (*CWR)* and the gross water requirement (*IWR*) are calculated bythe following equations, respectively [96]:

$$CWR = (ET_c - P_u) \qquad (3)$$

$$IWR = \frac{CWR}{\eta_r} \qquad (4)$$

with P_u represents 60% of the total monthly rainfall, and η_r is the overall irrigation efficiency (for Drip irrigation, $\eta r \cong 95$ %).

Referring to local authorities, carrying out on-site interviews with farmers and monitoring chronological archives of water demand are usually the main means of validating the calculated demand for water [97].

- **Selection of the pump motor**

For the application of PV water pumping, there are two main types of pump technologies: Pumps positive displacement and centrifugal. Positive displacement pumps are used in low volumes and cost-effective systems. Centrifugal pumps are generally exploited for applications with photovoltaic energy because of their feeble initial couple drive, and it runs with very low sunshine, for medium and high flows [98]. The daily hydraulic energy of the pump and its efficiency can be expressed by the following equations:

$$E_{hyd} = \rho . g . H . IWR \qquad (5)$$

$$\eta_p = \frac{P_{hyd}}{P_{mec}} \qquad (6)$$

where $E_{hyd}$the hydraulic and H is the total head. The hourly rate is calculated by the following formula:

$$\phi_h = \frac{IWR}{\Delta t} \qquad (7)$$

The global system efficiency η_g is equal to the product of the PV array efficiency and thesubsystem (motor and pump) efficiency η_{sys} and given by the following expression:

$$\eta_g = \eta_{pv} \, \eta_{sys} \qquad (8)$$

where η_{pv} is the efficiency of the PV array under running conditions, given as following:

$$\eta_{pv} = [1 - \alpha \ (T_c - T_r)] . \eta_{pr} \qquad (9)$$

where f_m is the matching factor (f_m= 0.90), η_{pr} is the efficiency of the PV array at reference temperature T_r. The Factor α is the temperature coefficient for cell efficiency.

- **Photovoltaic field**

Two procedures are handled for sizing pumping systems: Analytical method and graphical method [99]. The sizing of the photovoltaic field proper is the series-parallel arrangement of the panels which is determined in conjunction with the choice of the pump to ensure compatibility between supply and energy requirements [100]. The effective area of the modules can be found by following:

$$A_{pv} = \frac{(\rho\, g\, H\, \phi)}{G_t\, \eta_g} \qquad (10)$$

where G_t is the solar radiation received, and global system efficiency η_g.
The peak power P_c regarding hydraulic power efficiency can be expressed by the following equation:

$$P_c = \eta_r\, A_{pv} \qquad (11)$$

with η_r overall efficiency of the PV system, assuming 20% losses due to temperature.And A_{pv} is the total PV array.
The total number of modules N_{pv} constituting the Generator PV is calculated by the following formula [101]:

$$\boldsymbol{N_{pv}} = \frac{P_c}{\boldsymbol{P}_\text{p}} \qquad (12)$$

with P_p is the power of one PV module.

II.2.2 Examined configurations and simulation process

The purpose of this section is to examine the optimal configuration of the PV systemable of providing a submersible solar pump to meet the needs of remote crops. Consequently, two approaches are supported in search of an optimal design accordingto the size of the plots, the energy and hydraulic needs and the depth of the wells.

Firstly, the direct coupling configuration, which is most common in small scale practices because of its technological simplicity. Secondly, an improved configuration with a DC-DC converter equipped with a MPPT regulation assisting as a linear current booster. Indeed, to perform the PV system, PVSYST was used. It is designed to consider all the parameters and the avoidance of the losses of the system and the calculation of its performance.

II.2.3 Performances parameters

The performance of PVWP systems is evaluated on a monthly basis using many significant parameters including: energy output at the pump, system array and system energy losses, system efficiencies, and especially performance ratio which represents the ratio of the energy produced compared to the energy that would be produced by a system under standard conditions [102].

To calculate the performance ratio, two critical parameters are calculated, system's final yield Y_f and reference yield Y_r as expressed respectively in following equations:

$$Y_f = \frac{E_{net}}{P_o} \qquad (13)$$

with E_{net} is net energy output in kWh and P_o the Installed PV array in kW.

For PVWP, the system yield is the effective energy at Pump.

$$Y_r = \frac{H}{G_r} \qquad (14)$$

(

with H is Total plane irradiance in kWh/m^2 and G_r is PV reference irradiance in kW/m^2. The PR is the important factor to evaluate the performance of PVWPs and their continual guarantee and it is stated as percentage [103]:

$$PR\,\% = \frac{Y_f}{Y_r}\,100 \qquad (15)$$

II.2.4 Field survey and cost analysis

In Saiss region, the investigation shows that groundwater depth is between 9 and 19 m,it is s decreasing with an acceptable average of 0.5 m/year; which represent an opportunity for solar pumps and Smart irrigation to replace classic and abusive methods. The investment and operating costs can be very different for the same type of energy used. This study focused on small and medium-sized plots of 1 to 6 Ha to encourage the use of the PVWP systems for familial agriculture. This investigation helpsto underline the most adapted system for the region.

Crops selected are near to farmers and their homes **(**Figure *II.7***)**. For a long-term performance for pumping systems so they can pump water for trees and animals, dry aliments, and generate electricity for locals.

Figure II.7: Location of farms, village of Kasbah Hartal (33.930342, -.60077°).

In order to acquire the necessary information, the approach used does not seek to compare farms with each other, but a comparison for one potential farm. Information is analyzed and evaluated using triangulation. It is a method of analysis where potentially opposing results from multiple sources are compared to find valid data.

Investment and operating costs would be compared according to different energy systems for estimating the cost of 1 m^3 of water. The cost of installing a solar power system was evaluated from Pvsyst and compared with market prices. It used to calculate installation costs, from several operating parameters such as flow and well depth or borehole. The software determines the number and cost of solar panels and the cost of the electric pump and the drive to install [104]. Maintenance costs were estimated from the farmers surveyed.

The cost of installing an electrical energy system includes the cost of installing and the cost of the connection.

The latter was therefore not considered in the investment calculations because itdepends on the distance from the electricity network.

The operating cost is the cost of using energy, by the farmer, for pumping irrigationwater over an average rainfall year. It is estimated by the following formula:

$$OC = \beta \,.\, Q \,.\, t \qquad (16)$$

where β is the hourly pumping cost per cubic meter, with t =1700 h/year estimated for the region; And Q is the hourly flow rate.
The economic feasibility focuses on the levelized cost of water as an economic parameter to evaluate the cost-effectiveness of the designed SPVWP system.

- Levelized cost of water (*LCOW*) in $ /m³ can be calculated as:

$$LCOW = \frac{Annual\ operating\ costs}{365 \times Q} \qquad (17)$$

II.3 Cases studies analysis

The purpose of this paper is to develop a decision-making approach for an optimum implementation of solar pumps in the country within various regions. Thus, the reflective methodology is applied for two scenarios using two possible configurations. The main aim is to prove the opportunity for a reliable integration of PV systems. In this regard, the first case corresponds to 1 ha of tomatoes adapted for small farmers. The field survey in the region shows that most farmers involved in market gardening have small plots. 70% have farms that do not exceed 6 ha. The second case concerns the irrigation of 6 ha of olive trees in Meknes-Fes, which is the emblematic region of olivesin Morocco.

II.3.1 Comparison of two configurations for seasonal irrigations and small crops

II.3.1.1 Determination of the water requirements.

This was experimentally investigated that tomatoes need an average of 145 days to produce. It can be grown 2 times even 3 times in the year. However, it is necessary to study the worst case when the tomato is planted in May, for the development phase, it coincides with the dry season.

The assessment of irrigation needs remains a critical step before modeling pumping systems. For this reason, ET_0 estimation and water requirements for vegetable cropswith accurate meteorological information were imported and calculated using the CROPWAT tool, then compared to analytical calculation for the region studied.

According to the results, the reference evapotranspiration (ET_0) is higher from May to September and highest in August with 9 mm/day **(***next page* Figure *II.8***)**. This coincides with a decrease in precipitation **(***next page* Figure *II.9***)**. Using the information provided and the calculation of evapotranspiration, the effective rainfall is estimated at 80% of the total monthly rainfall. Notably, (ET_0) is maximal with an average of 7 mm /day at the time of the year when the higher values of irradiance were recorded and scarcity of rain falls.

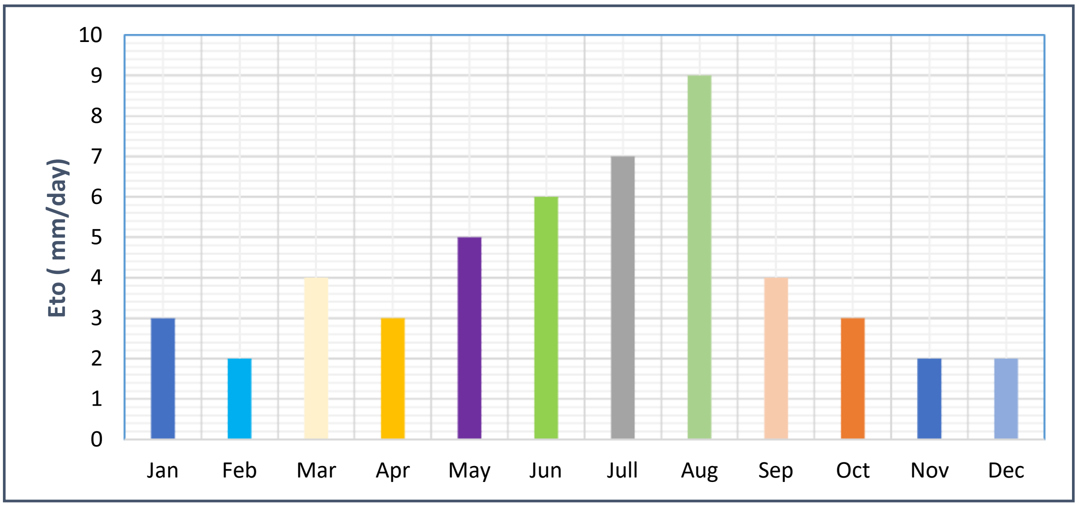

Figure II.8: Reference evapotranspiration for Sais Location.

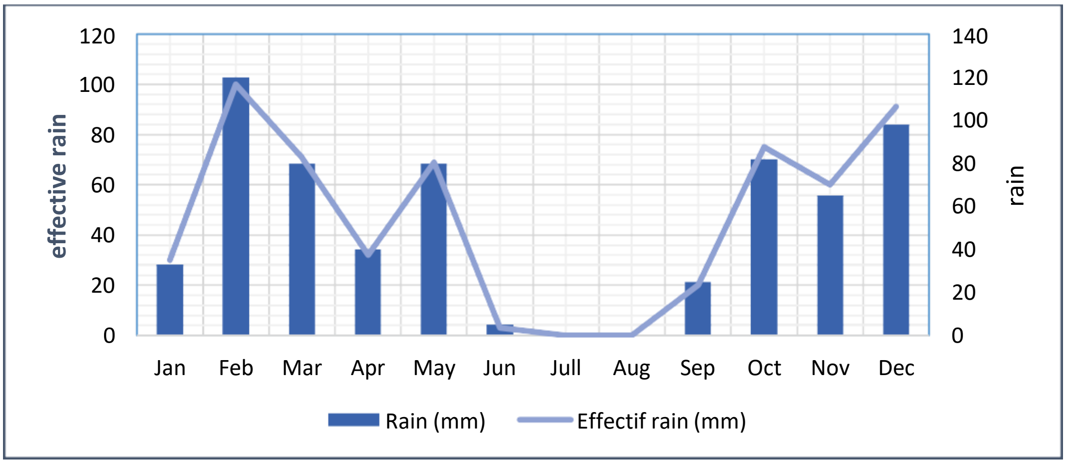

Figure II.9: Rain and effective rain calculation.

It is well-known that irrigation needs depend on many parameters: climatic conditions, type of plantation and irrigation technology. As necessary and critical to determine Specific cultural coefficient (Kc) during the entire cultivation phase.

As shown in figure *II.10*, for tomatoes planted in May, Kc varies between 0.6 and 1.5.

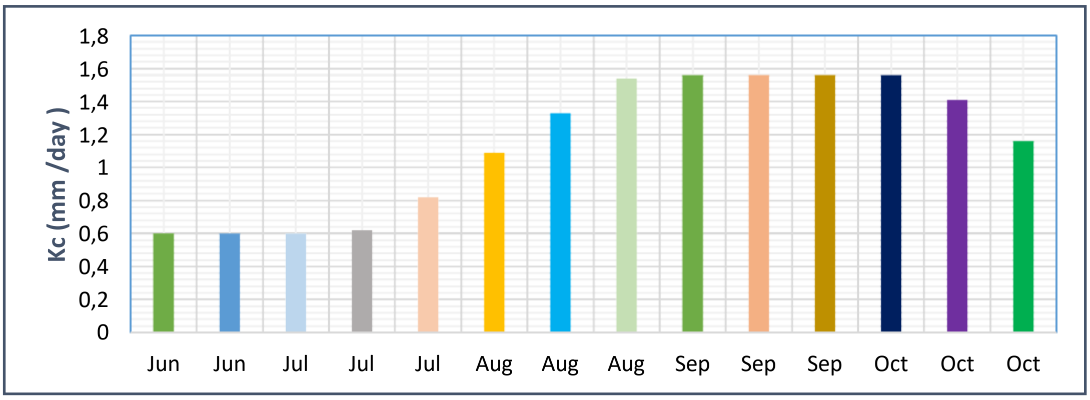

Figure II.10: Tomato Kc coefficient progression between Jun and November.

Additionally, the monthly average water requirements for growing tomatoes and the trend of specific evapotranspiration are presented in (Figure II.11). The water demand registered the peak value in August when the evapotranspiration is maximal too. Thus, to reach efficient irrigation, it is necessary to determine water requirement per decade.

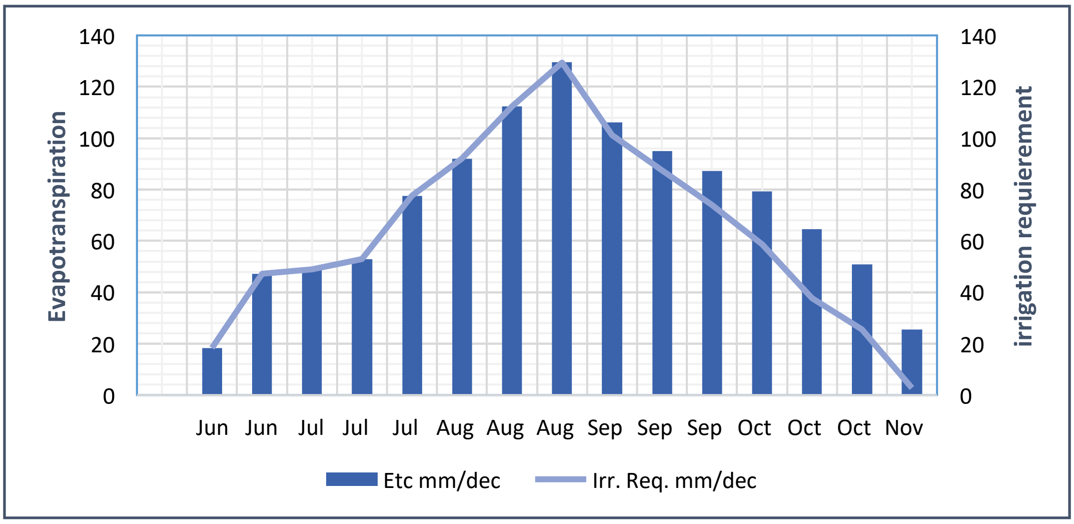

Figure II.11: Irrigation water requirement per decade for tomatoes.

Drip irrigation is the suggested to ensure the needs of tomatoes. As shown, the applied model and calculations estimate the daily average water demande for tomatoes at 36 m^3/ha /day. As an example of the first decade of September, in which irrigation requierements are about 100 mm/dec, an average of 10 mm/day, also 100 m^3/ day.

Table II.3 presents the calculated water requirements for the most frequent crops compared to practical water needs. Furthermore, there is not much difference are observed which confirm the feasibility of current calculations.

Table II.3: Water requirements in Sais region.

Crops	Practical (m^3/ha/day)	Calculated (m^3/ha/day)
Olive	17- 20	22
Vegetable	30-70	60
Forage plant	20-60	50
Cereals	20-40	15-30

II.3.1.2 PV Sizing results

Results revels that to cover such needs, it is proposed to use a solar pump of about 2.9 kW, with a peak power of 3.7 kWₚ of the surface PV and 20 % of accepted Missing. The characteristics of pump and PV module to be installed for this case are presented in Table *II.4*.

Table II.4: The main characteristics of system to be installed.

Component	Characteristics
Centrifugal pump	Model PS4000 C-SJ8-15, Lorentz Pump Technology Centrifugal Multistage Deep well pump Motor DC motor, brushless Associated or Integrated MPPT converter with voltage range 220 - 340 V.
PV Array	PV module Si-poly Model YL175P-23b Manufacturer Yingli Solar.
PV modules	Coupling 15 PV modules, with a total area of 19.5 m².
Pipe and well	The length of pipe was estimated at 40 m with 3 elbows, it is a pipe of 6/ 8 mm in diameter. The well depth is 37m.
well	The well depth is about 37m.

Considering the daily need in peak months. The pump selected was tested without regulation for many depths. The results show the performance of the direct coupling for low heads (34 and 43 m). As shown in Figure *II.12*, for example at 43 m deep well the system can attend 320 m³/decade, with a daily flow of 34 m³/day, at the average power of 1.5 kW and with hours of daily irrigation variably are between 3 to 6 hours.

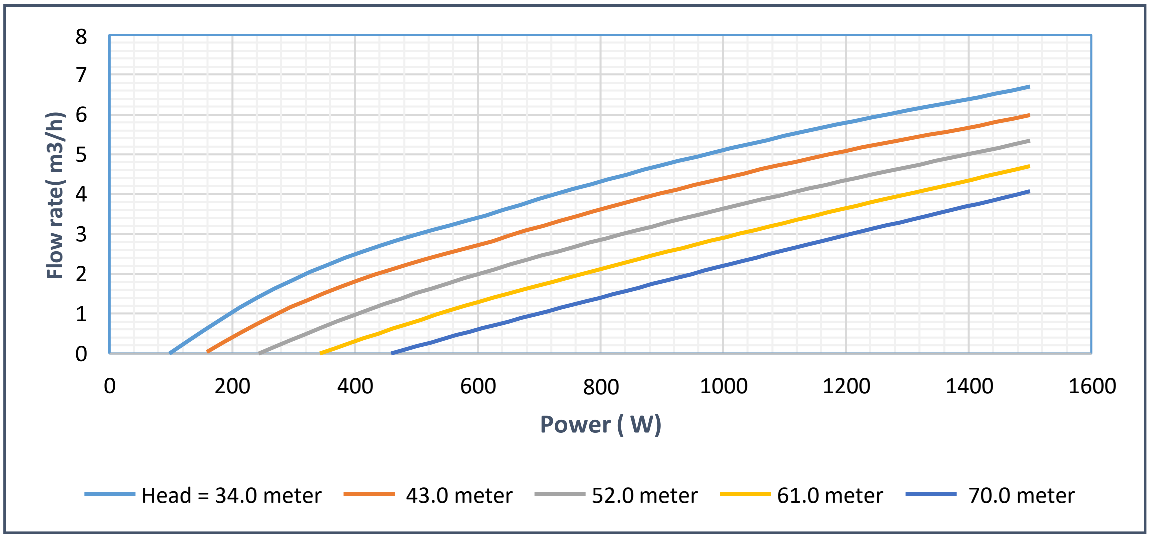

Figure II.12: Daily water flow for many Heads depth.

At reference conditions of Total Irradiance = 1000 W/m², Cell temp = 25 C, the nominalefficiency of the module is about 13.23% with a maximal power of 169.970 W, where themax power voltage is 23 Volts and the max power current is 7.4 Amps and the short circuit current is 8.1 Amps as shown in figure *II.13*. The system proposed can provide an average of 8 m ³/h when using an MPPT converter. Under usual conditions in the region, it is possible to attain 26m ³/ day. The system was examined through the whole year with dynamic simulation in order to estimate hourly outputs. It can be obviously realized from Figure *II.14* that for the system with a MPPT/DC converter, the pump starts to operate with a minimum of 180 W and the flow rate increase until the input power reaches 1.4 kW.

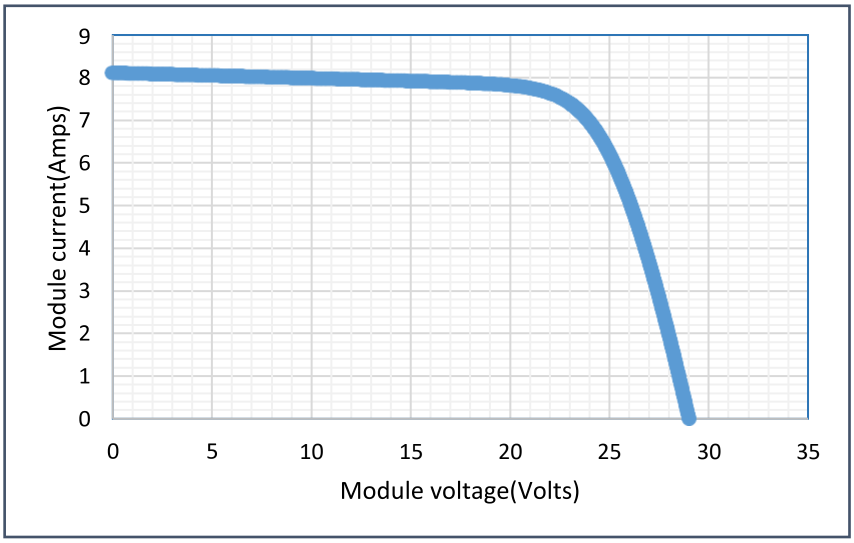

Figure II.13: PV Electric characteristics.

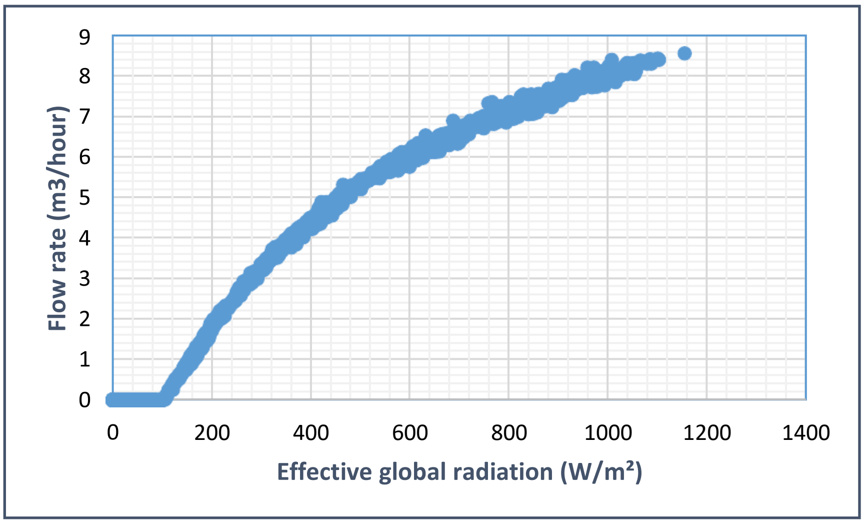

Figure II.14: Flow volume rate by radiation.

For both configuration direct coupling and MPPT/DC, the hourly flow in function of available energy at the pump are illustrated in Figure *II.15*. The system equipped with the MPPT DC converter is capable to provide water for low pump effective energy as faced to the direct coupling configuration. This could actually justify that configuration with MPPT DC converter starts to pump water at lower radiation and can also reach a high flow during the day.

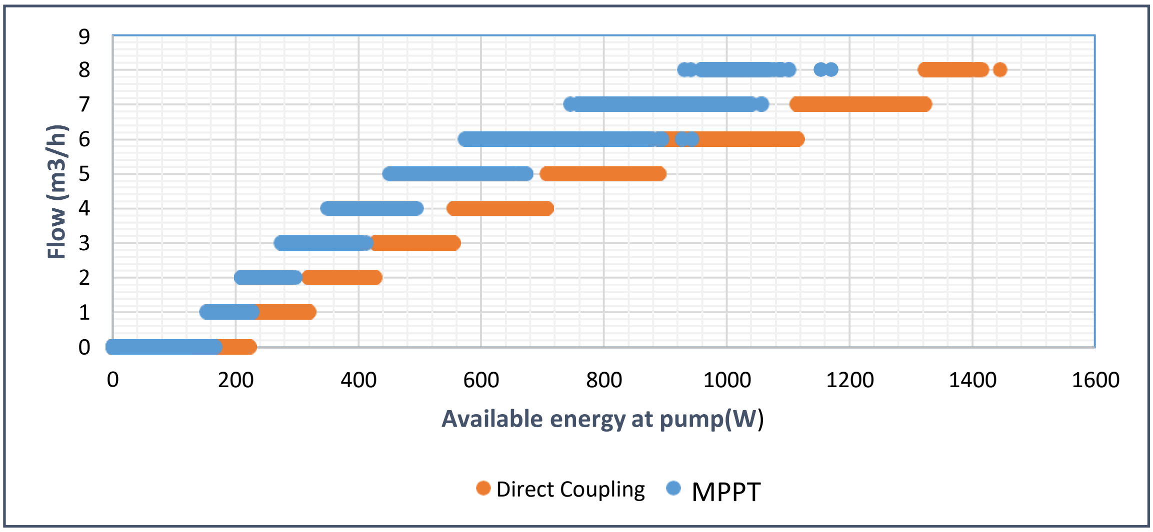

Figure II.15: Flow as a function of available energy.

II.3.1.3 Overall system performance

The Comparison of configurations analyzed predict the performance of systems with MPPT/DC. In next, figure *II.16* illustrates the monthly energy available at the pump and the losses of the system for both configurations. The numerical results indicate that the monthly values were expressively better, and the losses are reduced for the installation using a DC MPPT converter. In the dry season, they were generally less than 4.2 kWh/kWp/day for the direct coupled installation and greater than 5 kWh /kWp/day for the regulated.

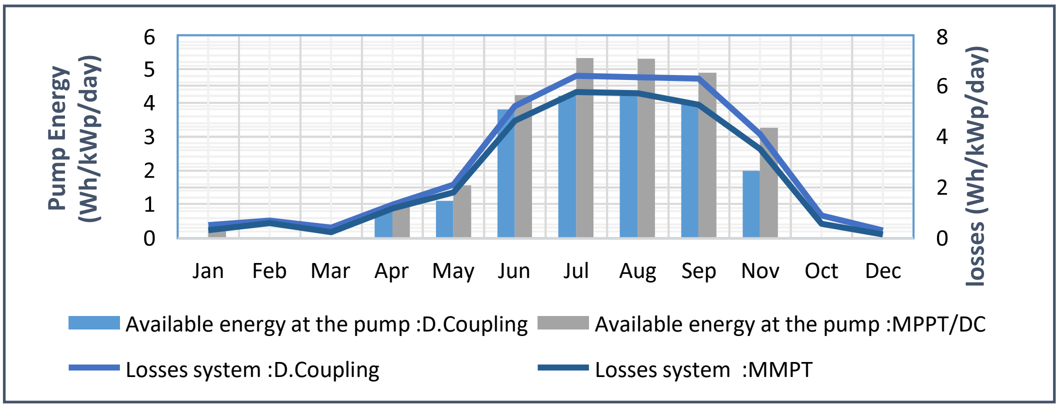

Figure II.16: Pumped energy and losses for the two configurations.

Based on the conducted analysis, the performance ratio (*PR*) gives a monthly review of whole system efficiency, it includes PV array losses, module quality, mismatch, cabling, etc.), and system losses (Solar pump, controller efficiency or storage/ battery/standby losses, etc.). Clearly, in Figure *II.17*, it can be seen a significant variability of the PR for both configurations. The PR diverged between 58% and 73 % in the dry season for the MPPT structure. While, it varies between 40% and 55% for the direct coupling design.

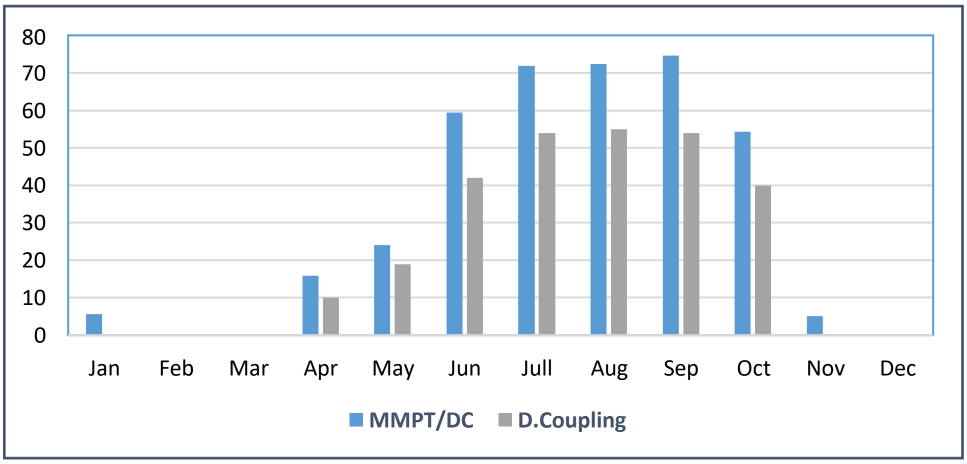

Figure II.17: Performance Ratio PR% of both configurations.

II.3.2 Configuration with MPPT coupled to drip irrigation for Olives

In this section, the results are substantially better when regarding requirements, assumptions and olives characteristics. The choice of olive was taken by consideration, to give an opportunity for the symbolic tree in all MENA countries. Through a real case study, the operation of coupling drip irrigation was underlined as the most favorable with SPVWP with MPPT/DC. Considering this, it minimizes evapotranspiration, waste of water, and assure reasoned irrigation (Figure *II.18*).

Figure II.18 : Drip irrigation for Olives in Morocco.

II.3.2.1 Practical method for water needs

However, even better results are achieved when using photovoltaic and drip irrigation, coupled as a smart and reliable solution for smalls and Medium crops. The second case selected in the area investigated is about 6 ha of olive trees. For reasons of optimization, it is proposed to divide the crop into 4 sectors of irrigation. The trees and the lines are separated by 5 m, which explains a density of 400 trees/ha. Each shaft is irrigated by 4 drippers of 2(l/h) at a pressure of 1 bar; for 7 hours to 9 hours a day, and 4 days a week. Therefore, the hourly flow of the area of the exploitation will be the product of the number of the tree by the flow rate of the drippers/trees, which equals 19.200 L / h equivalent to 134400 L / day. Thus, the daily flow is 134.4 m^3/ day. A pump with a flow rate of 20 m^3, immersed at 20 meters' depth. Optionally, the water storage tank allows containing a certain amount of water, in case of bad weather. For a plot of 6 Ha, consuming 134 m^3 per day, for a period of 2 days, this gives 268 m^3.

II.3.2.2 Technical performance

The analytical method shows that a solar pump of about 2.7 kW is required to cover such requirements; with a peak power of 3.75 kW of the PV surface. In another hand, numerical analysis underlines a solar pump of about 3.2 kW, with a peak power of 4.1 kW of the surface PV with 20 % accepted missing. The use of a submersible pump can be coupled to an MPPT-DC regulation. For the simulation, it was decided that the pump was placed at a depth of 20 m in a well with water at a depth of 17 m, with no variation during the year. The pumped water is injected at the top of a tank, at 1 m of soil. The length of pipe was estimated at 26m with 3 elbows, it is a pipe of 12 mm in diameter. The main constraint is the ability to pump an enough quantity of water. The flow depends strongly on solar radiation. Therefore, in the local condition, the average daily water pumped is 127 m^3, in terms of daily effective global irradiation (5.5 kWh/m^2). The output power of the PV system has a linear relationship with solar radiation as shown in Figure.32. Practically, the system starts to pump water from 0.5 to 1 kWh/m^2. In optimal condition, the flow rate can attain 18 m^3/h.

As shown in Figures *II.19-II.20*, with drip irrigation, unused energy is more considerable. Solar pumps assure autonomy of water, approximately 50 % of the energy is stored as water. During the dry period it is concentrated the highest values of produced electrical energy and during the rainy period was registered the lowest values with a little decline in the performance ratio. Generally, PR illustration shows how close a system approaches ideal performance.

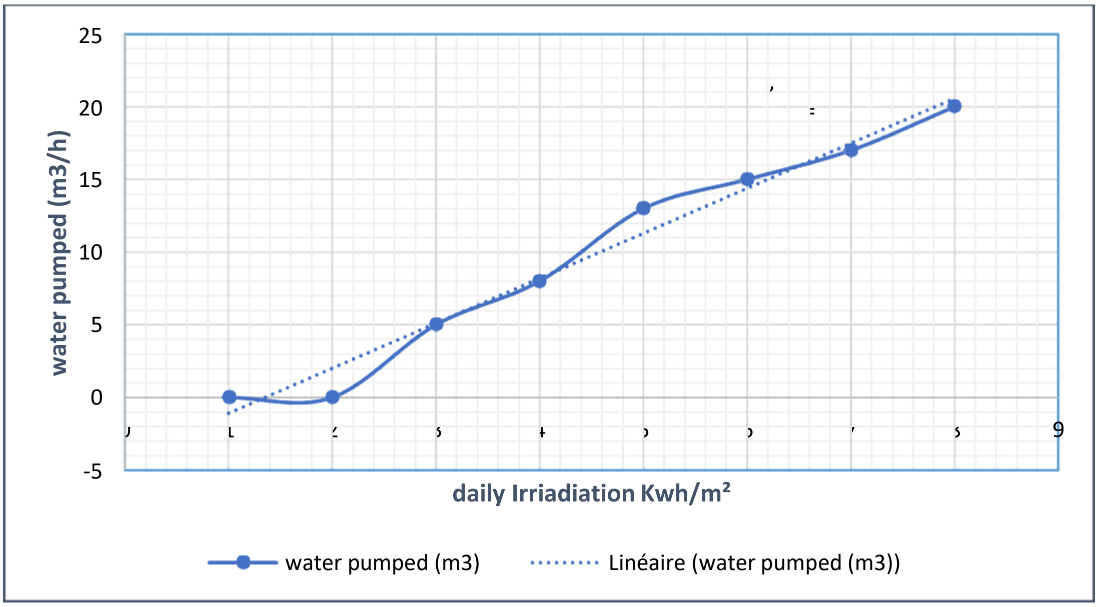

Figure II.19: The non-linearity of water pumped with daily effective global irradiation.

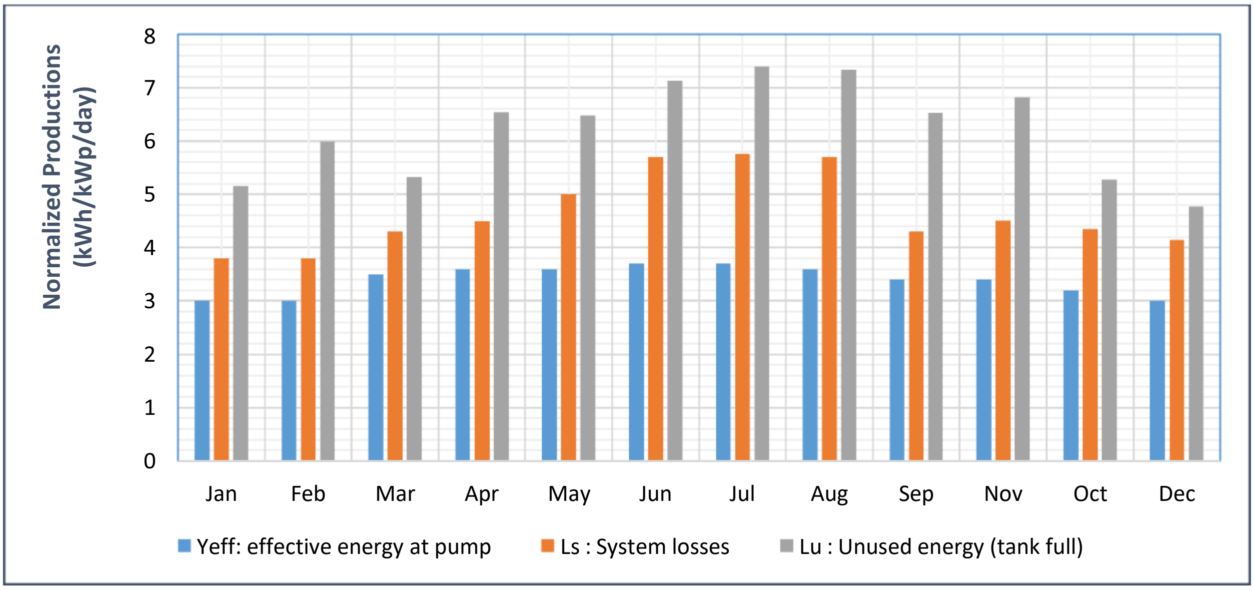

Figure II.20: Normalized Production.

The system shows it performance in the dry season with an average of 61% (Figure II.21). The performance of the present system varies from 54% to 62%, which is very significant for medium crops, comparing to accepted performance in literature.

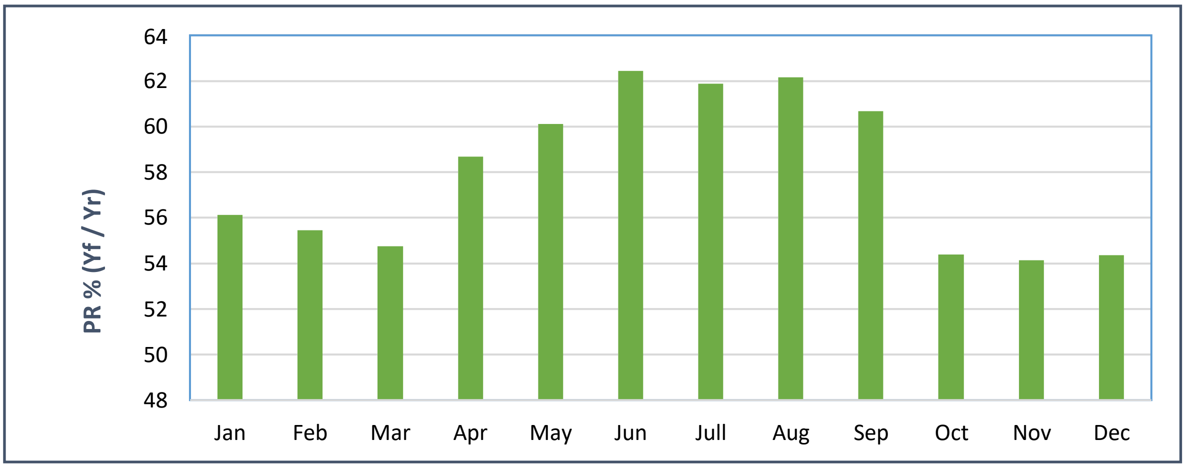

Figure II.21: Monthly performance ratio for the system selected.

Considering the obtained results and field exigencies, the next table resumes many simulation studies and verification for many scenarios in the main region.

To underline the well-adapted system, MMPT regulation is always recommended with direct coupling, considerably to optimize the system while operation and reduce the PV array, as shown in Table II.5.

Table II.5: Capacity and land distribution by farm size.

land(ha)	Total head	P_{pump}(kW)	%area	Proposed coupling
1 to 5	17-50	0.15---4.5	25%	D. Coupling / MPPT-DC
5 to 10	25-50	4.5---12.5	45%	MPPT-DC
Up to 10	25-50	12.5≤	30%	MPPT-DC/AC

From technical viewpoint, the MMPT configuration is the most suitable solution to pump water for agriculture. For economic analysis, the next section gathers to compare Solar systems and classic methods.

I I.4 Summary of Cost analysis

According to calculations and the Benchmarking, photovoltaic systems prove its priority, due to the absence of operating and low maintenance costs (Figure *II.22*). Practically, the comparative analysis of solar pumps with diesel pumps and electrified pumps revealed that LCOW of photovoltaic water is significant, it is approximately in the range of 0.08US/ m³ (Figure *II.23*).

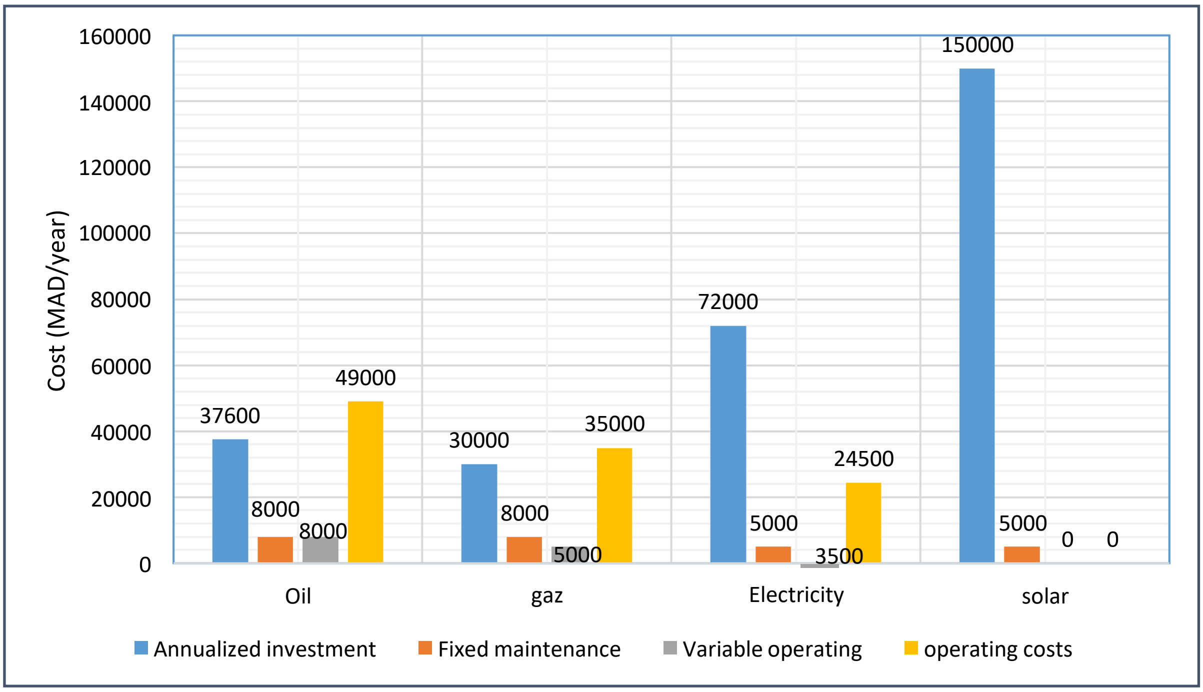

Figure II.22: Different costs (MAD/year) by using energy for Moroccan case.

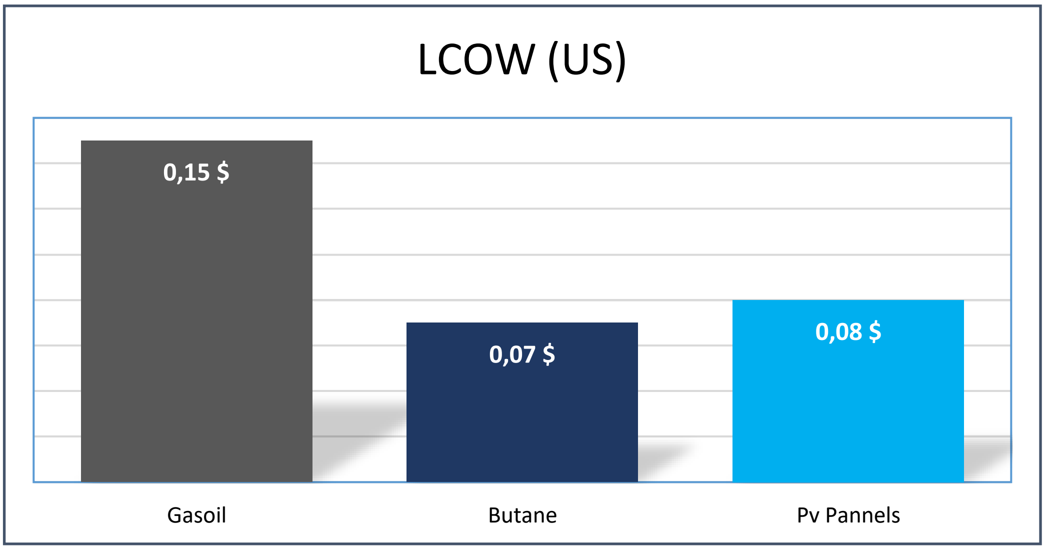

Figure II.23: Levellized cost of one cubic meter of water.

Considering the first scenario to irrigate tomatoes in the main region selected; Figure II.24 shows the result of the after-tax cash-flow of SPVWP system for 25 years. It is clear the system is profitable from the third year. Thus, considering long-term benefits and the high performance in the dry season, photovoltaic systems must be considered as the first choice for farmers in the Sais region to replace unsustainable pumps.

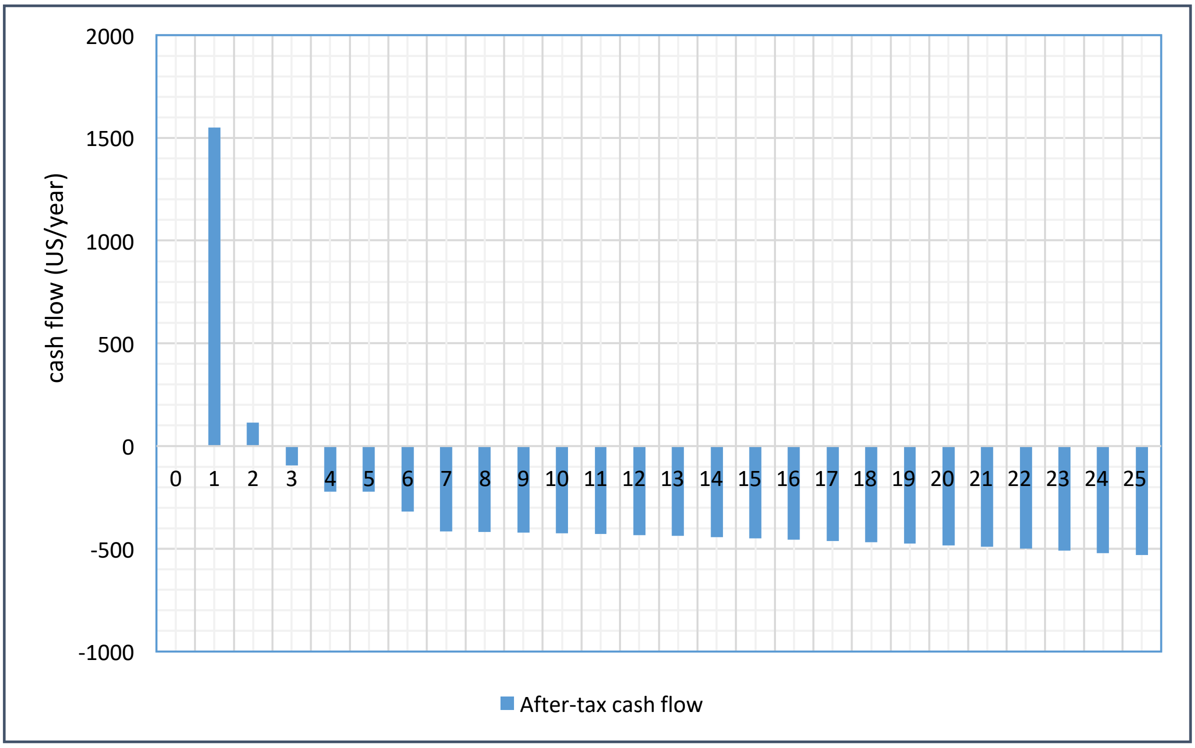

Figure II.24: MPPT coupling lifetime

I I.5 Discussions on the SWOT analysis

Based on the analysis of the case studies, the comparative cost analysis, and the local regularities, a summary of the attractiveness of water pumping projects in agriculture, can be presented in a SWOT analysis. As is well known, the objective of any SWOT analysis is to classify main internal and external issues which are critical for attaining the given goals.

It a large strategic challenge for governments and policy makers to promote solar water pumping implementation. The outline of the SWOT analysis is given in the form of a quadrant map regarding the water solar pumping development in morocco. The section progresses in comprehensive discussions on those aspects. It should be noticed that such a SWOT analysis may comprehend more elements which are not considered in this work. However, the elements considered are all relevant for constituting preferential decision-making.

II.5.1 Strength analysis

a. **Rich natural resources in the region studies**: The agricultural activity is exemplified in the Sebou River. The most fertile part of the Sebou is the Saiss Basin. It holds about a quarter of Morocco's arable land but only uses a little of the national water reserve. This region is characterized by the diversity of soils and their fertility. Additionally, it holds an important solar potential with average sunshine of 3000 h/year and a yearly average solar radiation of about 5 kWh/m^2/day. The disposal water resources are stocked in the region with a total head of fewer than 30 meters.
   Generally, in Saiss region the total head varies between 9 and 20 m depth), fortunately, due to disponibility of precipitations with an annual average of 520 mm which places the zone in the favorable market.
b. **Environment-friendly:** Among all other forms of renewable technologies, solar energy has the lowest GHG emissions ranging. Likewise, SPVWP that substitutes a fossil-based systems will avoid about 1 kg of CO_2 per kilowatt-hour of energy output.
   Practically, SPVWP can offer benefits with respect to air pollution and human health compared to fossil fuels.
c. **Minimum O&M and LCOE/W costs:** The operating and maintenance costs increases because of the substitution of materials. The inverters are warranted for 10 year, the periodic maintenance and the cleaning are done twice a year.

Notably, For the SPVWP, LCOE/W are very competitive. Moreover, the current comparative analysis of solar pumps with diesel pumps and electrified pumps revealed that LCOW of photovoltaic water is significant, it is approximately in the range of 0.08US/ m^3.

d. **Simplified system design:** As proven before, direct coupling remains as the possible and most cost-effective solution for small and medium-scale applications. Otherwise, to provide more flexibility to the SPVWP system and to make it more autonomous, a simple controller and tank full of sensors could be introduced, which is still cheaper and less complicated than an inverter for AC motors.

II.5.2 Weaknesses

a. **High initial investment**: The high investment cost is the major obstacle in the development of SPVWP in rural areas. It is the first limitation for the use of SPVWP applications. While the reduction of LCOE can be controlled if the balance of system costs were individually reduced. But Generally, SPVWP systems still a cost-effective application for the remote population in morocco.
b. **Lack of cooperation and materials**: For the defensible development of the solar energy DC systems need to be imported and developed comparing to AC devices. As well as the performance of DC Systems is developed, public recognition will grow toward a large-scale use of Nevertheless, the lack of coordination and structuration still a real weakness in rural areas.
c. **Poverty of rural population**: The fundamental human needs are food, water, health-care, hygiene, sanitation, and education. All these conditions are linked to pure water. The solar pumping systems could guarantee an unceasing water supply and an outstanding agricultural production. But, in almost of Moroccan rural communities, the drinking water is still the major problem for most of groups, thus the solar systems have not attained a noticeable success yet.

II.5.3 Opportunities

a. **Grid parity achievement:** All over the world, PV module costs are falling swiftly to such an extent that some of them had already achieved solar grid parity i.e. the price of electricity from solar PV is equal to or lower than the conventional fossil fuel-based electricity.
   The opportunity of achieving grid parity also lies in the mitigation of the cost of solar supportive components like solar inverters and installation cost.

b. **Increasing efficiency of solar pumping configuration:** With the rising efficiency of the PV materials, prices of DC pumps and PV panels are rapidly decreasing. In morocco, direct coupling with MPPT regulation showed their efficiency specially by using more efficient materials and drip irrigation. Those configurations offer a cost-effective opportunity to solar energy development in the region.
c. **Financing for solar system:** The "Credit Agricole Maroc"developed the program financing around 3000 solar pumping systems off-grid. Moreover, new financing instruments are presented by the Moroccan Sustainable Energy Financing Facility for rural communities.

II.5.4 Threats.

a. **Conventional technologies:** Among the most ferocious threats to any renewable project, still remains fossil-based technologies as the real obstacle. For the reason that they produce energy at low prices, as they have enormous experienced experts, operators and technical staff, looked to renewable energy which is still slightly integrated at a large-scale.
b. **Lack of balance of systems:** A second major threat to the development of solar energy is the absence of support products in the Moroccan market. Products such as regulators, inverters, and DC terminal devices.

Following the SWOT analysis, it is possible to transform weaknesses into strengths and convert threats into opportunities. On the other hand, strengths and opportunities must be combined to optimize water resources and properly integrate solar energy into agricultural practices. The Summary of the SWOT analysis of solar energy is given in Figure *II.25*.

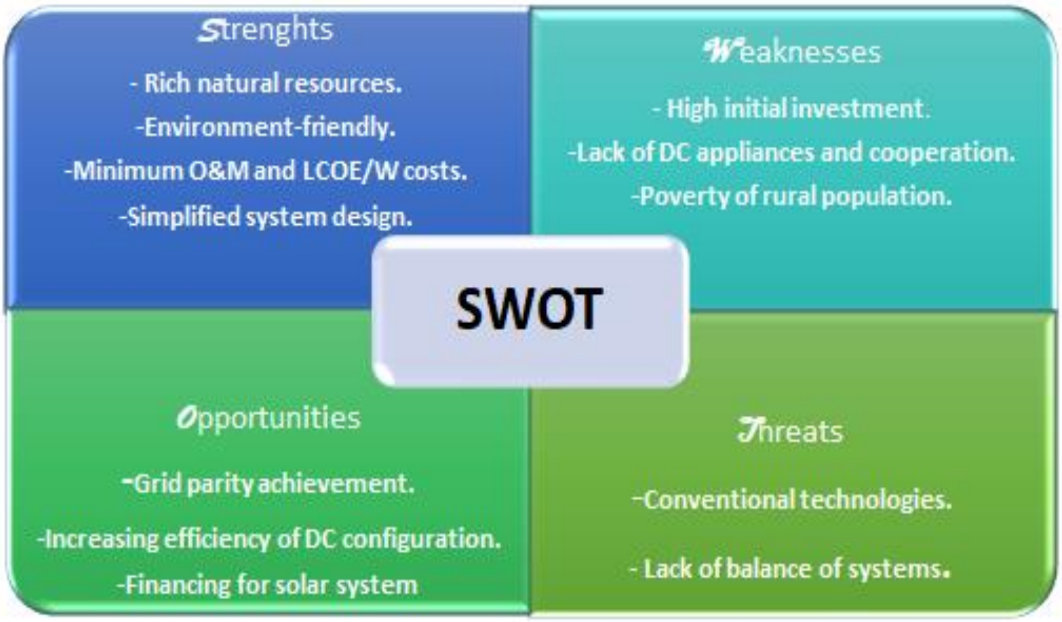

Figure II.25: SWOT analysis summary.

As a source of renewable energy and opportunities for rural and remote populations, solar irrigation offers a potential solution to agriculture and small businesses to resize rural metabolism. This strategic intent puts citizens, farmers, factories and laboratories at the heart of this multifaceted transition. It gives a new perspective to our society and a key model for MENA countries and African agriculture.

Under the Moroccan sun, irrigation is needed for most of the year, but irrigation is expensive for many farmers. Solar energy pumps offer an environmentally friendly, economical and robust solution; there is a growing interest in photovoltaic water. An effective way to reduce costs in agriculture is to use renewable energy. Based on our empirical results, we developed recommendations that would allow the positive effects of solar pumping and validate direct coupling systems as being suitable for small and medium-sized crops. In this study, drip irrigation costs and little maintenance. However, direct coupled solar systems need to be integrated with solar-based MPPT and electronic control systems and other climate variability data to improve and improve system performance.

In general, for small-scale irrigation, direct linkage with MMPT regulation seems most appropriate for family farming and for the investment capacity of farmers. Solar pumps have many benefits and can have a significant impact on rural society. This is the first application to familiarize farmers with renewable energies and to reorient agriculture towards sustainability for more renewable energy integrations. Then a solar pump can provide lighting, irrigation, livestock; or water to agricultural biomass.

The hybrid system should be seen as the next step in transforming farms into self-sufficiency and surplus production. As the results show, the unused energy accounts for almost 50% of the total energy produced at the pump. That can be stored electrically and used to illuminate and raise animals, or used to provide water to a biomass plant. The results of the simulation include a large amount of significant data and quantify losses at all levels of the system, which helps identify weaknesses in system design. The recorded CO2 is also produced and calculated using the PVsyst digital tool.

In both cases study, PVSPWs show their annual performance, the analysis of losses, It's necessary to indicate that head losses such as head loss due to pipe elbows, tank entrance and exit losses and the head loss across banks of collectors in series shall also be included in the system head loss. Consequently, researchers should be aware of that fact.

Some limitations might be related to collecting our data, like the absence and the omission of some important variables. A National interest was accorded with a colossal nation investment trough Green Plan Morocco to cover Initial costs. But, it's seems familial agriculture suffer the poor infrastructure and weak management of water and matter. Moreover, Socio-economic development varies from one country to another, even in the same country. Although an appropriate technical solution in one region may not be appropriate in another. In developed countries, SPVWPs are generally intended for livestock and holiday homes, but in developing countries, applications are severely limited to drinking water and micro-irrigation applications. Thus, photovoltaic solar water pumping is a cost effective application in remote areas. The reliability of solar pumps makes them the best choice for pumping agricultural water in developing countries.

In future works, big interest will be accorded to biomass and hybrid systems to consolidate the part of Green technologies in Moroccan agriculture. This make clear that sustainable agriculture is the first key stage to asses' *Industrial ecology* and *Social metabolism'*. Furthermore, Green technologies have the ability to familiarize and integrate rural population and educate their children. Moreover, the agriculture can teach urban sphere many ways on how to conserve water, and energy.

II.6 Conclusion

As a source of renewable energy and opportunity for rural and remote populations, solar irrigation offers a potential solution to agriculture and small businesses to resize rural metabolism. Under the Moroccan sun, irrigation is needed for most of the year, but irrigation is expensive for many farmers. Solar energy pumps offer an environmentally friendly, economical and robust solution. The results derived from a series of simulations reveal that an increase of 30 % in annual performance and a decrease of 10% of system losses are observed when using MPPT DC converter for small and medium sized crops. In addition, cost comparative analysis revealed that LCOW of SPVWP is significant, approximately in the range of 0.08US/ m^3, which is very competitive comparing to other sources. Based empirical results, author recommendations may allow the positive effects of solar pumping and validate direct coupling systems as being suitable for small and medium-sized crops. Moreover, direct coupled solar systems need to be cohesive with solar-based MPPT and electronic control systems to improve system performance. In general, for small-scale irrigation, DC with MPPT regulation seems most appropriate for family farming and for the investment capacity of farmers.

Globally, this work revealed a significant potential of the agro-pole Meknes-Fez to hold more than 17000 solar pumps with capacities between 0.6 up to 40 kW. This proves that solar pumping must be widely considered as the most suitable solution to manage water and reduce almost agricultural CO2 emissions.

Solar pumps have many benefits and can have a significant impact on rural society. It is the first step to familiarize Moroccan farmers with renewable energies and to reorient agriculture towards sustainability. From an economic and environmental point of view, those systems prove to be a key answer to develop one of the most ambitious renewable energy supplier for water pumping in Morocco and specially to promote the main economic sector which is agriculture. The projected approach can fulfil as a reference for evaluation studies of water management in Morocco, in particular for ambitious social and agro-economic development programs in remote areas.

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CHAPTER 3

III

Power generation from agricultural biomass

Contents

III.1 Introduction

Over the last decade, climate change has been the major focus area. Currently, it is considered an evident reality and impacts greatly agriculture, water supply, and our ecological sphere. In fact, the impacts are strongly related, generally the world population growth and economic extensions are attended by an accelerating demand of energy which is currently supported by unsustainable sources [105]. It was agreed that Energy is primordial provender of life, and it can be acquired from different sources, renewable and non-renewables. There are various renewable energy resources including biomass, solar, wind, tidal, hydro, geothermal, etc., which can be used to recover the energy demand of the burgeoning population [106]. On the other hand, agriculture is still energy intensive and the world largest driver of global warming. At the same time, the most affected by these changes [10]. The challenge is further complicated by the need not only to produce more, but also to sustain the entire food supply chain much more efficiently and reduce waste which has reached unacceptable proportions (estimated at 30%) [107]. Mostly, in several developing countries, where fossil fuels predominate in their energy mix, and new photovoltaic technologies have only been used to turn on radios, televisions or mobile phones. In spite of this, rural populations in those countries have been omitted from the profits of energy independence and sustainability. Thus, the notion of sustainable development is the pillar guideline to reach a stable and circular economy, accompanied by both rational management of natural resources, and social development integrating rural society [108].

In this regard, waste to energy technologies can be mentioned as a means and a solution, so that our society can achieve sustainability and reduce its dependence on fossil sources. Those technologies can boost the social development and revalorize wastes as energy sources, especially in rural areas where poverty is constantly increasing [109]. These renewable energies source may play a crucial role to promote the agricultural sector and provide great alternatives to developing countries [110]. Biomass energy possesses promising perspectives and became popular worldwide.

Thereby, biomass is considered as suitable for any nation that relies on agricultural economics [111].

This promising source of energy is tilled with abundant quantities, butstill barely used globally, with 7 to 12% of the world primary energy consumption [112][113]. Moreover, biomass is composed by different organic materials (celluloses, hemicelluloses carbohydrates) which make biomass as a source of different valuable fuels [114].

We should remember that biomass can generate many biofuels or forms of energy by relying on several processes [115]. These biofuels come from a wide variety of materials that can be classified under five types: virgin wood, energy crops, agricultural residues, agro-industrial waste, and co-products [116]. Biomass materials represent sustainable energy that can replace fossil fuels and reduce their negative effects. Biomass allows the recovery of waste, and offer a solution to environmental problems. So, the sustainable use of this technology can bring an interesting opportunity to both rural and urban societies [117]. Further, biomass is almost CO_2 neutral and the average calorific value of bioenergy crops is comparable to coal. Therefore, natural gas would be replaced by biomass [118]. The primary methods for recovering energy from biomass include combustion, pyrolysis, gasification, liquefaction, anaerobic digestion, and fermentation, [119]. Combustion is the most used process to produce heat and energy from biomass [120]. In particular, agricultural biomass could be attractive for energy production in rural areas. The development of new technologies for the use of biomass in small-scale combined heat and power systems has progressed rapidly in recent years, and several technical systems are now available [121]. Other technologies, such as fuel-efficient small-scale Stirling engines for fuel, are currently promoted by several companies [122], while small-scale biomass gasification plants have so far existed as a demonstration [123]. However, agricultural land is a limited resource and the production of large energy crops will displace food products and eventually result in natural or semi-natural land for agriculture [124]. Interestingly, sustainable agriculture has the unique potential to mitigate global warming and fortify the resilience of renewable solutions to face the impacts of climate change. It is precisely defined as the ecological balance of interactions between modern human's kind and their local ecosystems [125]. The aim is to integrate all these key parameters into an equilibrated production system. Mainly, ultimate goals about sustainability in agricultural systems focus on the need to develop sustainable practices that seamlessly integrate environmental health, energetic profitability, social and economic fairness [126]. The strategies reviewed in the literature to deepen sustainable agriculture focus on reducing the consumption of fossil fuels on farms [127] [129]. This includes as well as the reduction of the consumption of chemical fertilizers, the use of biodiversity practices, improvement of water efficiency and, above all the evaluation of both energy production opportunities and biofuels in the agricultural sector [129]. To merely ensure sustainability in developing countries and quality of life, it is necessary to increase the profitability of crop production [130] and reduce the negative impact on the environment by adjusting agricultural input application rates as needed locally [131].

Managing water resources, is also a key equation to strongly integrate agricultural sustainability [132]. Generally, solar photovoltaic pumping coupled to drip irrigation systems are the most efficient for agriculture and providing water to the rural population. Mainly, solar systems are the friendliest to supply water for agricultural activities and biomass plants. Yet, many studies have focused on the use of energy in agriculture, generally, they underlined machinery and electricity as the most energy consumers in agricultural sectors [133] [134] [135]. Thereby, it is necessary to attend new policies to engage producers in energetic-efficient practices to achieve more sustainability [136].

To sum up, (Figure 39) shows the principle keys to reach sustainability, and widely integrate waste to energy technologies in agriculture. Therefore, agricultural biomass is one of the important sources of renewable energy. InMorocco, as in the majority of agricultural countries in the Mediterranean region are extremely rich in agricultural biomass. But the exploitation of this energy remains weakor almost absent in several countries. Of course photovoltaics and wind turbines are the icon of the energy transition, but biomass is the key to linking between two urban andrural metabolisms, agricultural biomass is the way to recycle our waste, produce energyand especially for developing countries it is the only technology able to integrate otherforms of renewable energy, to create agro-industrial and industrial synergies, and especially to integrate environmental disciplines and the appreciation of agricultural waste. However, the structural integration of biomass technologies depends on severalvariables that change from one country to another, and even in the same country and region, it changes from one farm to another. Also, calculating agricultural energy inputs is more complex because it differs on several variables. Accordingly, this work focuseson agricultural bioenergy, through a quantitative study of the Moroccan potential. As well as a technical and economic feasibility study of CHP systems are carried out to upgrade biomass and producing energy from agriculture.

III.2 Biomass assessment and energy potential

Despite the current economic situation and the different challenges of developing countries, biomass still widely used in developed countries [137]. After coal, oil and gas, biomass is the fourth largest source of energy. In addition, unlike hydroelectricity, solar and wind power, it is present everywhere in the world [138]. Five million metric tons of biomass are produced annually from agriculture [139], which is promising if policies and efforts exploit this potential.

The energetic assessments of biomass in a given time, usually within one year for a geographic area, can also be considered as a strategy for sustainable and social development. By 2070, up to 400 EJ can be made available through biomass, out of which 75% will be from energy crops [140]. The available annual biomass residues are varied according to local conditions, among which climatic factors, agricultural production, a variety of livestock, planted crops, energy content, and yields [141]. One of the major barriers to biomass development is the absence of knowledge about the resource potential in its logistics [142] [143]. Precise quantitative estimates of biomass sources are needed to facilitate the integration of this technology at regional and national scales.

Several studies have focused on the sustainable biomass potential from agriculture, with an increasing interest in such studies. In Colombia, is estimated that some 61,000 to 119,400 GWh of the bioenergy potential from agricultural residues and livestock wastes can be technical exploited [106]. It was found that Pakistan proceeds about 40 million tons of crop residue that can be translates to an estimated potential of about 11,000 MW of electricity generation capacity, and 16,000 MW by the year 2035 [144]. Ukrainian biomass projections for 2035 are up to 28 million tons of oil equivalent, which is enough to produce 104 billion kW/h [145]. In Sicily over 3.9 million tons per year of agricultural biomass is available. Equivalent to a potential 255 million Nm^3 of biogas capable of producing 408,072.1 MWh / year of electricity energy and 305,672.0 MWh / year in thermal energy [146]. In Greece, Messenia province, it is possible to recover about 7956 tons of biomass per year in Messenia province, and to produce 6630 MWh of electricity and 8580 MWh of thermal energy [147]. In India, at Uttar Pradesh province, the yearly biomass potential is about 71 million tons, enough to supply a power of 7,028 MW and a significant reduction of the *GHG* emissions [148]. Only in China, 60 to 100 million tons of biomass can be retrieved and used to operate about 350–600 power plants with a capacity of 8400–14400 MW [149].

For Argentina, vegetable biomass is estimated to 204,536 t/year, which is able to provide electricity to 76,00 users, and heat to 25,160 [150], and 1500 PJ/year of biofuel can be produced in Europe from 1.5 to 2 billion tons of agricultural biomass [151].
As reviewed, the energy potential of residual biomass is significant and very important to reduce dependencies, and achieve energy sustainability (Table *III.1*).

Table III.1: Survey results based on the international review.

REFERENCE	COUNTRY-REGION	RESIDUE TYPE	BIOMASS POTENTIAL	ENERGY POTENTIAL	OUTPUTS
(Cheng et al., 2014)	China	Forest and agricultural	60 to 100 million tons	8400–14400 MW	Electricity and Heat
[148]	India, Uttar Pradesh	Forest and agricultural	about 71 million tons/y	7,028 MW	electricity
[146]	Italy-Sicilia	agricultural biomass	3.9 million tonnes/year	255 million Nm^3 of biogas	Biogas
[150]	Pueyrredón, Argentina	herbaceous and vegetable residues	204,536 t/year	76,000 users electricity/ 25,160 use heat	Electricity and heat
[147]	Greece, Messenia Province	Forest and agricultural	7956 tonnes/year	6630 MWh electricity /8580 MWh heat	Electricity and heat
[144].	Pakistan	crops residues	40 million tonnes	11,000 MW	Electricity
[106]	Colombia	agricultural residues and livestock wastes	–	61,000 to 119,400 GWh	bioenergy
[151]	European Union	agricultural crops	$1.5\times10^{12}$to 2×10^{12} tons	1500 PJ/yr.	biofuel

III.3 Biomass availability in Morocco

Moroccan agriculture depends heavily on unsustainable sources, a typical characteristic of developing countries. in 2008 the Moroccan government announced the strategical ''Moroccan Green Plan'', to promote the productivity of agriculture, by addressing as well as climate change, overexploitation of groundwater, and alleviation of poverty [152]. Concerning the energy recovery from biomass in Morocco, very few studies have confronted this subject, this lack of research motivated the present study. Therefore, it is the first survey of the energy potential from agricultural waste for Morocco.

Besides, the biomass sector will be strengthened to replace fuel oil in agricultural and industrial practices. However, this potential has not yet been untapped by national actors. The main constraint of biomass as a technology of energy production is the non-mastery of technology and the current undeveloped status of Morocco.

Residual biomass, municipalities, the agricultural sector, and industry represent an unsuspected potential for energy production up to 950 MW [40], and it is mainly in rural areas where traditional biomass is still used for everyday use. Annual wood consumption is estimated at 30 000 ha, while forest land is about 9 million ha [153]. Accordingly, the urban contributes 11% against 89% of the rural in the national biomass which amounts to more than 11 million tons/year (Table *III.2 next page*). The 9 million ha of the forest provides almost 5 million tons every year, which accounts for over 52% of all biomass produced, so the estimated agricultural biomass is around 3 million tons. Total solid bio-energy potential is estimated at 12.5 GWh/year, with a further 13 GWh/year from biogas and biofuels. The biogas sector presents a total installed capacity of 33,800 m^2, with an annual production of about 21.6 million m^3 [30]. Despite the countless benefits and quantities of biomass (Figure *III.1 next page)*. Morocco uses only 2% of these potentials, because of colossal investments and especially to the lack of technical knowledge.

To see that there is no integration of biomass in the industrial sector. In particular, agricultural biomass is the key step to weave agro-industrial synergies to valorize the materials and to promote energy biomass. Moreover, Morocco has a large capacity in olive growing, for example, the city of Meknes produces more than 4,000 tons of olives/day. Notably, 2 kg of olive stones represents the equivalent of one litter of gas oil, almost 10 kW, which is a very interesting figure to value. Thus, the biomass could, in particular, be of interest for energy production in rural areas where end-users are near the farm producing biomass.

Table III.2: Biomass Production in Morocco[11]*.*

Area	Forest Wood(tons)	fruit Wood(tons)	Agro-biomass(tons)	Total(tons)
Urban	887,900	230,790	155,030	1,273,720
Rural	5, 078,900	1, 920,400	3, 030,190	10, 029,490
Total	5, 966,800	2, 151,190	3, 185,220	11, 303,210

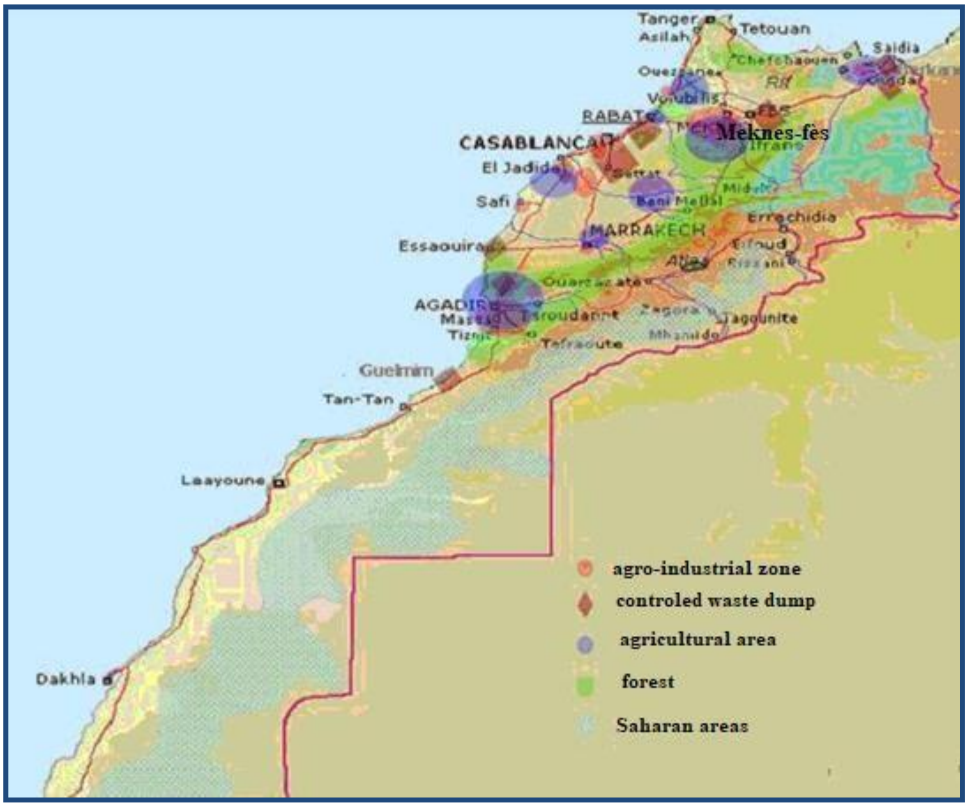

Figure III.1: Biomass distribution in Morocco.

But several challenges loom for Morocco; Social development, energetic transition, and sustainability are vestigial but must be aligned with energy efficiency and agricultural activities. Compared to the size of conventional technologies, Green technologies are smaller, giving them an advanced opportunity to be incorporated in industry, urban, and rural activities. As quickly solar and wind power are accelerated in adopting to reduce costs and increase benefits.

[11] *Own estimations by comparing annual reports of the Ministry for agriculture (http://www.agriculture.gov.ma/).*

III.4 Methodology

III.4.1 Goal and scope

This study obtains more proper understanding of the quantities of biomass and the exploitation of combustion techniques to valorize the residual matter, and convert it into electricity. Therefore, we cast light on the Meknes-fez region, by evaluating the theoretical biomass potential of the most predominant species in this region, with the prospect of transforming the resource into electricity. This article set out to elaborate on the parametric and sensitive analysis of the model output parameters and the Levelized Cost of Electricity (*LCOE)*, in order to prove their performance for the located region. As stated in figure *III.2*, the flow chart summarizes the proposed Methodology.

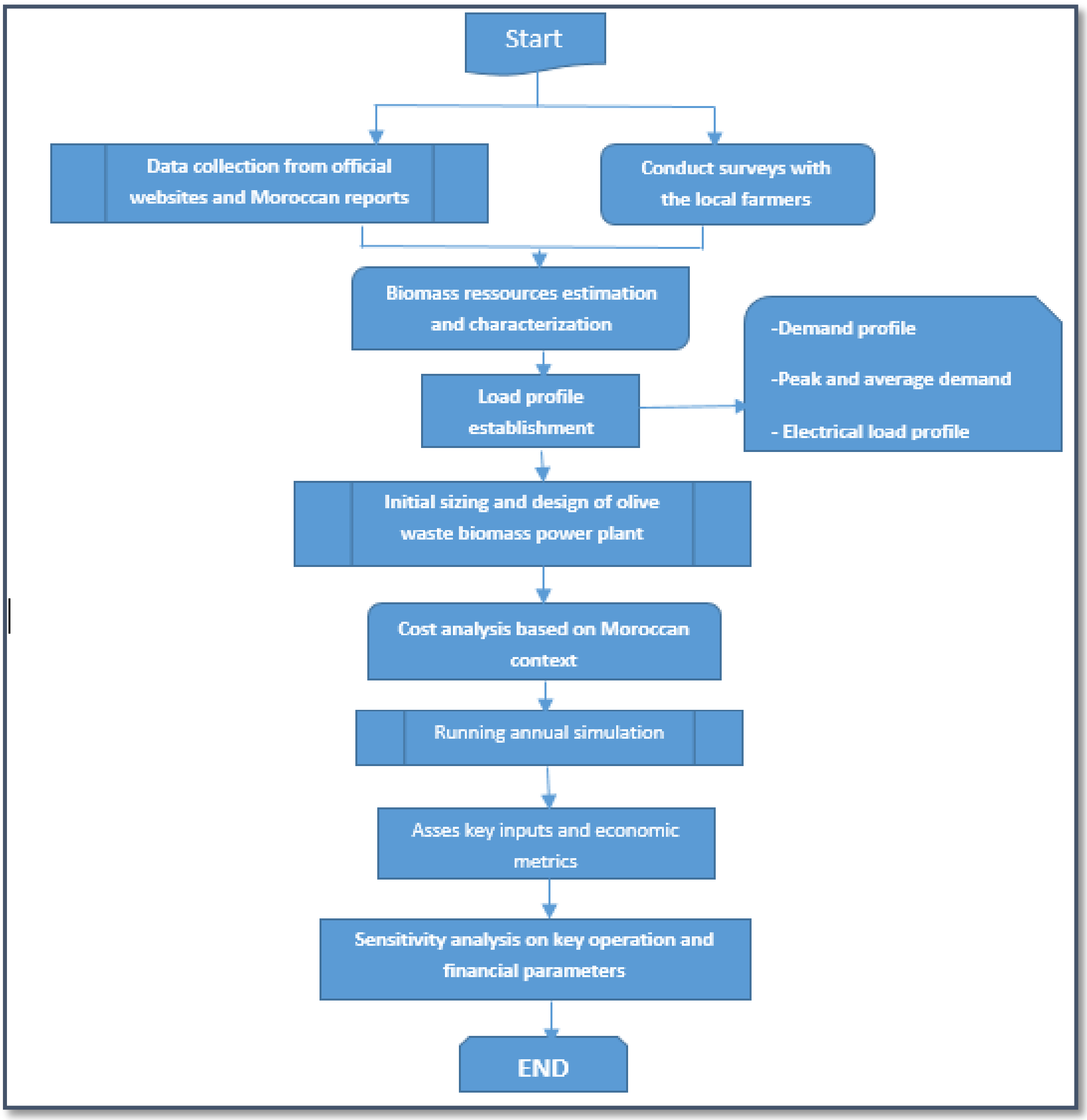

Figure III.2: Flow chart methodology.

III.4.2 Biomass availability and feedstock selection

Biomass feedstock availability is favorably related to location, climate, and seasons. This work aims to estimate regional biomass resource availability. The biomass of forest origin is not considered for the unavailability of some data. In the absence of country-specific studies, crop residue yields per hectare were estimated. These estimates took into account the productivity levels calculated from the areas and productions collected from the Regional Directorate of Agriculture in Fes-Meknes. The calculation aspect involves estimating the number of agro-residues generated and their potential for electricity production. For tackling this, the current study tried to lay emphasis only on the biomass produced by crop residues. Biomass of forest origin, livestock waste, and waste food industry are not considered due to the unavailability of some data.

III.1.1.1 Raw dry residues

Agro-residues include all crop residues which would have normally been regarded as waste. These remains have usually been disposed by burning or deposition in dumpsites if they are not combustible. The total production of straws or grains is calculated by multiplying the yield in straws or grains by the cultivated area and the associated harvest index. However, the amount of biomass thus estimated includes the portion of straw required for ground cover after harvest [154]. This fraction of the biomass must be deducted from the total quantity produced at the regional scale. The formula used to estimate the production potential biomass of plant origin is expressed as follows:

$$Q_p = A \times n_i \times H_i \tag{1}$$

where A is the area under cultivation (*Ha*), n is the straw yield, and H_i is the Harvest index in straw.

III.1.1.2 Biomass Properties

Before any biomass power generation evaluation, it is crucial to distinguish the categories of biomass resources and their physical properties. One of the most important properties are :

- Moisture: it represents the percent of water existing in biomass substance. It is frequently expressed on a dry basis (M_{db}), as follows:

$$M_{db} = (W_{wet} - W_{dry})/W_{dry} \tag{2}$$

where W_{wet}, and W_{dry} are the weight of wet and dry product respectively.

- Heating value: expressed in [*J/kg*], it properly identifies the chemical energy bound in the fuel. Heating values are strongly related to the moisture as shown in next [155]:

$$LHV = HHV\ (1 - M_{db}) - 2.443M_{db} \quad \textit{(3)}$$

where *LHV* is the lower heating value, and *HHV* is the higher heating value. Empirically, the heating value can be calculated using the following formula [156].

$$HHV = 3.55C^2 - 232\ C - 2.23\ H + 131\ N + 20.6 \quad \textit{(4)}$$

where *C*, *H*, and *N* are the biomass weight % of carbon, hydrogen, and nitrogen, respectively.

III.4.3 Olive waste to energy

Olive is a major woody crop in arid and semiarid regions, where it has great economic importance, it is the chief fruit crop in Morocco [157]. The olive tree is very resistant to drought [158] and can grow over a large part of the territory, except coastal and desert areas [159]. It is mainly available in the following regions: Fez Boulmane Taounate, Meknes Tafilalet, Marrakech Tensift Haouz, Beni Mellal Tadla Azilal, and Tangier Tetouan region.

Morocco is the 5th largest producer of olive oil in the world. The total planted areas are about 560 000 ha, from which 200 000 ha can benefit from irrigation. The average annual production of olives (average of the period 2010-2015) is around 1,500,000 tons of which 65% is for crushing, 25% to the table olive, the remaining 10% representing self-consumption and losses. This represents 5% of Morocco's *GDP* and the workforce for this crop is estimated at 15,000,000 days worked per year [160]. The olive residues are largely sufficient for biomass fuel production. The residues of olives are composed of olive kernels/stones/pits and olive dried husk.

As shown in Table *III.3* , olive pits have a high heating value (about 20kJ/kg) and contain low moisture (9-10%) [161].

Table III.3: Olive pits proprieties.

Olive pits proprieties	**Value**
Carbon	52.27 Wt%
Hydrogen	7.48 Wt%
Nitrogen	0.06 Wt%
oxygen	40.00 Wt%
volatile	80.94 Wt%
Ash	0.56 Wt%
Moisture	9-10 Wt%
LHV	18.96 MJ/Kg
HHV	20.70 MJ/Kg

Accordingly, olive pomace, pulp, stone, make up the biomass of the olive tree and open the way to new sources of energy. This biomass could be a particular interest in energy production in rural areas where end-users are near the farm producing biomass. It is an alternative for boilers that produces heating and generate electricity. Two kilograms of kernels represent the energy equivalent of one litter of gas oil, almost 10 kW, a very interesting figure to value the energy potential of this biomass.

III.4.4 Conversion technology

After having discussed the essential characteristics of olive, this part furnishes a brief description of the main small-scale power generation plants. As shown in Table *III.4*, many viable technologies convert biomass into generated electricity [163] [164] [165]. Biomass power plants are very comparable to coal-fired power plants [165].

Table III.4: Main conversion technologies.

Conversion technology	Biomass type	feedstock	Main products	End use
Combustion	Dry biomass	Wood logs, pellets, solid biomass	heat	Heat/electricity
Co-firing	Dry biomass	Straw, agro-forest residues	Heat/electricity	Heat/electricity
Gasification	Dry biomass	Wood chips, pellets and solid waste	syngas	Heat/electricity
Pyrolysis	Dry biomass	Wood chips, pellets and solid waste	Pyrolysis oil	Heat/electricity
CHP	Dry biomass	Straw, forest residues, wastes and biogas	Heat/electricity	Heat/electricity
Anaerobic digestion	Wet biomass	Manure, vegetable waste…	Biogas	Heat/electricity
Hydrolysis/ fermentation	Sugar , starches and cellulosic material	Sugarcane, woody biomass and corn	ethanol	Liquid fuels

Standardly, the system uses biomass in the combustor to generate efficiently steam, which then turns into a typical Rankine cycle turbine. This steam turbine is connected to an electric generator that produces electricity (Figure *III.3*).

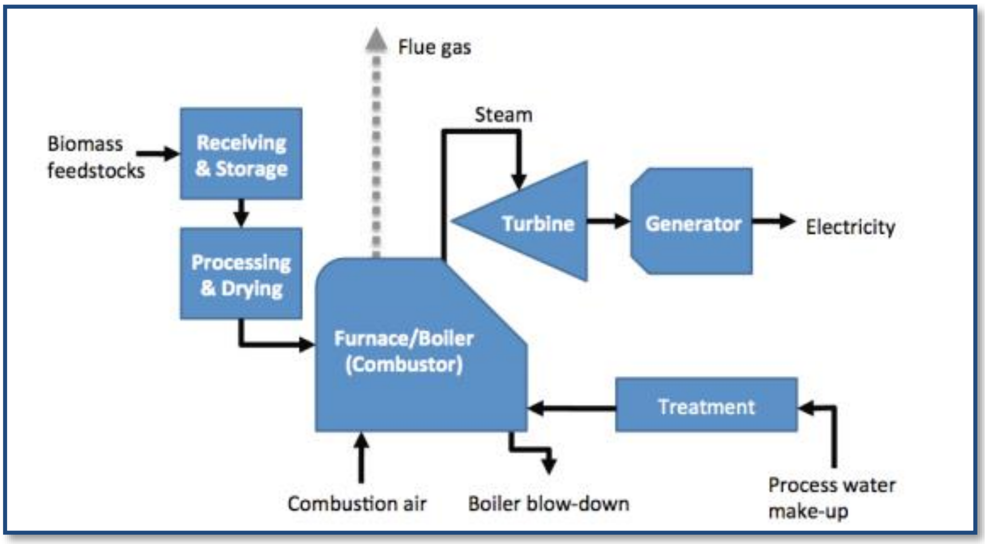

Figure III.3: Biomass plant layout and components

The mathematical formula estimating the amount of heat produced and transferred from the combustion system to the boiler is expressed as follows [166]:

$$= M \times (100 - (e_{dryflue} + e_{radiation} + e_{unb.carbon} + e_{latentheat} + e_{fuelmoist.}))/100 \qquad \textbf{(5)}$$

where M is the dry biomass rate, and ***e*** the various efficiency losses.

III.4.5 Potential of electricity produced in the area of study

This section discusses the biomass power generation potential. Accordingly, the esteem of potentially predictable electricity could be landed from the quantity of biomass and the heating value.

-The electrical energy predictable during a year is found by applying the efficiency of the system to the total heat produced from biomass as following:

$$E_t = \sum_0^{8761} Q \times \eta \times t \qquad \textbf{(6)}$$

where 8761 represents operating hours during the year, and η is the Rankine cycle efficiency. The efficiency of the steam Rankine cycle was reported to be in the range between 25% and 40% [167].

III.5 Economic Analysis

The biogas plants operate with capacity ranges from 20 to 110 MW, while the effectiveness of the systems is between 20 and 29% [165]. In this section, the economic feasibility of the proposed power plant is analyzed by estimating the *LCOE* using *SAM* Financial model. The *LCOE* is estimated based on 25 years, which represents the expected lifetime of the power plant.

The levelized cost of energy is largely used as a financial metric to assess various renewable energy-producing plants [168]. The (*LCOE*) in ($/kWh) is given by the following:

$$LCOE = \frac{Sum\ of\ costs\ over\ the\ lifetime}{Sum\ of\ Electrical\ production\ over\ lifetime} = \frac{\sum_1^t \frac{M_t+I_t+F_t}{(1+r)^t}}{\sum_1^t \frac{E_t}{(1+r)^t}} \qquad (7)$$

with (I_t) is the annual investment expenditures. (M_t) is the annual operations and maintenance expenditures. While (F_t) is the fuel expenditures in the year and (E_t) the electrical energy generated in the year. The (r) represents the discount rate and (t) is the Expected lifetime of the system.

More particularly, as part of this economic analysis, the investment decision is taken into account. Although, the capacity of the Biomass project can be determined from the different investment possibilities and whether or not to invest.

However, to implement this project, the major costs include those for equipment, maintenance (*O&M*), fuel, logistics, storage, and others. As shown in Table 5, fixed investment capital is divided into two components: direct and indirect costs. The direct capital cost relates to the purchase of equipment, and installation expenses, including contingency costs. Where the indirect cost includes costs related to the land, the construction of the power plant, including analysis and engineering costs:

- Direct costs amount to around 80% of the total investment [169]. The total installation cost reaches a value of 1,469,521,920.00 $, which is equivalent to a total cost per capacity of 3,755.70 $/kW. Whereas the cost of the boiler, turbine, and generation represents almost 40% of the total costs [170].
- Indirect costs related to the land are about 5% of direct cost, while the construction of the plant and engineering costs represent 20% of direct cost [171] [172].
- *O&M* costs represent the costs of material and resources used in the repair and operation of the plant. Maintenance costs are based on plant capacity and power generation, estimated at 200 $/kW and 4 $/MWh respectively [170].

- The cost of fuel includes the price of agricultural waste (olive) and costs such as logistics and transport costs. Logistics costs are classified into two categories: fixed distance delivery cost and variable distance delivery cost. The fixed distance cost includes a set of materials (harvesting engines, trucks, handling, etc.) and human (personnel, tours, etc.) resources. As well as the variable distance cost shows the cost of transporting one ton of biomass harvested per one thousand [173]. In this analysis, it has been proposed that the ton of biomass does not exceed $ 40 and that the costs of harvesting storage are ignored [174].

It is convenient at this stage to list the cost figures used in the present analysis (Table *III.5*).

Table III.5: Economic model parameters.

Parameters	value
Logistics	
Distance-fixed delivery cost	6.00 $/dry ton
Distance-variable delivery cost	0.10 $/tone-mile
Direct capital cost	
Boiler	750.00 $/kW
Turbine& generator	510.00 $/kW
Fuel handling equipment	330.00 $/kW
Other equipment	270.00 $/kW
Indirect capital cost	
Engineering, Procurement and Construction	20.00% direct cost
Land Cost	5.00 % direct cost
Total installed costs	3755.70 $/kW
Total Operations and Maintenance cost	
Variable cost by generation	4.00 $/MWh
Fixed cost by capacity	200.00 $/kW-year

III.6 Results and discussion

III.6.1 Outline of the region study and selected Model

The region selected for this work is Meknes-Fes. This area typically occupies a strategic geographical position. Overlooking Europe at North and bordering the Algerian frontier in the East, this region is predestined to play the role of crossroads of communication and exchanges, which form a hyphen between Africa and Europe. Thus, and given the climatic conditions favourable for most crops, this region knows an enormous diversity of plants and animal production. The agricultural plain is situated in the Sebou basin that covers 40,000 square kilometers of the coverage areas, representing 6% of the national territory and contains 30% of Moroccan surface water resources.

At the scale of the agro-pole Meknes-Fes, it is possible to recover more than 4.22 million tons of agricultural residues, this is equivalent to more than 0.5 Mtep / year as revealed in Table *III.6*. In terms of the potential mobilized output, the total residue is over 4.2 million tons. Broadly, olive residues in the majority represent 48 % of agricultural wastes.

Table III.6: Agricultural biomass quantification in the selected region [175].

Species	Average area (ha)	Production (t/yr)	Straw yield[12] (t/ha)	Harvest straw[13] (t/ha)	Residue quantity (t)
cerals	**779, 065**	**1, 312, 288**	1.68	2.50	1, 947,662
olives	**342, 902**	**407.737**	1.18	6.00	**2, 057, 412**
rosaceae	**68, 055**	**509.372**	1.50	2.00	136, 110
vegetables	**29, 094**	**749.646**	2.00	0.50	14, 547
legumes	**137,795**	**118.249**	0.85	0.50	68, 897
total	**1, 356, 911**				**4, 224, 628**

As mentioned earlier, the current study focuses on the utilization of olive residues in the province of Fez-Meknes, which has the highest potential energy production, with a value of about 2828.11 GWh/year.

According to recent statistics from the High Commission for Planning of Morocco, the rural population of the Meknes-Fes region is around 1,673,968 with 319,384 households, 11% of these install photovoltaic systems and 254,252 dwellings use fossil resources.

[12] These estimates held productivity levels calculated from the areas and production published by the Ministry ofAgriculture (2008-2016).

[13] Straw yields and index harvest was calculated by comparing FAO data and local indicators.

The daily average electricity demand for the residence has been estimated at 4.3 kW. Mainly, figure III.4 presents the hourly electricity load for 254,252 households compared to the system power generated in 8761 hours per year. Indeed, to compensate monthly variations of electricity load and demand, the energy produced is assumed to be supplied to the national grid, and from there, recovered by the local villages.

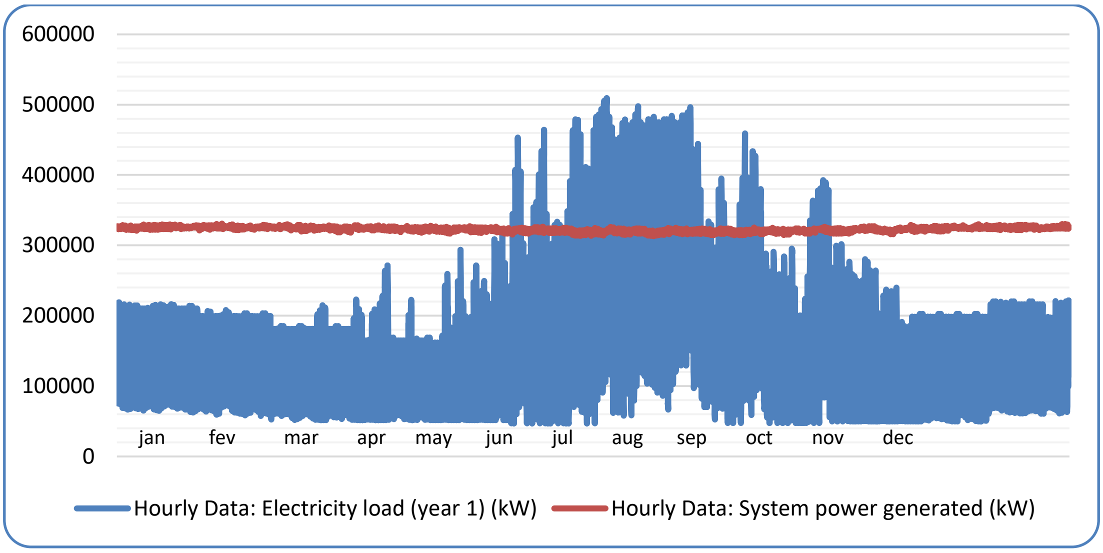

Figure III.4: Electricity load and system power generated profiles.

According to *SAM* simulations, the main results of the performance and financial model are presented in Tables III.7. It can be perceived for a total installed cost of 3755.70 $/kW, that the average real *LCOE* is estimated at 15.03 ¢/kWh, which is exceptionally promising and competitive compared to other power generation modes in Morocco.

Table III.7: Technical and financial model parameters.

Metric performance	Value
Annual energy (year 1)	2, 828, 113, 664 kWh
Annual biomass usage (year 1)	2, 057, 410 dry tons/yr
Capacity factor (year 1)	82.50 %
Total boiler efficiency	79, 8055 %
Plant capacity	391, 278 kW
Economic Parameters	
Real levellized COE	15.05 ¢/kWh
Feedstock cost	40.00 $/dry ton
Real discount rate	5.50
inflation rate	2.50

III.6.2 Sensitivity and parametric analysis

This section deals with the sensitivity of the performance and financial model results. In this regard, the sensitivity analysis is used to investigate how sensitive the production of electricity, capacity factor, and *LCOE* to the main parameters**.** Principally, the uncertainty of outputs is related to variations in the values of input variables. The parametric analysis involves assigning multiple values to one or more input variables to explore the relationship between the input variables and resulting metrics.

III.6.2.1 Technical parameters

It has been accorded in previous literature that bio-power generation depends on the following input variables: excess air percentage, flue gas temperature, and moisture content. In this work, we further test the sensitivity of the results to thermal properties with an incremental variation of 10%. Therefore, the sensitiveness of energy production and annual capacity factor to these variables is studied. The results of the sensitivity analysis are illustrated figures *III.5*. The temperature of the combustion gases has a great impact on output results. Changing temperature by 10% leads to changes in both energy production and capacity factor by 1%.
Similarly, degradation of stock moisture content by 10% change outputs by 1%. The other two variables equally affect energy production and annual capacity factor, but their contribution is lower. Consequently, we conclude that results are directly related to the temperature of the combustion gases and moisture component, but much less sensitive to variations in the thermal proprieties.

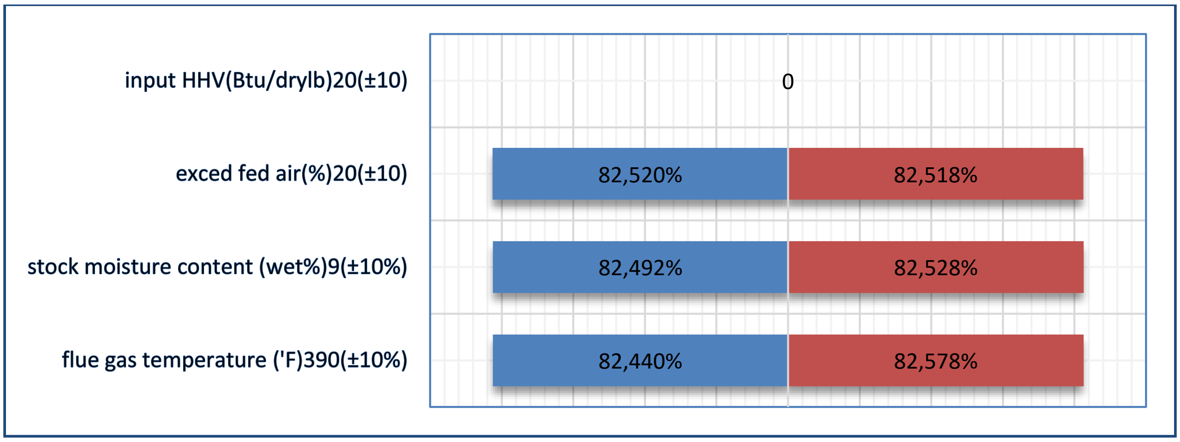

Figure III.5: Sensitivity of annual capacity factor for different important parameters.

Consequently, we conclude that results are directly related to the temperature of the combustion gases and moisture component, but much less sensitive to variations in the thermal proprietiesIII.6).

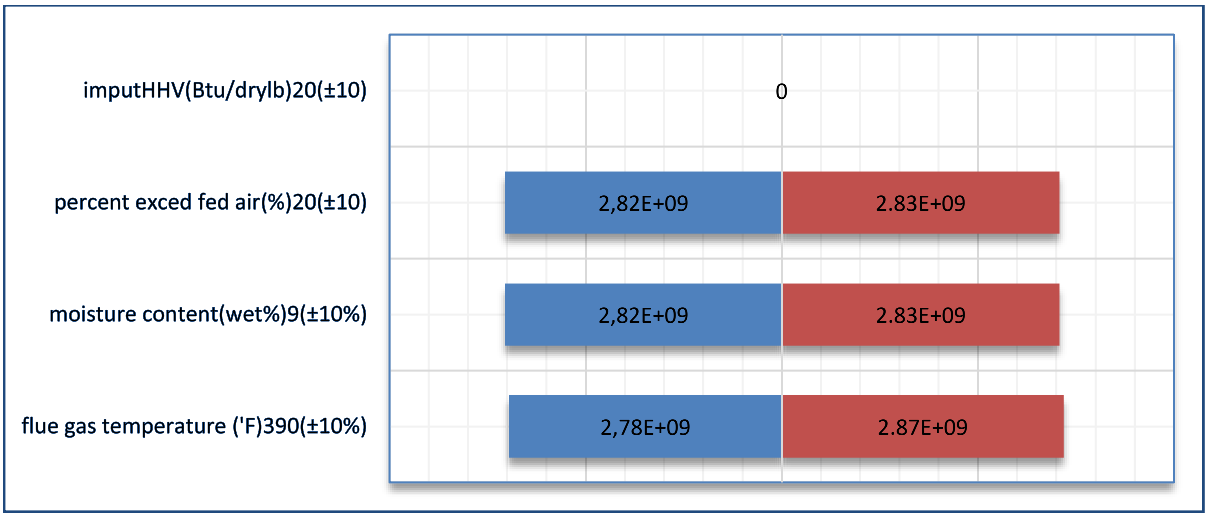

Figure III.6: Sensitivity of annual energy production (kWh) for different important parameters.

The temperature of the flue gas reveals how much energy is being dropped away to the atmosphere. This input variation greatly acts on the annual production, which influences the thermal efficiency of the boiler and how well it transfers heat. In this study, two boilers have been considered with the same thermal outlets because of the decent capacity of the biomass plant.

While, figure III.7 exhibits the sensitivity of annual energy to the temperature of the boiler gas. According to this, the temperature impresses thermal efficiency and annual production. This is accepted in normal assessment because boilers should always run with a limited volume of flue gas.

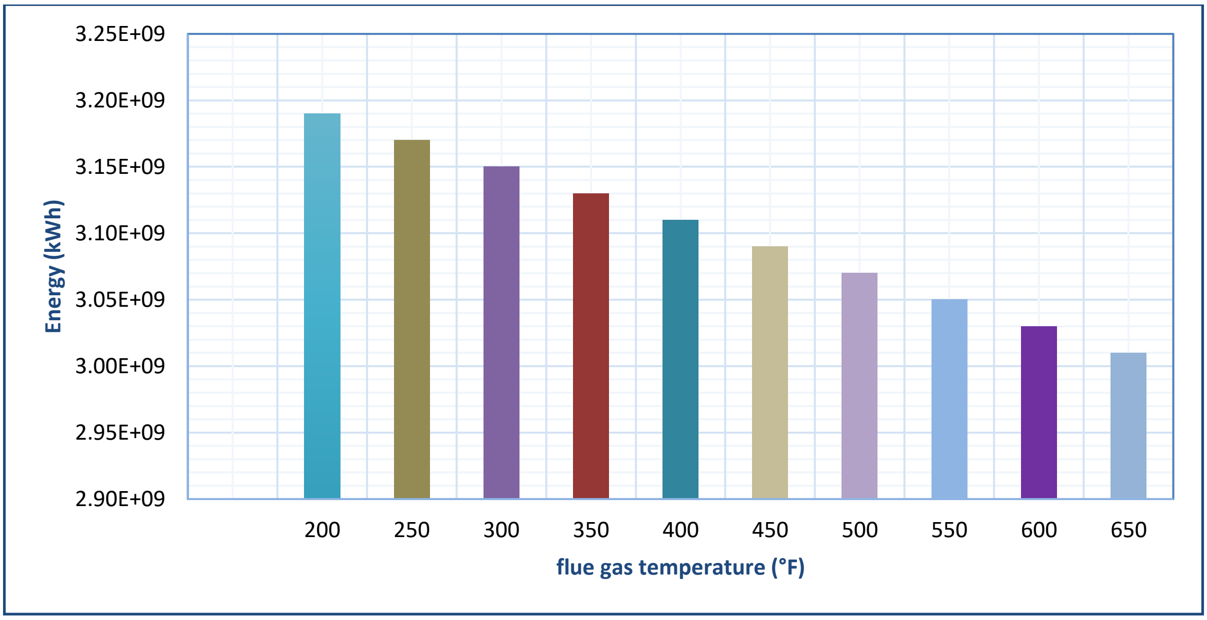

Figure III.7: Variation of annual energy with flue gas temperature fluctuation.

Figure III.8 shows the sensitivity of annual energy and capacity factor to the moisture of olive residues. The simulations portray that energy outputs depend slightly on biomass proprieties. Consequently, it concluded that the levels of these operating parameters affect marginally the performance of the proposed plant.

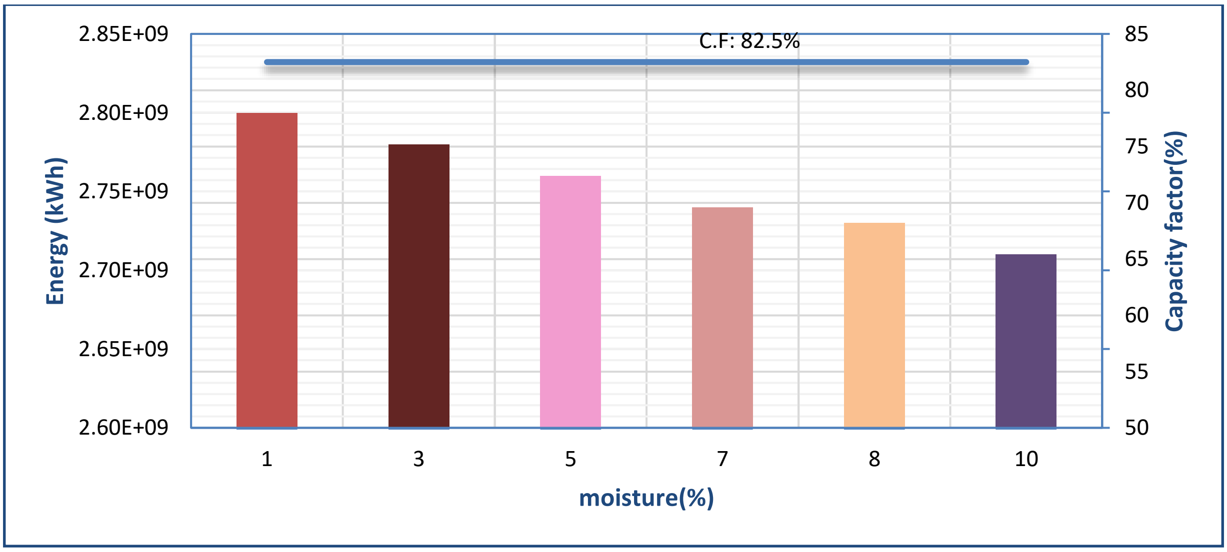

Figure III.8: sensitivity of annual energy and annual capacity factor to moisture variation.

III.6.2.2 Financial parameters

The sensitivity of the *LCOE* to the important cost parameters of the system (feedstock price, inflation rate actual discount rate) is carried out. The results, illustrated in Figure *III.9*, show that *LCOE* is very sensitive to feedstock prices and the discount rate. As indicated, an augmentation of 10% in the cost of feedstock increases the *LCOE* from 15.04 to 15.49 cents/kWh. This explains why accurate data on the price of raw materials and the actual discount rate must be collected and updated. This current sensitivity analysis also reveals that *LCOE* is less sensitive to inflation. As determined, the levels of operating parameters require further study to understand their major effects and interaction effects on energy efficiency and *LCOE* to improve system performance. The feedstock price is an important parameter influencing the economy of the project, therefore it shall be analyzed within a sensitivity. Its impact on real *LCOE* is shown in Figure *III.10*. Apparently, with each increase of feedstock price, the *LCOE* increase by a larger-factor.

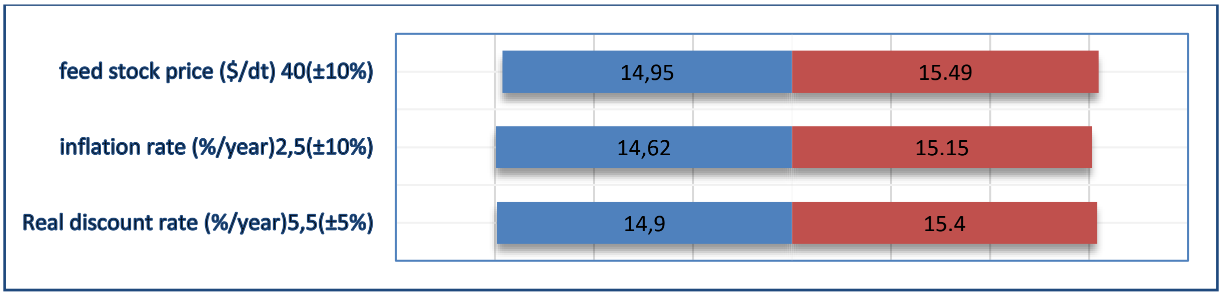

Figure III.9: Sensitivity of real LCOE (cents/kWh) for different important parameters.

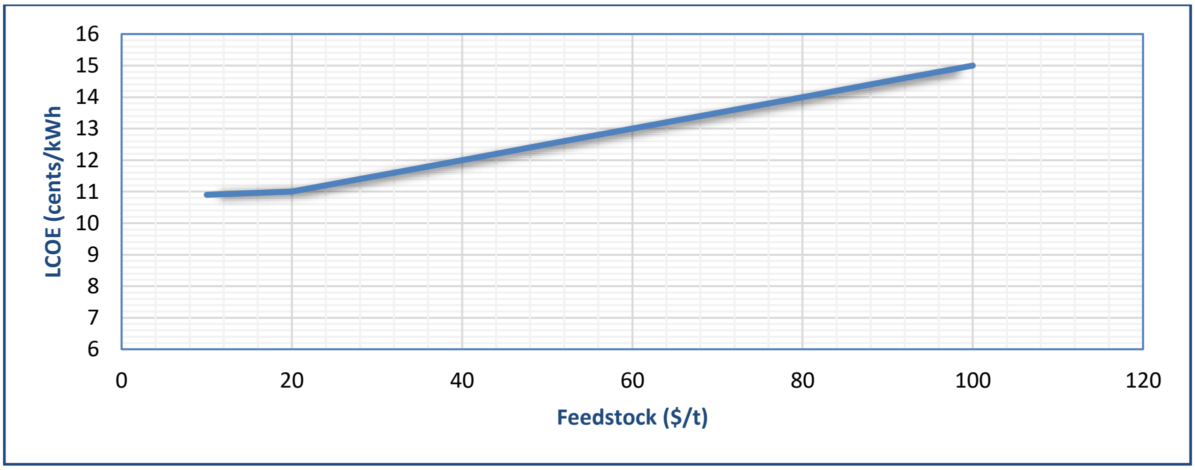

Figure III.10: Fluctuation of LCOE with feedstock price variation.

It is also portrayed in figure *III.11*, that *LCOE* was much more sensitive to other financial parameters (the inflation rate and real discount rate).

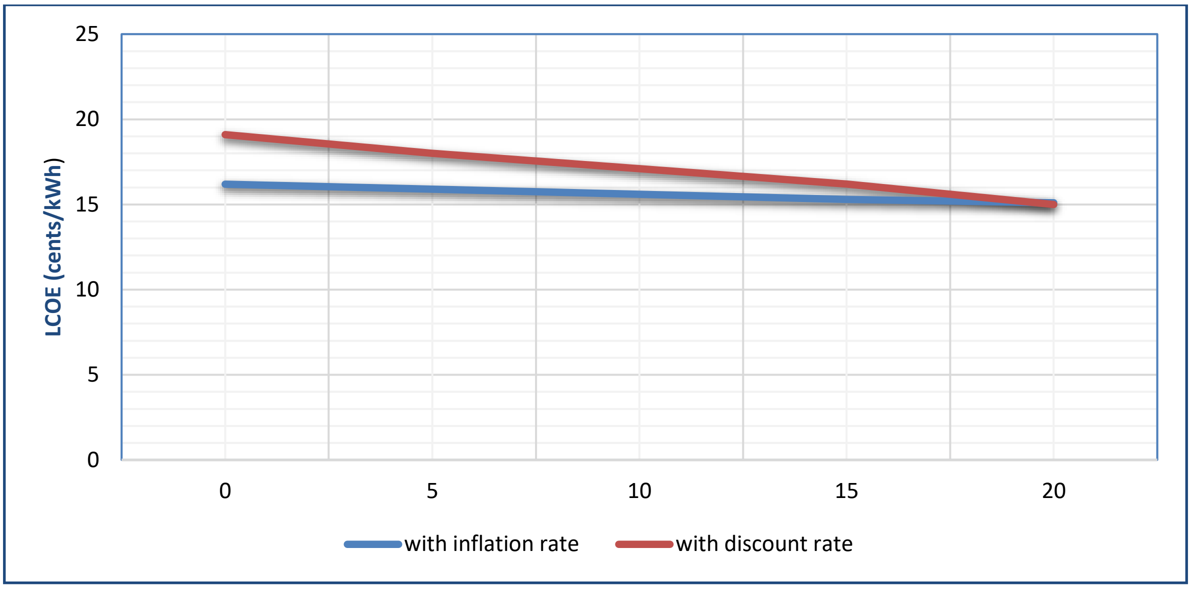

Figure III.11: Variation of LCOE with the inflation rate and discount rate (%).

III.6.3 Comparing CSP and Bio-power plant LCOE in Morocco

In a global context, Morocco is highly dependent on fossil fuels by exporting 97% of its energy envelope. Aware of this situation, morocco is progressing the integration of renewable energies by developing the large Nour-Ouarzazate complex with a total installed capacity of 510 MW and by investing around 7 billion dollars for solar energy, which explains the total installed cost per capacity of 13,725.49 $/kW. Accurately, the LCOE generated by the NOOR I is about 0.2450 $/kWh, 0.19 $/kWh for NOOR II, and 0.17 $/kWh for Redstone [176].

Biomass combustion can be more profitable and competitive. In the current work, the model performed has an *LCOE* of 0.15 $/kWh with a total installed cost per capacity of 3755.70 $ /kW. This explains the good factor capacity of this technology and the flexibility of the *LCOE* to be more reduced. A more critical examination of the uncertainty analysis reveals additional economic profitability of the studied power plant.

For example, a reduction of 20% in the boiler and turbine equipment price minimizes the *LCOE* from 15.04 to 14.54 cents/kWh (figure *III.12*).

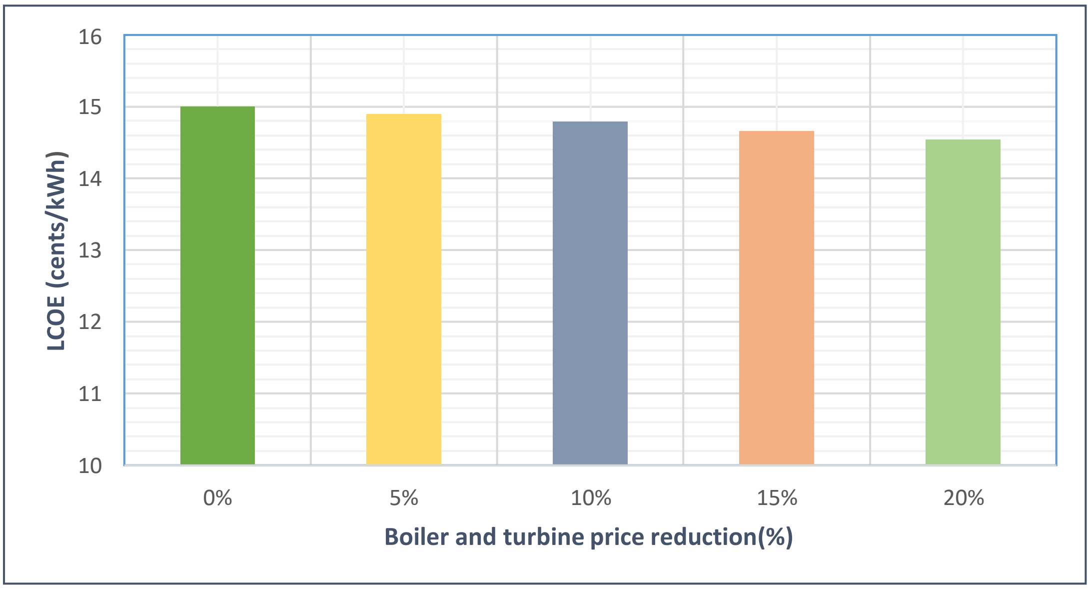

Figure III.12: Variation of LCOE due to reduction in components price.

According to the International Renewable Energy Agency (*IREA*), the LCOE range of CHP plants varies between 11 and 28 cents/Kwh, for the year 2012. As reviewed before, in Egypt, the electricity cost is about 10.55 cents/Kwh when using straw rice [166], and 26 cents/Kwh for Pakistan [177], in both cases the cost is highly related to the rice husk price. Recently in 2020, the LCOE was estimated from academic papers between 12.3-25 cents/Kwh [178]. Thus, An LCOE of 14.54 cents/kWh, seems to agree with literature, and prove the viability of the proposed system comparing with key previous literature survey.

III.7 Conclusion

Nowadays, photovoltaic and wind turbines are the icon of the energy transition, but biomass is the key to linking my two urban and rural metabolisms. In this context, agricultural biomass is the way to recycle our waste, produce energy and especially for developing countries it is the only technology able to integrate other forms of renewable energy, to create agro-industrial and industrial synergies, and especially to integrate environmental disciplines and the valorisation of materials.

The analysis of the structure of energy consumption in the Moroccan agricultural sector shows that the energy consumption of this sector is of the order of 1,561.8 Ktep with an annual increase of 9.5%. These are concentrated on two uses: tractors and agricultural machinery (diesel) with 686.2 Ktep and pumping for irrigation (gas, oil and electricity) 398.6 Ktep. More accurately, these two consumers represent 69.5% of the total energy consumption of the sector. According to the current situation current energy in Morocco is highly dependent on fossil fuels, Morocco is seeking to increase the share of renewable energy in the country to 42% by 2020 and 52% by 2030, divided between hydro, wind and solar energy. Yet, Morocco produces more than 400 million tons of agricultural products a year. Much of the agricultural biomass waste consists of various natural fibers that have brilliant properties and could be successfully exploited in the development of composite materials for various structural and non-structural applications.

Biomass power generation is a promising way to recycle from agricultural waste to produce clean electricity. The development potential of bio-power plants has been analyzed in Morocco. The analysis was performed from technical and financial data using *SAM* software to assess the energy and economic effectiveness of biomass power generation. Parametric and sensitivity analysis was performed to understand the effect of different parameters on the project viability. The results revealed that only with olive residues, using combined heat and power systems (CHP) for electricity production has the potential, of about 2828.11 GWh /year with a high annual capacity factor of 82.5%. The system power generated in 8761 hours per year can supply electricity to 254,252 households. Indeed, to compensate monthly variations of electricity load and demand, the energy produced is assumed to be supplied to the national grid, and from there, recovered by the local villages. The main results of the financial model can be perceived as a total installed cost of 3755.70 $/kW. The average real and nominal LCOE of 17.23 and 15.03 cents/ kWh respectively. Thus the LCOE is too competitive to thermal energy parks installed in the country. Furthermore, the LCOE is more flexible to be reduced, if we take into account the sensitivity study developed. For these reasons, it can be concluded that bio-power plants can be considered very reliable. Thus, there is a need to follow modern policies to force producers to engage in energy-efficient practices, as an effective way to inaugurate sustainable production systems. Many strategies can be adopted like accepting minimum efficiency standards for technologies and devices, reform and reorient energy subsidies, and using Artificial Intelligence with renewable technologies.

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CHAPTER 4

Secured Smart Sustainable Agriculture (S.S.S.A) in Morocco IV

Contents

IV.1 introduction

Agriculture is mutually the food provider and an energy-intensive consumer, mostly in emerging countries. Throughout, it must guarantee food security and preserve resources for future generations. Actually, this socio-economical sector is facing several challenges such as high population growth, climate change, intense production, and pollution of soils. However, structural changes are needed to move towards a sustainable agriculture capable of meeting the needs of 10 billion people in less than 30 years.
In spite of this, artificial intelligence will allow the renewal of existing systems and the alignment of technology with agriculture. It will be able to bring about the favorable changes necessary for renewable solutions and agricultural practices. This work seeks to define the intersection of agriculture, renewable energy, artificial intelligence, and sustainability, in order to identify the key issues that need to be addressed. This transdisciplinary approach reveals what exists between disciplines, what can be done with AI for the transition to sustainable systems and precision agriculture.
The main objective of this study is to help to better understand the potential impact and the opportunity to integrate Smart solutions, in particular for agriculture in Morocco. Indeed, it is very important to determine the potential contribution of smart technologies to promote renewable energy systems in rural activities, with the aim of generating greater economic and political engagement in favor of a successful agricultural metabolism. Otherwise, it is difficult to predict events, like financial crises, human or animal epidemics, and price volatility of agricultural inputs and food, amplify the uncertainty about farming activity and raise serious concerns to consumers and authorities [178]. As sustainable agriculture attracts the intent of several nations and politicians, smart innovations will be needed to produce sufficient quality food in a sustainable manner.
The idea that all challenges will be overcome by using technology and Artificial intelligence. Recently, (AI) has gained considerable attention in the field of agriculture due to its potential and advanced analyses to ensure good resilience and efficiency of agricultural production [179]. All over the world, Artificial Intelligence (*AI*) has started to play a major role in daily life, expanding our perceptions and our abilities, (AI) have proven to be essential for information and services in the fields of health, education, , trade and other fields, and have contributed to increased transparency and accountability [180] ; surprisingly, agriculture, despite being the least digitized. While the digitalization and Agriculture report presents the example of two sectors that demonstrate how AI can increase the circularity of many economic initiatives. AI could make it easier to choose projects to eliminate waste in the food sector: AI technologies could indicate when fruits and vegetables are ready to be harvested, and improved real-time monitoring, crop production, processing and water efficiency [181]. Another sector of activity, the use of agricultural robots and drones are designed to determine various important parameters such as weed detection, detection of crop yield and quality and many other techniques.

IV.2 Scope and Motivation

The Intergovernmental Panel on Climate Change (*IPCC*) projections revels for every decade since 1970, a 0.5 degrees' Centigrade temperature increase has been observed, greatly exceeding the global average by about 0.15 degrees; Actually the *global temperatures* were estimated at 1.7 *degrees* [182]. In a regional context, the Mediterranean climate is considered by seasonal contrast, where the dry and warm summer climate can affect agriculture. Developing countries are highly exposed to climate change too, an increase in degradation of lands is predicted as a consequence of reduced precipitation [183]. Annual precipitation is projected to decline by 10-40 percent, including a 10-30 percent decrease during the wet season from October to April, and a 10 to 40 percent decrease during the dry season, from May to September. As a consequence, droughts and other extreme weather events will be increasing in frequency and intensity in Morocco [184]. Thus, Climate data remains as one of the sources of information necessary for the integration of any possible technology related to the biosphere. In agriculture as for renewable energies, parameters such as wind, temperature, relative humidity, availability of resources must be quantified and calculated rigorously in order to ensure a good prediction or use.

The point of view of this article is that the ecological transition and the digital transition can meet on the issue of sustainable agriculture. As well as, AI and machine learning have the potential to provide elements to improve agriculture and sustain the production. This work defines firstly the dimensions of sustainable agriculture. Afterward, a survey review on the use of artificial intelligence in agriculture was elaborated. This study generates a framework based on the Artificial intelligence-agriculture-environment nexus for the development rural communities. Water management, bioenergy and the prediction of climatic hazard can potentially promote agriculture as their future perspectives for large-scale integration and achieving (*SSSA*).

I V.3 Sustainability and smart management

In fact, we are experiencing a world with a growing population and millions of people going hungry. It will take all our knowledge and imagination to deal in an integrated way with the challenges of maintaining soil fertility, water scarcity in many parts of the world, eliminating pests and diseases that affect both crops and animals.

Thus, sustainable agriculture is precisely defined as the ecological balance of interactions between modern human's kind and their local ecosystems [125]. The aim is to integrate all these key parameters into an equilibrated production system. Mainly, ultimate goals about sustainability in agricultural systems focus on the need to develop sustainable practices that seamlessly integrate environmental health, energetic profitability, social and economic fairness [126]. The strategies reviewed in the literature to deepen sustainable agriculture focus on reducing the consumption of fossil fuels on farms [127], [185], [128].

This includes as well as the reduction of the consumption of chemical fertilizers, the use of biodiversity practices, improvement of water efficiency and, above all the evaluation of both energy production opportunities and biofuels in the agricultural sector [129]. However, the structural integration of sustainability in agriculture depends on several variables that change from one country to another, and even in the same country and region, it changes from one farm to another. Also, calculating agricultural energy inputs is more complex because it differs on several variables.

Yet, many studies have focused on the use of energy in agriculture, generally, they underlined machinery and electricity as the most energy consumers in agricultural sectors [133][134][135]. Thereby, it is necessary to attend new policies to engage producers in energetic-efficient practices toachieve more sustainability [136].

To sum up, sustainable agriculture can be defined as a set of methods to ensure sustainable food production, respecting ecological, economic and social limits. As illustrated, figure *IV.1* shows principle keys towards SSSA.

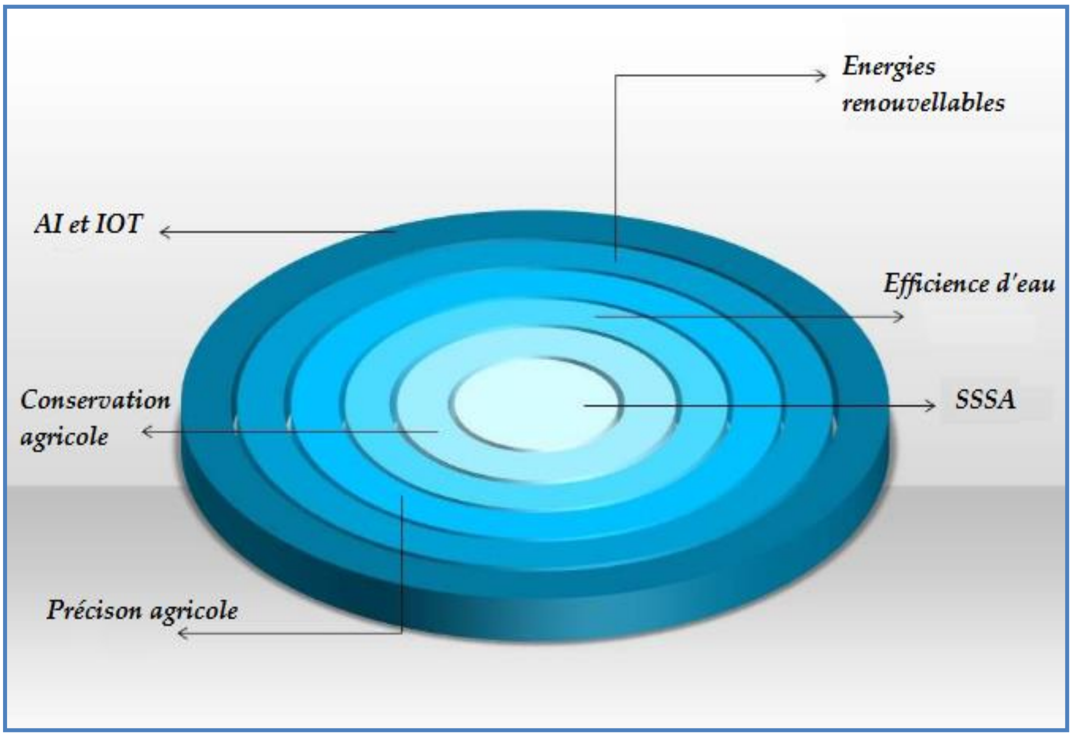

Figure IV. 1: Sustainability chart process in agriculture.

The term Artificial Intelligence was introduced in 1956, as "the science and engineering of making intelligent machines". The main notion is to create a technology which perform like a human brain, it is a way of artificially making a computer intelligent [186]. This is committed by studying human brain processes, to develop intelligent software and systems able to provide us with desired output for every valid input, just like the human brain [187]. The field of artificial intelligence is rapidly expanding, including Machine Learning and Deep learning. we differentiate the term (*ML*) as obtaining a computed model of complex nonlinear relationships or complex models in the data, and AI as the framework for making machine-based decisions and actions using ML tools and analytics [188]. ML has long been used for non-linear regression, to trace models in data, and help as one approach for achieving AI goals [189].

Today, ML algorithms are trained using three prominent methods commonly recognized as “supervised” where the system learns from labelled data; “unsupervised” where the unlabelled system finds patterns in data; and, “reinforcement” learning where the system is programmed to make guesses at solutions, those learn from new situations using a trial-and-error method [190][191].

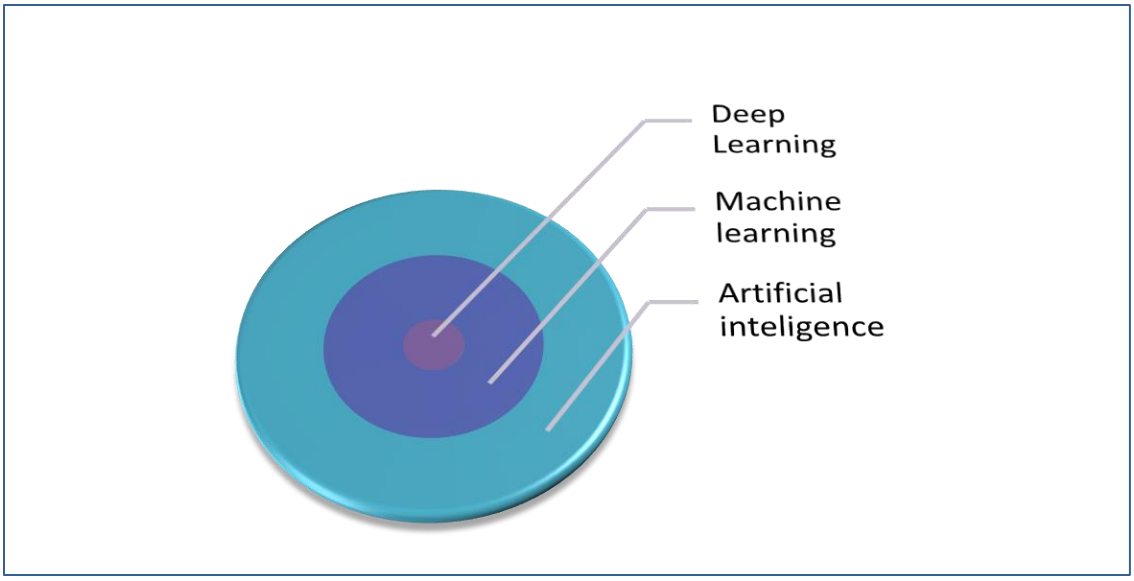

Figure IV. 2: Sustainability chart process in agriculture.

AI has proven its significant contribution to improving the efficiency of all areas and led the challenges and problems of different industries (figure *IV.2*). These technologies have even reached the agricultural value chain from production, transport to distribution and marketing. Agricultural robots have brought a high value of A.I and intervene in several phases of agricultural production such as increasing crop yield, reasoning irrigation, detecting soil content, monitoring crops, and weeding.

From another point of view, intelligent systems are able to process information, deliver complex reports, and serve farmers in decision making and comply with quality requirements. Accordingly, AI has the potential to provide an essential solution to face different challenges and will make it possible to produce better and more, with fewer inputs. However, in the context of this study and to facilitate the presentation to the reader, we propose to discuss the great dimensions of agriculture which suffer many challenges and must face deep mutations that AI can also respond to. The forms in which AI can intervened in the agriculture are presented in following sections.

IV.3.1 Precision agriculture Concerns.

Precision agriculture (*PA*) is a key element, whose primary objectives are to increase the profitability of crop production and reduce the negative impact on the environment by adjusting agricultural input application rates as needed locally [131]. The mission of PA is to reduce nitrogen, which also leads to better yields. The return on investment is then made on several levels: savings on the purchase of plant protection products and fertilizers, and better valuation of crops [130]. This concept operates through the use of new information and communication technologies (*NICT*) and internet of things (*IOT*).Precision agriculture is still referred to as satellite agriculture or site-specific crop management (*SSCM*) because it uses satellite and aerial imagery, weather forecasting, variable rate fertilizer application, and health indicators. By collecting those parameters, AI could meet consumers' needs and increase crops profitability. M.L makes it possible by learning from experience, analyses data from both inputs and outputs, and perform crop production with an enhanced degree of precision [192] (figure *IV. 3*).

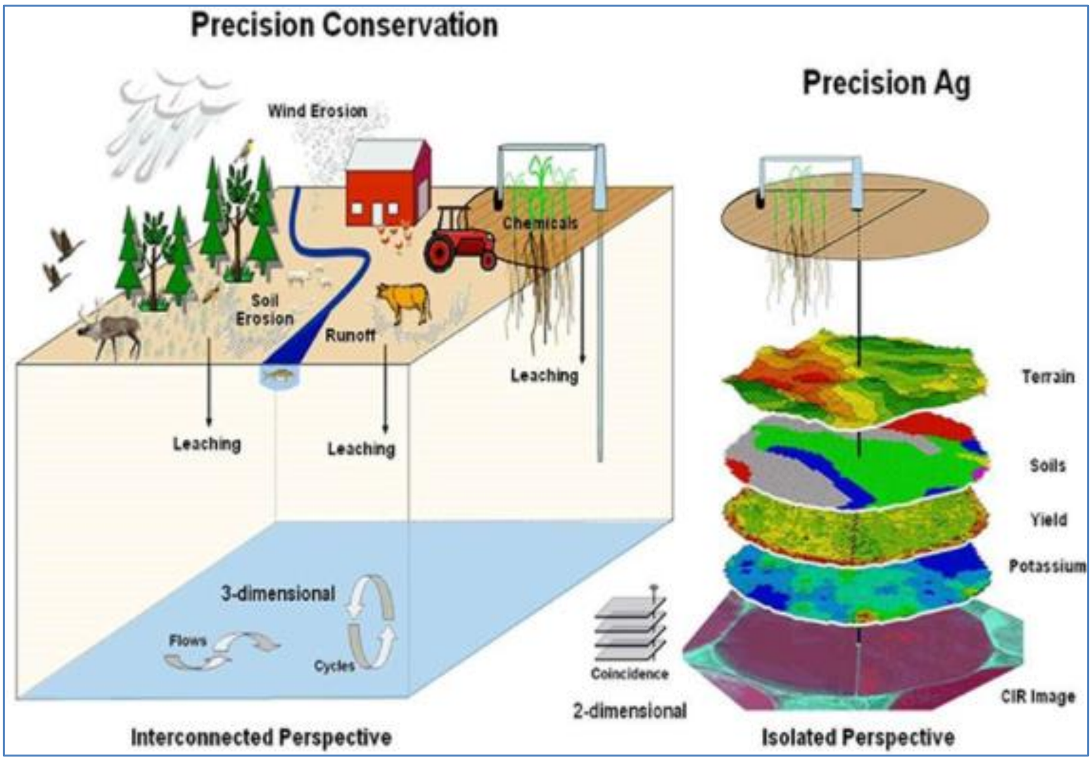

Figure IV.3: The site-specific crop management [193].

IV.3.2 Crop monitoring and soil fertility

Soil is the basis of all production systems in agriculture. Thus sustainable agriculture aims to protect crops and increase soil fertility by promoting appropriate agricultural practices and eliminating those that consume and contaminate the soil. Using AI is an efficient way to monitor and characterize likely crop health problems or nutrient deficiencies in the soil. Using deep learning (*DL*) applications coupled with ML algorithms AI, it is possible to analyse phytosanitary patterns in agriculture and to better understand, soil health, plant pests and plant diseases [194]. By using AI, the chances of plant or soil degradation are reduced and crops are able to meet the market trends, maximize the return of different soils [195], and ensure a better crop mapping for decision-making (figure *IV.4*) [196].

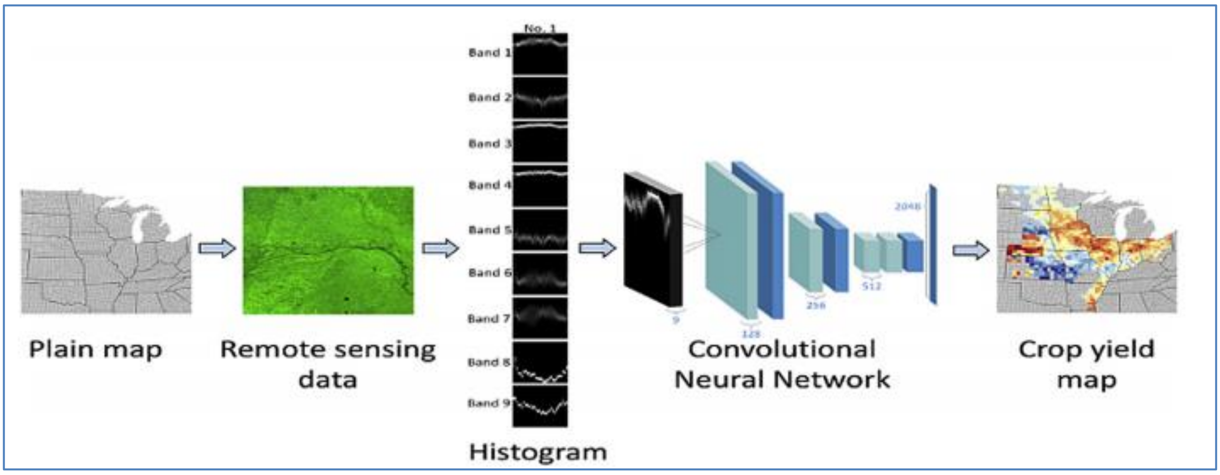

Figure IV. 4: Crop yielding map using machine intelligence algorithms.

IV.3.3 Water ressource management

Sustainable agriculture must focus on planning, developing, and managing water resources, which remains the heart of all agricultural and human action. It is the key equation to strongly integrate agricultural sustainability [132]. But agriculture is still an intensive consumer of water resources, approximately 85% of fresh water available in the world. A percentage that continues to increase in the face of rapid population growth and the increasing demand for food, which requires more efficient technologies, in order to reason and optimize irrigation.

Technologies have been developed to facilitate the linking and the sharing of data between the machines and with the server through the main network between all the nodes of the agricultural field. We are talking about Machine to Machine (*M2M*) technology, capable of detecting moisture content and temperature at periodic intervals, in order to automate the irrigation of agricultural plots with exact needs [197].

Remote sensors using Arduino technology can be used, thus installing digital cameras becomes more convenient for automation and irrigation monitoring (figure *IV.5*) [198]. At the same time, as reviewed in table *IV.1*(*next page*), the development of thermal imaging in crops has industrialized thermal cameras that can offer new opportunities for estimating the hydraulic conditions of plants by acquiring thermal indices of plants, which help to precisely determine water needs [199].

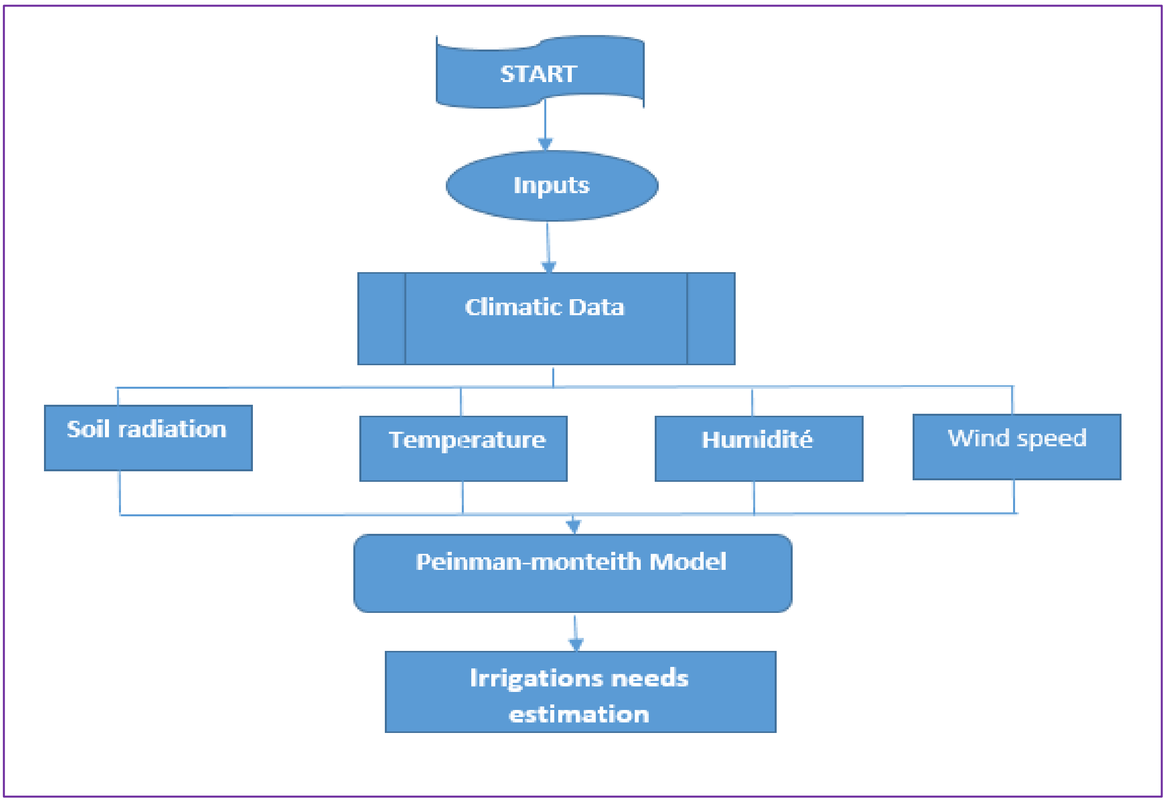

Figure IV. 5: Process methodology to estimation plant water requirements.

Table IV.1: Literature survey on water management models.

Application	Inputs	Algorithms	Method model	Technology	Performance
[200]	climatic conditions, soil moisture content	Partial Least Square Regression (PLSR)	Evapotranspiration model	Economic Hardware, sensors, (IOT).	increased efficiency and economic feasibility
[201]	temperature, soil humidity	Fuzzy Logic Controller	Penman—Monteith model	Wireless sensors networks (sensor nodes, hub and control unit)	automated drip irrigation water conservation
[202]	climatic conditions, soil moisture content topography of lands	ANN method	**soil moisture model**		precision and robustness of soil moisture prediction water-saving
[203]	soil water content and meteorological data	convolutional neural network-)	Pearson correlation, soil water content autocorrelation	deep learning Near-infrared (NIR) spectroscopy	prediction accuracy 93%
[204]	moisture, weather forecast and water level	Machine Learning algorithm –	________________	IOT, Zigbee technology, Arduino microcontroller	Drought prediction
[205]	meteorological data,soil contenent	artificial neural network (ANN) Machine learning techniques	Evapotranspiration model	unmanned aerial vehicle (UAV) remote sensing platforms	Performance to predict water stress

IV.3.4 Weeding and integrated pest management

Sustainable agriculture allows combining several cultural, physical, and chemical parameters to control pests and agricultural production without resorting to chemical pesticides. This ecological management can widely generate economic, ecological, and social favors. Remote sensing has been widely used to forecast production and crop yield expected in a given area. It could help protect natural resources such as land, air and water, and reduce the amount of inputs needed for successful crops. Remote sensing coupled to neural networks and ML is able to identify variable areas in fields for reducing environmental impact through more efficient use of nutrients and pesticides [206]. The development of crops is highly susceptible to weeds, disease or infestation by pests and insects. Furthermore, this conditions influences crops and adds a huge budget to the farmers' bills. So, removing these risks takes great intention. However, the precise and rapid detection of diseases or weeds will make it possible to take control measures and secured management of the fields [207].

To this end, as reviewed in (table IV.2 and figure IV.6), the methods of computer vision and artificial intelligence are developed to automate this diagnosis of disease detection and herbs identification [208].

Table IV.2: A.I performance and limitations for weed and disease detection.

Application	Inputs	Method/algorithms	Performance	limitations	ref
Weed detection	unmanned aerial vehicle UAV images	Fully Convolutional Network (FCN) method	weed mapping: 94% weed recognition: 88%	requires vast human expertise	[209]
Weed detection	hyper spectral images	ANN, Genetic Algorithms(GA)	Performance. Reduces trial and error.	Requires big data, expensive	[210]
Weed detection	hyper spectral images	Support Vector Machine (SVM), ANN	Quickly detects stress in crop that will prompt timely site specific	Limited crops; Only detects low levels of nitrogen weeds	[211]
Weed detection	Digital Image	(DIA), GPS	Has above 60% accuracy and success rate.	Its success was achieved after 4 years and as such, it is really time consuming	[212]
Weed prevention	Sensors and GPS data	Mechanical Control of Weeds. ROBOTICS. Sensor machine learning	Saves time and removes resistant weeds.	Expensive. Constant use of heavy machine will reduce soil productivity	[213]
Weed prevention	Yield sensing and imagery data	Colour Based and Texture Based algorithms; Greenness Identification; Fuzzy Real Time Classifier	Use Robotic arms for mechanical removal Accuracy 92.9%	expensive	[214]
Weed detection	(RGB)/ hyper spectral images	Deep Convolutional neural networks	High accuracy 98.23%	Requires big data.	[215]
Disease detection	UAV images (RGB)	CNN	Overall accuracy 89% ,94%	Requires big data and human expertise	[216]
Disease detection	UAS images	GA, ANN	Accurate results in the tested environment.	Inefficacy of DB in large scales.	[217]
	Data Base (DB)	Rule-Based Expert,		Can affects good species	
Disease detection	UAV image and sensing data	Phenotyping technology, remote sensing methods	Early season detection and performance	Require big data	[218]
Disease detection	meteorological data	Fuzzy Logic (FL), Web GIS	High performance of forecasting	Internet dependence	[219]
Disease detection	DB	Web-Based Expert System	High performance	Internet dependence	[220]

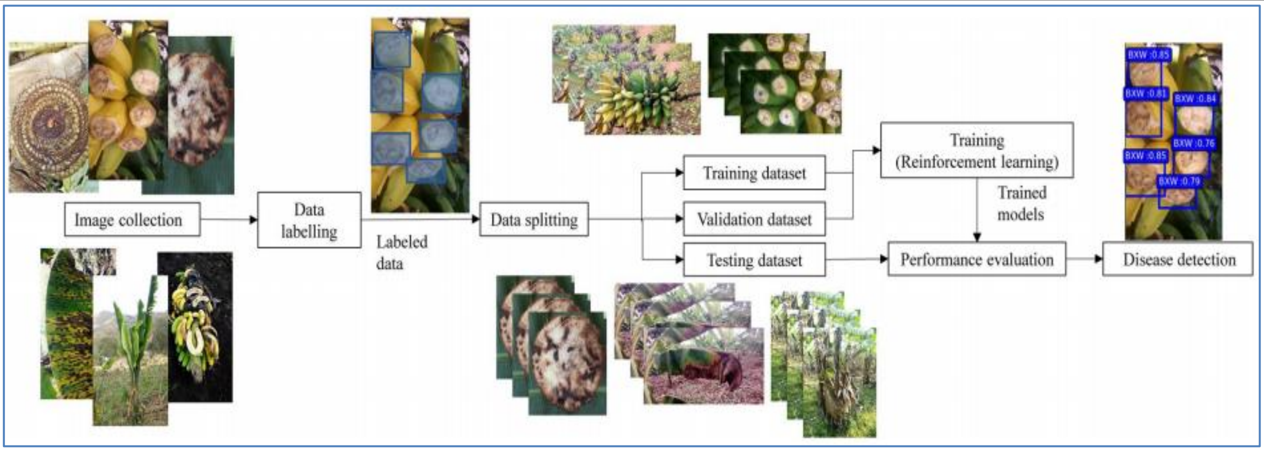

Figure IV. 6: Banana disease detection using ML algorithms [221].

I V.4 *Unmanned aeronautical vehicles for agriculture*

In the current era, developing nations are resorting to adopting agricultural precision to increase crop profitability [222]. While agricultural drones in other developing countries have proven their accuracy in improving the productivity and sustainability of agriculture, this solution relies on observation, exact measurement, and decision-making and action in real time. Unmanned Aerial Vehicles (*UAV*), or Remotely Piloted Aircraft System (*RPAS*) are remote sensing systems equipped with technologies such as infrared cameras, GPS and navigation systems, programmable controllers, multi rotors and automated flights. Thus, using drones provides better imagery resolution compared to satellite limitations [223]. There are many uses for drones in poultry farming such as crop monitoring [224], fertilizer spraying [225], crop height estimation [226], soil salinity management [227], seed planting [228], forest plantations and biomass estimation[229].Generally, The UAV remote sensing system are able for monitoring the temporal changes, backing for better management decisions, improving crop yields, and increase overall cost-effectiveness. Recently the price of drones has progressively decreased, comparing to satellites, and robots. The drone market is expected to growover 38% in coming years [230], which can lead drones to promote farming management and improving more flexibility in Moroccan agricultural practices. As shown (figure *IV.7)* [231], Drones can be used for several applications in Agriculture.

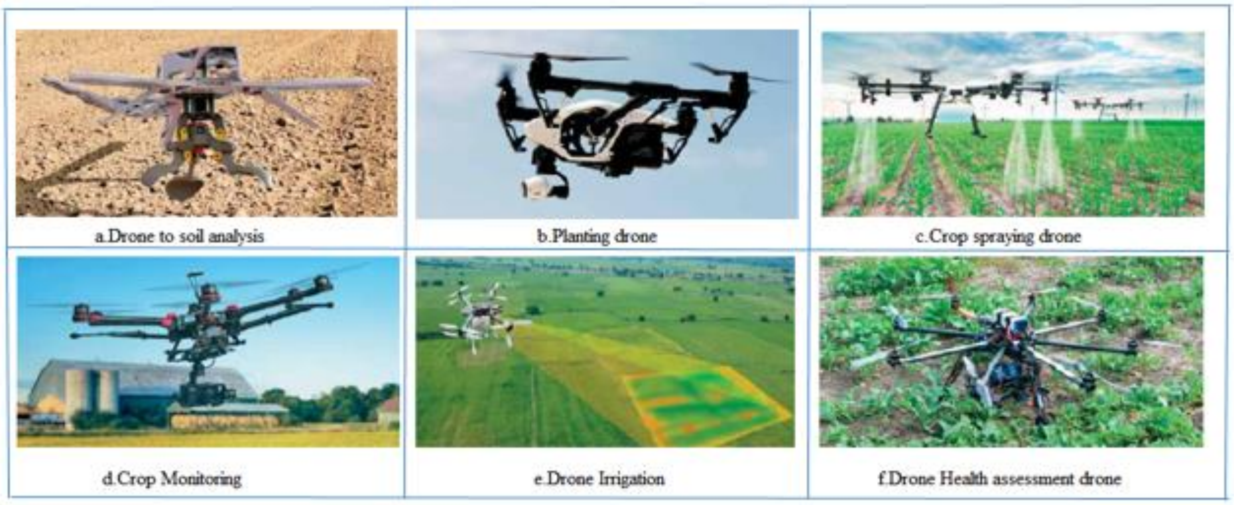

Figure IV. 7: Drone applications in agriculture.

I V.5 AI & NRTs Promotion for Agriculture

The existence of humankind and the continuation of life on earth depend basically on solar energy. Mainly as photosynthesis, water cycle, wind movement and all synthetic processes are driven by solar energy.
Recently the sun drive Humans practice (hot water, heating, cooling, electricity and their technologies to sustainability and renewables energies because it's free, clean and friendly to the environment. Energy is a constantly changing sector, limited by technological, political, societal, and environmental developments.
In a few years, energy has become one of the great challenges facing the world despite all the evolutions, it remains predominantly by fossil sources. Already today, nearly 2 billion people do not have access to electricity. These needs can only be met by a diversified energy mix combining renewable energies and increased energy efficiency. However, the share of fossil fuels in the energy mix must be replaced by renewable energies in order to achieve sustainability objectives and facing global warming. Furthermore, the challenges are also technical. Unpredictability is the big question facing renewables energies. At a time when it is urgent to optimize energy consumption and imperative to accelerate the energy transition, AI appears to be one of the means to meet these objectives.

The point of view of this article is that ecological transition and digital transition can meet on the issue of resonant and smart agriculture. As reviewed before, several machine learning models have been developed. Artificial neural networks for forecasting temperature in crops, or for estimating soil moisture, irrigation needs and nutrient requirements, as well as fertilizers. In summary, IoT allows the collection of large amounts of data, and build predictive mathematical models, which could assist decision making in agriculture.

As well, AI and machine learning have the potential to provide elements to improve distribution, balance energy consumption loads, and manage fluctuations in renewable energy production. Whether for wind power or photovoltaic power, both depending on weather conditions, the power of computer systems, and their analytical capacity. Thus, the energy transition can incorporate artificial intelligence for more opportunities to improve the efficiency of production and consumption.

Indeed, the A.I allows identifying all the inputs and outputs of the energy systems and the consumption points in systems (figure IV.8). Therefore, the intelligent automation of load control with smart meters and continuous energy auditing in real-time.

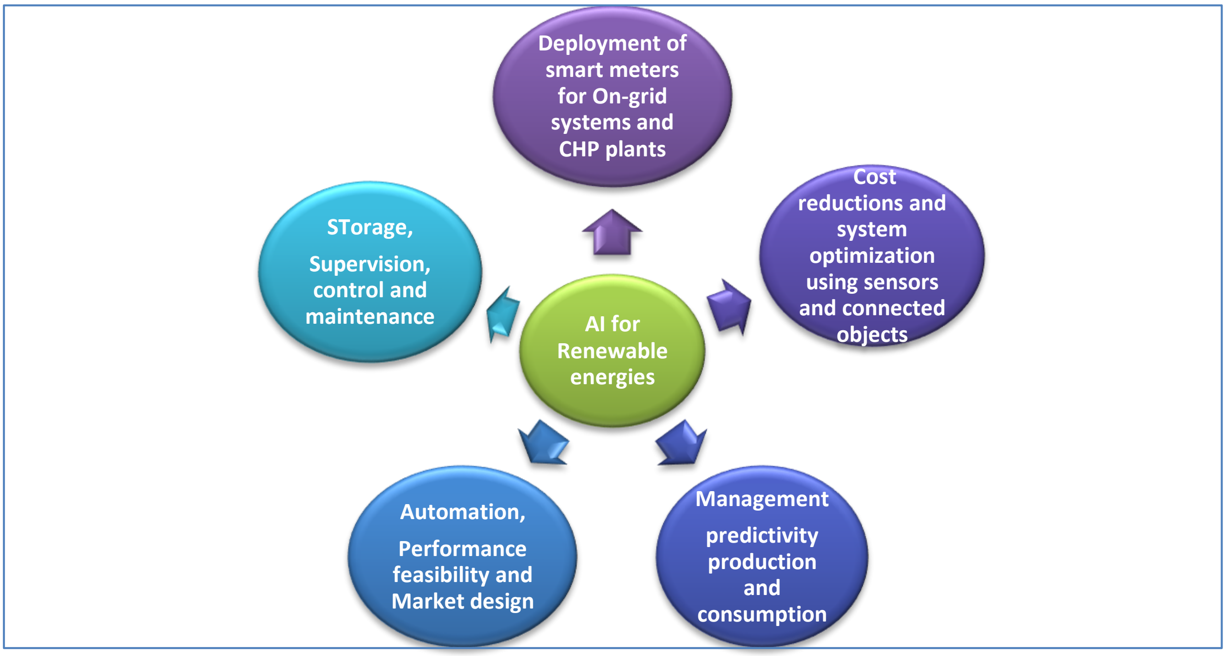

Figure IV. 8: A.I benefits for renewable energies.

IV.5.1 IOT for Weather forecasting and un-predictivity analysis

Weather forecasts are essential to ensure the good progress of several agricultural activities and especially for the renewable energies which depend on these conditions. However, conventional methods provide hourly forecasts for large areas, which is often imprecise. In this context, real-time or near-real time forecasting is possible with the development of IOT coupled with sensors [232]. Several solutions were proposed to examine weather conditions in particular areas [233][234][235].

Therefore, table *IV.3* review more recent solutions around the world. The majority of systems inspected environmental inputs, like temperature, precipitation, relative humidity, light intensity. Generally, the design involves sensors coupled to a master microcontroller such as Arduino or Raspberry Pi. The outputs possessed were processed by a computer or an online cloud platform. a mobile application can be proposed for the display of results with precision, in the short term [236].

Table IV.3: Performances and limitations of A.I on weather predictability.

applications	technologies	Imputes	Performance	limitations	reference
Weather forecasting	Wireless sensors network, fuzzy control	Air (T, atm and RH), rainfall, radiation, and wind speed and direction climatic data	Meteorological disaster early warning, Forecasting	Need of connection in farmland, debugging process	[237]
Greenhouse monitoring	n ZigBee and GPRS wireless network	temperature, humidity, light intensity and rainfall	real-time detection of greenhouse environmental factor	_____	[238]
Farm facilities environment	wireless sensors network, GPRS	Crop storage temperature and moisture levels	Cost feasibility, helps farmers to achieve a more quality of crops	Short battery lifetime	[239]
Forecasting	Machine learning models, ANN	metrological parameters	Forecasting min and max temperature. long distance communication	Short period prediction(10 days)	[240]
Crops Water management	Machine learning, IoT	Crop proprieties, and precipitation	autonomous irrigation, low error rate	cost	[241]
Smart farming	IoT	soil quality ,environmental conditions fertilisation, and irrigation data	Elasticity and scalability of the platform		[242]
Weather forecasting	ANNs	metrological parameters	Acceptable errors percentage, fast prediction. prediction results till 2050	Increasing of percentage predicted errors with time.	[243]

IV.5.2 Proposed idea for local farmers in morocco

This section involves the study and design of a low-cost local weather station and monitoring irrigation platform for local farmers. In the design of our platform we have sensors that can retrieve information on temperature and humidity, soil moisture, the presence of rain and detection of day and night. All this recovered information will be sent to a Firebase database via a Wi-Fi Shield. We have developed a mobile application with Ionic that allows us to ensure access to information in real time. A smart phone allows farmers to monitor their fields in real time. In a regional framework, this platform of sensors allows to retrieve information on air temperature and humidity, soil humidity, the presence of rain and day and night detection.

All this retrieved information will be sent to a Firebase database by a Wi-Fi Shield. We have developed a mobile application with Ionic that allows us to ensure access to information in real time (figure *IV.9*).

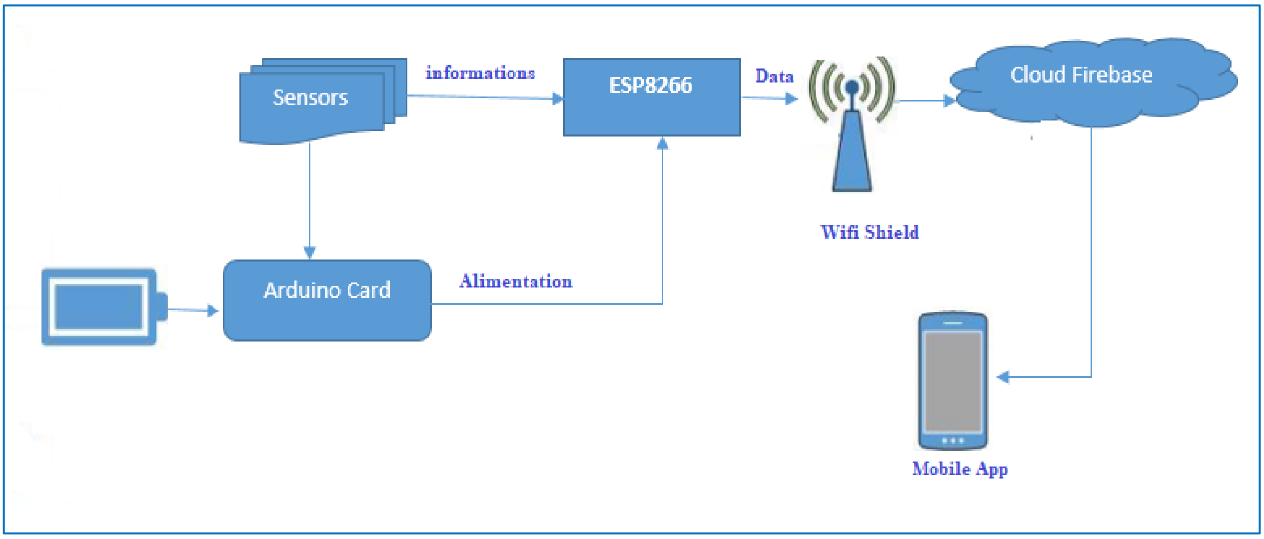

Figure IV. 9: Functional diagram of the proposed solution.

IV.5.2.1. Sensors used for detection

The role of the Arduino board is to store a program and make it work. It is also used as an expansion card with various functions such as: relays, motor controls, SD card readers, Ethernet, Wi-Fi, GSM, GPS, Bluetooth, clock, and LCD displays with the sensors.

- **Soil Moisture Sensor:** The electrical conductivity of the earth depends on the humidity of the soil, in other words the electrical resistance of a soil increases with the drought of this one. To measure this electrical resistance, two electrodes are used which are fixed on a fork-shaped support which is planted vertically in the ground. It has two outputs: one digital with an adjustable threshold by potentiometer and the other devices. The YL 69 sensor is a simple humidity sensor that can be used to detect when soil is lacking in water (high level) or not (low level). The sensor can be widely used for Automatic watering of indoor plants, Watering the garden, Irrigation of crops, Analog humidity measurements, Flood alarm, and Rain detector [244].
- **Temperature and humidity sensor:** First, the Arduino activates the sensor by placing the data line at LOW for at least 800µs). During this time, the sensor prepares the temperature and humidity measurement.

Once the data line is released to the sensor responds to the microcontroller by keeping the data line at LOW for 80µs, then to HIGH for 80µs.The sensor will then transmit a series of 40 bits (5 bytes). Both first bytes contain the humidity measurement. The next two bytes contain the temperature measurement and the fifth byte contains a sum control which verifies that the data is correct.

- **Precipitation Sensor:** It includes a printed circuit board (control board) which "collects" the drops of rain. When the raindrops are collected on the circuit board, they create parallel resistance paths which are measured through the amplifier operational. The lower the resistance (or the more water), the higher the output voltage is low. Conversely, the less water there is, the higher the output voltage on the spindle. This sensor has 2 outputs: - a logic output D0 which allows an all or nothing detection (a screw is used to adjust the detection threshold). This output is at 1 when the detection plate is dry, and at 0 when it is wet.
- **Light sensor:** A photo-resistor, as its name suggests, will change its resistance depending on the light around it. When the resistor is placed in a dark room, it has a resistor of a few mega ohms and, as we emit light on the sensor, its resistance begins to decrease, from mega Ohms to a few Ohms. This property helps the LDR to be used as a light sensor.

Figure *IV.10* shows the inter-connection of different sensors used with Arduino module.

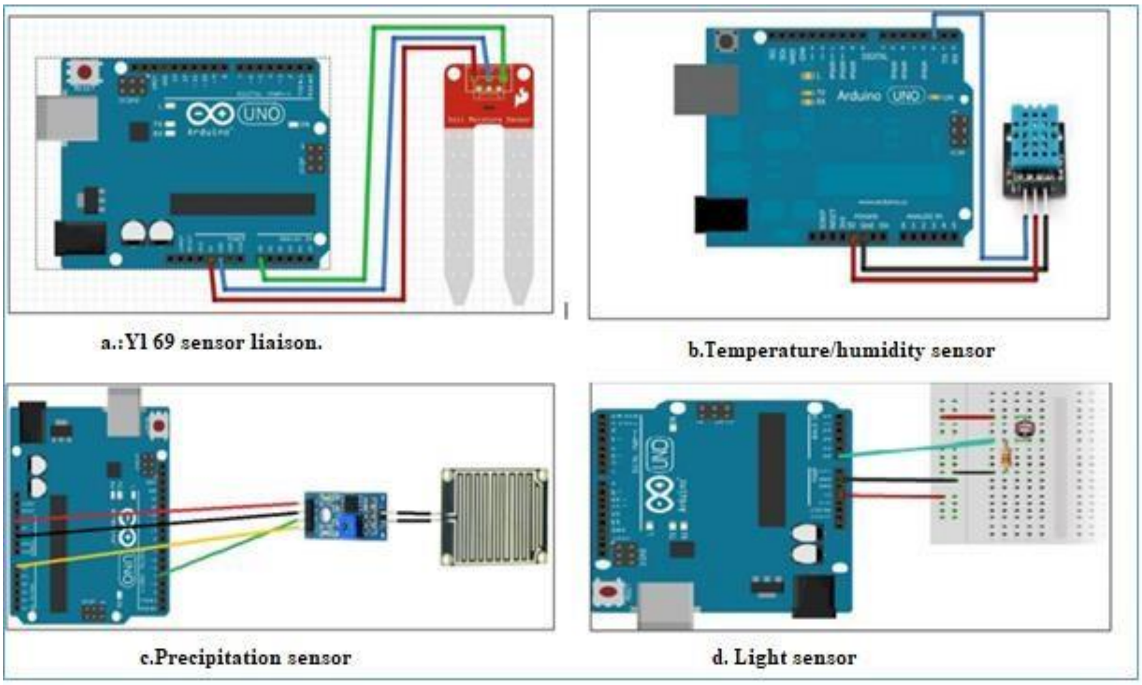

Figure IV. 10: Different sensors used for detection

IV.5.2.2 Communication Modules

- Module RTC DS3231: Communication of the RTC module is via the I2C interface. Data is sent to the module or received from the module via the I2C interface. So we need to get the DATE and TIME information through this interface. The module can operate on a regulated supply of + 5V. Then the module's SDA link to controller SDA and SCL is connected to the controller's SCL (Figure *IV.11*).

Usually, information is sent or received byte by byte. When the current drops, the RTC module chip automatically draws its power from the battery source connected to it. So the time will be up to date. And when the system restarts, the controller can get the module real time without error.

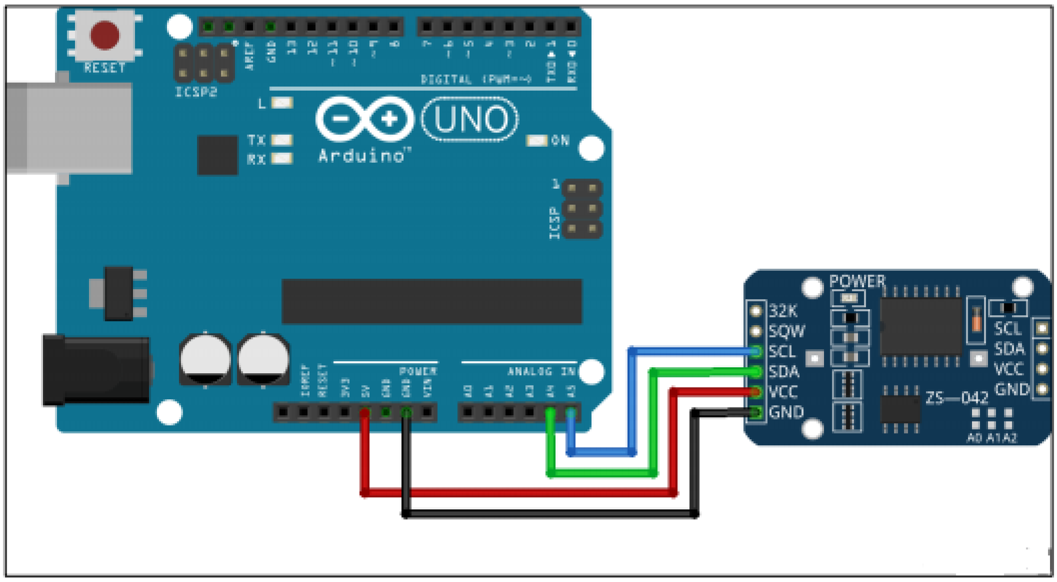

Figure IV. 11: RTC connection with Arduino.

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- **Module Wi-Fi: ESP8266-12E Node MCU Kit:** ESP8266 WI FI module can be controlled from your local Wi-Fi network or internet (after port forwarding set on your router). The ESP8266 communicates with the Arduino through a serial interface. It uses Arduino's Rx and Tx pins (digital pins 0 and 1) connected to the ESP8266 ESP-12E module to receive commands and communicate again. The module offers a full TCP / UDP stack load and can be configured as a web server. To send data to Firebase, the ESP must be connected to the router.

- **Data-base and Mobile application:** As access to the platform in real time is a requirement, we have developed a mobile application that gives the user access to the information that the platform provides in real time. In this work, we were interested in Firebase technologies which provides the database where online information is stored and Ionic which allows us to develop a single application executable on all mobile platforms (Android, IOS, Windows phone, etc.)(Figure *IV.12-13*).

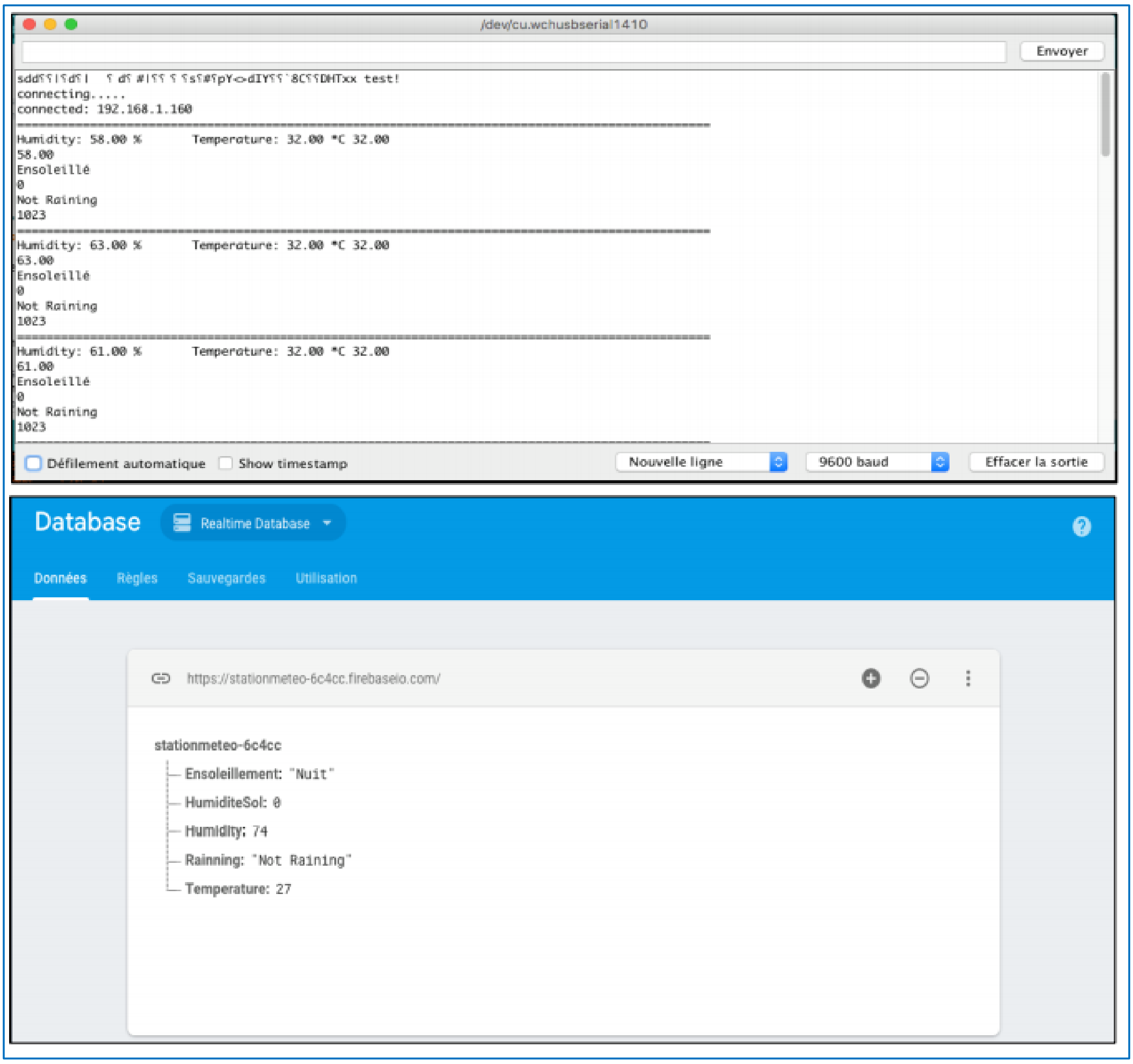

Figure IV. 12: Retrieving and storing information on Firebase.

Figure IV. 13: Mobile application interface.

The proposed solution can be developed as an irrigation monitoring and control system. This system will be an alternative for the traditional agricultural methods, to automate irrigation and allow farmers to follow the status of their field from their home or any part of the world. Currently, industries use expensive automation and control devices and not suitable for agricultural use. Thus, the idea is to propose a low-cost intelligent irrigation technology capable of controlling the Solar pumps via Arduino and visualizing the status from the farm in real-time on Android mobiles using Wi-Fi (Figure *IV.14*)

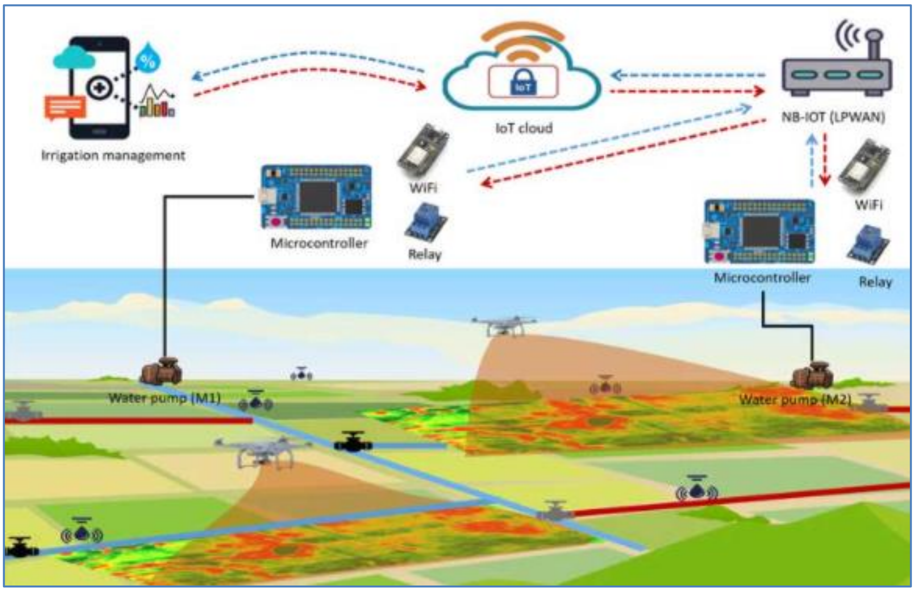

Figure IV. 14: IoT for water pumping system [245].

I V.6 Suitable Solutions for greenhouses in Morocco .

Faced with climate change and the global economic situation, Morocco can better reason its agriculture and optimize the allocation of its resources, breaking with the paradigms of food self-sufficiency, food security and even more food sovereignty in remote areas. Agriculture is the most prosperous sector of the Moroccan economy. In Morocco, fruits and vegetables are grown for local markets, but primarily for export. Consequently, the number and volume of exports of Moroccan market gardening products have evolved rapidly over the past ten years, thanks to the expansion of cultivated areas under large tunnels and the use of cultures under shelter (mini-tunnel, mulch plastic and drip).

In 2018, Morocco is ranked 6th worldwide among the countries with the largest agricultural areas covered, against Spain and China which occupies the top ranks. Surfaces under large tunnels occupy more than 20 000 ha [246], most of which is located in the Souss Massa region in the south of the country on the outskirts of the coastal city of Agadir. Vegetable farms under large tunnels have an average area of 5 to 10 hectares [247]. In this regard, in order to optimize greenhouse production, some heating and cooling installations, ventilation and misting systems, various shading and lighting of CO2 enrichment mechanisms and systems are essential. These installations are massive consumers of energy. in some studies, the costs of energy consumption in greenhouses represent up to 50% of the energy bill [248] [249]. A greenhouse is an enclosed space protected with transparent or translucent materials such as glass, fiber-reinforced plastic (FRP), and polyethylene film, in which sunlight passes through the lid and hits the opaque surfaces inside (floor, walls, crops, etc.) where part of the light energy is converted into heat. The heat produced is trapped inside the greenhouse resulting in an increase in the air temperature, offering favorable growth conditions inside [250]. Protecting plants against climatic hazards and diseases. Greenhouse cultivation brings together different types of greenhouse production or cultivation, including the production of horticultural plants (vegetables and ornamental plants, fruit trees or ornaments) among others.

Depending on the type of crop considered, different types of greenhouse are used. A wide variety of greenhouse exists, but two main types can be distinguished: "heavy" greenhouses, often multi-chapel glass greenhouses and simple plastic shelters, often tunnel greenhouses. As shown (figure *IV.15*). In Morocco there are:

• The low tunnel: Nantes tunnel and flat tarpaulin; the plastic cover can be perforated, gradually perforating with the advancement of the culture cycle. It can be single sheet or double plastic sheet.

• The large tunnel: examples, Horticulture-greenhouse, Inter-greenhouse, etc.

• The Canary Island greenhouse: 3 to 4 m high (5-6 m for the Canary Islands) and of different dimensions to cover areas of about 1 ha and various types of land.

• The metallic multiplane greenhouse.

Figure IV. 15: Type of greenhouses in Morocco [251].

At the global level, we find these types of greenhouse shelters and other types of greenhouses, with glass roofs, with different chapels, symmetrical or asymmetrical, fixed or mobile. They can be semi-cylindrical bi-chapels, in the form of a building with different floors.

IV.6.1 Renewable energies for greenhouses

Renewable energies are used all over the world for the production of heat, electricity and the production of bio-fuels. They can cover all the energy needs of agricultural greenhouses in a sustainable and reliable way.

The popularization of these technologies in the northern regions could allow an increase in greenhouse production and particularly in the off-season and thus the northern regions could compete in terms of quantity with the southern regions (Morocco, Spain), large producers of tomato where the sun is much more important with the cost of labor is much lower [252].
The average energy consumption of a greenhouse is 297 kWh/m ^{2}/year, including many greenhouses heated with natural gas [253]. However, the development of energy efficiency measures and the integration of renewable energies into greenhouse production can improve agricultural durability in Morocco.

IV.6.1.1 Solar Energy

Solar energy can be used in greenhouses for heating and power generation. Both thermal and PV applications in agriculture aim to increase profitability in this sector by enhancing yields, reducing losses, and accelerating production, assisting in better management of natural resources [254]
The agricultural greenhouses which are solar-powered are primarily classified into passive and active solar greenhouses. Passive solar greenhouses are designed in a way to collect as much solar energy as possible, while active solar greenhouses are integrated with solar systems such as PV, PVT, or solar thermal collectors to intensify the capture of solar energy [255]. In both designs, employing thermal energy storage can increase the overall thermal performance of the greenhouse.

a. Solar-PV Electricity Generation in Greenhouses

The use of photovoltaic in greenhouses for power generation is an emerging technology to mitigate their dependency on fossil fuels. Solar PV modules can be integrated with greenhouses in the same way as buildings [256]. But they are depending on power needs and the size of the system. Rapid fall of PV cell prices and the gradual increase of grid electricity prices result in increasing the attractiveness of the installation of solar-PV systems in agricultural greenhouses for covering all the power needs of them. Due to economic concerns, the better use of PV systems connected to the grid. Solar PV systems integrated with agricultural greenhouses are categorized into two main configurations of on grid and off-grid systems [257].

In on-grid PV systems, the generated electricity by the PV modules is directly consumed by the greenhouse, while the excess amounts are injected into the power grid (figure *IV.16)*. Those systems are the most common types used in greenhouses [258]. Generally, On-grid PV systems are Suitable for use in greenhouses to produce electricity [259].

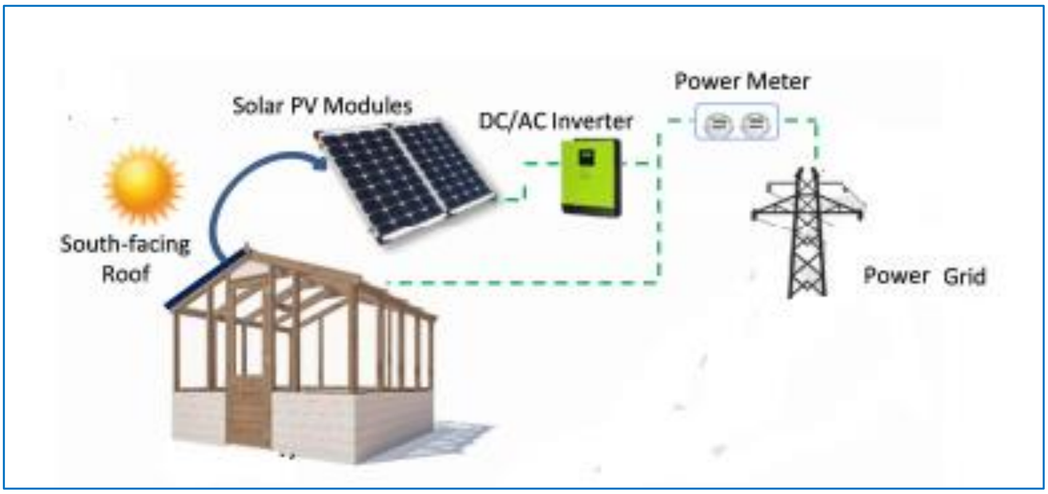

Figure IV. 16: On-grid PV systems for greenhouses.

b. Solar heating of greenhouses

Solar heating can be obtained with storage of thermal energy which is collected during day time and used later. Heat can be stored in water in various solutions with or without phase change [260], in the soil or in a wall constructed in the north side of the greenhouse [261]. Thus, it's possible increase few degrees (2.6-10 °C) in greenhouses [262], which is insufficient to cover all thermal needs. Nevertheless, it is recommended to combine with another heating production system.

c. Solar Cooling of Greenhouses

Solar cooling in greenhouses can be obtained with a system of empty plastic tubes buried in the ground beneath them [263]. The tubes are connected with a fan which circulates air from inside the greenhouse through the plastic tubes which is cooled as it passes through the tubes since the temperature of the ground is relatively constant and lower in the summer than the inside temperature of the greenhouse [261].

IV.6.1.2 Biomass

Several different types of biomass boilers can be supplied with agricultural residues; their sizes range from small (10÷20 kW), to medium (50 kW and above), and to power-station (100 MW and more) [264]. Combined heat and power (CHP) can be seen as an important technology to reduce carbon emissions resulting from energy production [265]. Power (CHP) systems, known for their excellent energy efficiency forModern greenhouses [266].

Considering the progress of cogeneration systems, combined cooling, heating and power (*CCHP*) system can be an effective and potential solution to compensate the different energy demands for agricultural greenhouses, but they are not economically viable, due to the lack of knowledge in developing countries.

However, these systems have shown their performance in hybridization with solar systems [267] (Figure *IV.17*). Generally, the potential benefit of these systems is to simultaneously supply electricity by the main turbine, heating and cooling by heat recovery and utilization systems [268].

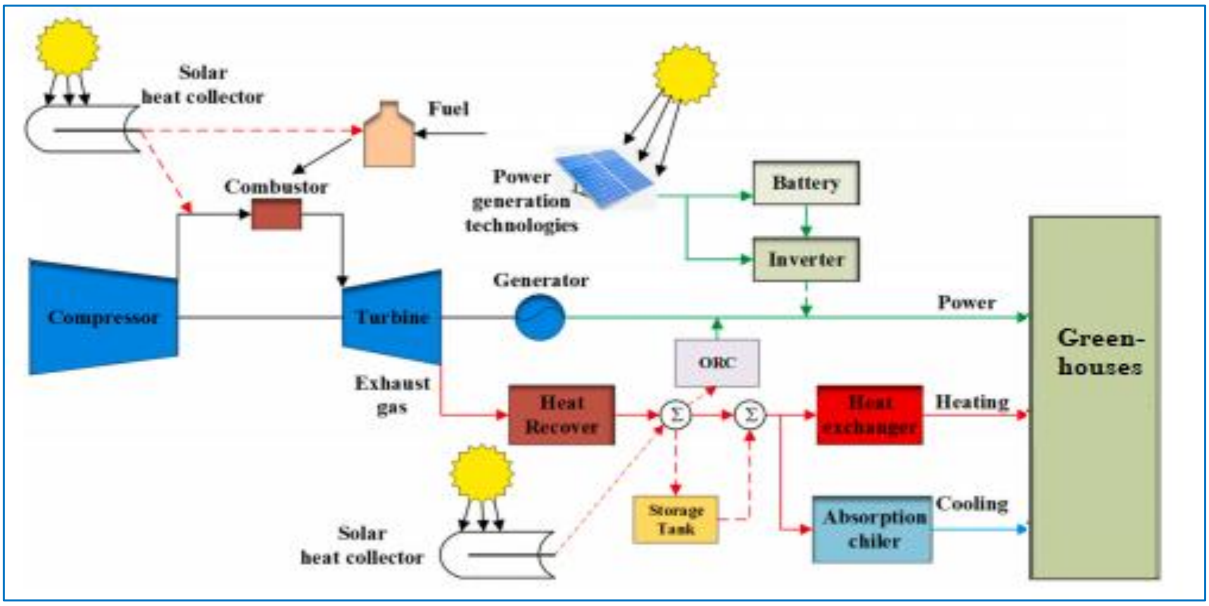

Figure IV. 17: Possible configuration using solar energy and combined cooling heat and power for greenhouses.

Otherwise, Biogas have been used for heating greenhouses. Biogas produced from landfills has been used in nearby greenhouses for covering their heating needs [269]. The flue gases after biogas burning contain CO2 and they can enrich the atmosphere inside the greenhouse improving crops growth and productivity. Since biogas is produced from wastes (either from landfills, or from cattle wastes or from sewage treatment plants) its cost is low.

Its heating value (5,000 Kcal/NM^3) is approximately the half of heating oil and it can cover all the heating needs of the greenhouse. Apart from biogas, solid biomass in the form of agricultural by products and residues has been used for covering all the heating needs of greenhouses [261].

Biogas from using agricultural and cow can be combined to various renewable energy sources like, solar energy and geothermal energy to ensure the effective heating of a greenhouse [270].

IV.6.1.3 Geothermal

Geothermal energy can be used either directly utilizing warm fluid at 50-80°C or with low enthalpy heat pumps. A greenhouse heated with geothermal fluid of 100°C in Northern Greece has been used for cultivation of roses and an inside temperature of 20°C was required. The used geothermal fluid with mass flow rate of 42 tons/h and temperature of 95°C was maintaining an inside temperature of 20°C when the outside temperature was 7°C. The installed geothermal space-heating system of 2.26 MWh was covering all the heating needs of the greenhouse of 10.000 m² [271].
A proposed hybrid using of solar–assisted vertical ground–source heat pump has been reported in turkey [272]. For ambient temperatures of 5.8-12.5 °C the inside temperatures were 15.8-22.5°C. The COP of the heat pump was varying between 2 and 3.13 and it was proved that the heating system was operating satisfactorily without serious defects. A greenhouse heated with low enthalpy geothermal water with temperature of 28oC which was circulated in plastic pipes placed on the ground was studied in Argentina [273]. Fortunately, geothermal energy can be exploited for agricultural greenhouses in Sais region.

To sum up, (table *IV.4*) compare various renewable energies to supply energy to greenhouses.

Table IV.4: Renewable energy sources for supplying energy to greenhouses.

Energy source	Initial investment	Fuel Cost	Outputs	Covering Greenhouses Needs
Biomass-CHP	Low-medium	Low-medium	Heating/cooling/power	all
Biomass-Biogas	Low-medium	low	Heating/cooling	Part of needs
geothermal	high	low	Heating/cooling	all
Solar-heat-storage	low	0	heating	Part of heating
Integrated PV systems	low	0	Heating/cooling/power	Part of needs

IV.6.2 AI for greenhouses

Regarding the idea that optimization algorithms and smart sensors in greenhouse production becomes so essential, especially in a country that is keen on R&D to diversify without an energy mixand enhance the agricultural economic sector. Artificial neural network (*ANN*) can beused to solve the greenhouse problem in optimizing heat and energy management. ANNs have been used successfully in similar and many other applications like building,such as equipment control[274][275], electricity consumption prediction[276], ventilation[277], and heat load estimation[278].

From the author's point of view, the table presents the points of optimization in the production of greenhouses.

Table IV.5: Aspects of optimization in the production of greenhouse.

Greenhouse	points of optimization	AI solutions	ref
Energy	▪ Optimization of energy production (heat) ▪ Equipement control ▪ Electricity consumption ▪ Modeling and control	ANNs	[279][280] [281][282]
Conditionning	▪ Temperature modeling ▪ ventilation	ANN-CNN	[280]
Processus	▪ Drip irrigation ▪ Fertilizers and pesticides ▪ Regulation of evapo-transpiration	IoT, ANNs, digital images fuzzy logics	[283][284] [285]

IV.6.3 Profits from the employment of Sustainable systems in Greenhouses

The outcomes of sustainable energies in agricultural greenhouses comprise various environmental, socio-economic values as well as:

a) Mitigation of CO2 emissions into the atmosphere through the adoption of sustainableenergy systems with low environmental impact.

b) Reduction of the use of fossil sources and the promotion of renewable energies.

c) Energy independence of farmers and reduction in production costs of agriculturalplots and greenhouses.

d) Possibility of creation of an added value to farmers when using solar-PV energy or C.H.P. systems in the greenhouse and injecting the electricity to the grid.

e) Increase the employability rate in rural areas and generate more local incomes.

IV.7. Questions and challenges raised by the use of AI

AI has completely revolutionized the agriculture in the last years. However, the questions and challenges rising by of using and exploiting of AI in agriculture at the present and future time are not clear. The most relevant questions are cited in the following.

IV.7.1 The question of trust

Trusting AI in the decision-making process for our food production has its advantages and drawbacks. The advantages are clearly visible on the wide embracing of this technology for automation processes and taking decisions based on data. The limitations of trusting these algorithms in agriculture can be seen as the emerging self-driving cars technology. It will be difficult to define ethics for insurance to cover liability in case of fatal decisions and accidents. The need of normative rules for these innovations is the next step in the near future.

IV.7.2 The question of applying AI stochastic algorithms

Data used by AI/ML to model complex living ecosystems as environment, soils and crops, lose all the physics behind. Integrating these stochastic algorithms in deterministic approaches such as biophysical models is a hot topic that researches are on it. Scientists are actively working on the integration of the physical aspect inside the ML algorithms for more targeting approaches. The other issue is in the misemployment of these AI/ML algorithms for different problems. Fixing rules and guidelines (statistical, computational, etc.) to supervise the use of these algorithms is also a primordial question.

IV.7.3. The question of data

The future of smart agriculture lies in the efficient collection and analysis of data. Data are not readily available, particularly at a local farm scale, and if available could contain high uncertainty. However, these data contain information and patterns about weather, soil, crops, water resources and more, that with AI and machine learning algorithms could be extracted and used as decision support for farmers, researchers, agricultural advisors, and market services, and input suppliers. Development of an open-source database, at a global and local scale, will serve as a baseline for scientists, economist and farmers. This database will contain satellite imagery, Internet of Things (IoT) sensors data, weather forecasting and other data concerning soil, crops, water, tillage and surface temperature, etc.

At the stage of data collection, IoT networks can help to collect data measured from sensors located at the field, in the soil, in a tower, or mobile on tractors, and make them available in real time. The next stage concerns the integration of collected information with other data from cloud-based systems such as databases on crop and soil types, present and future weather conditions, cost models to finally extract insights and patterns by machine learning models. These predictive models assist farmers and scientists to detect existing and future issues. The challenge now lies in promoting global efforts for availability, accessibility, and usability of data in agriculture [125].

IV.7.4. The question of interpretability

AI and ML models, howsoever powerful it may be, they stay considered mysterious and black boxes. At the present time it is difficult to measure and justify their results. Interpretability is the inherent issue with the use of AI. Two levels of interpretability can be distinguished in machine learning models:

1) high interpretability: this level includes basically classical regression algorithms such as linear, multiple linear, decision trees, Ridge and least absolute shrinkage and selection operator (LASSO) regressions.

2) Low interpretability: this includes ML models such as support vector machine (SVM), neural networks and deep learning. The lake of interpretability is justified by the use of multiple interconnected layers' structure containing different types of neurons; in the case of deep learning, or complex geometrical foundations; in the case of SVM.

I V. 8 Conclusion and perspectives

The evolution of agriculture towards that of precision and the new agrifood 4.0, will encourage farmers, young and old, to invest in automation and artificial intelligence. The integration of green energies slowly introduced in agriculture, will find technological support based on deep learning and others methods are used to improve production and agricultural security.

Nowadays, Artificial intelligence techniques are developing on a rapid scale and it can be used for detection, analysis, and estimation using CNN, RNN or any other computational network. Wireless technology and IOT come into play and use the latest communication protocols and sensors that can implement meteorological monitoring and control without human presence on the farm. This will allow us to manage water resources, avoid over-irrigation or lack of water.

Different integrated approaches can be used to create a viable environment and increased growth, and the uses are many such as in planting, fertilizing and irrigating, crop weeding and spraying, and harvesting.

In this context, this article proposes the use of computer vision technologies and artificial intelligence in agriculture. Importantly, this review provides an in-depth understanding of Promising Applications for Agriculture (SSSA).

For this scientific contribution to knowledge, towards one hundred articles support the analysis of scientific work on smart agricultural technology trends.

From these reviews and analyses it is evident that integration between new technologies allows smart, secured and sustainable agriculture. In fact, new technologies at the same time have new challenges in the management of different areas of human knowledge.

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CHAPTER 5

V

Conclusions and perspectives

Contents

V.1 General Conclusion

The new energy and climate challenges require the development of renewable facilities in rural and pre-urban areas. In fact, our rural world is facing an alarm situation. One question looms: how to give humans society new perspectives ?

Agriculture is the pillar of our health and our social model. It is one of the most important sectors of the Moroccan economy and the MENA countries. In the current scenario, there is a further problem with food security and water scarcity. One way to overcome this problem is to increase the use of renewable energies. Energy inputs are diverse and occur at every stage of the food supply: from egg laying and electricity harvesting to the animal housing to irrigation systems. While the efficient implementation of renewable energy can help agricultural producers to save energy without harming productivity and the environment. it is essential to adapt the modes of production and consumption in order to rebalance all the spheres that connect man to his nature. There is growing interest in photovoltaic water. The exploitation of these resources in Morocco presents a key step towards a sustainable agriculture and a durable development.

The nexus of man and nature in the world can be preserved only by the artifice of logical analysis and the strictly scientific approaches of the mind and the society of Men. Correlatively social development would not be what one wants if one does not reach a certain ecological understanding and the reasoned management of the resources. The analysis leads us to see that the relationship between science and the expansion of the circular economy passes particularly through the use of renewable technology. In this perspective, it is difficult to ignore strong connection that must be established between green -technology and rural society. This causality appears to us as a circuit whose starting point is the management of blue gold insofar as it is important to conceive, study, act and establish a relationship between science and action in the rural sphere. Water, the main resource consumed, is mainly the major stake for agriculture, energy and all forms of life. The positive impacts of use NRTs in agriculture include: additional income for farmers, reduced greenhouse gas emissions from their energy consumption, increased employment in the local community and decreased energy dependence in Morocco.

The approach included in this thesis highlights the use of innovative applications of renewable energies in Morocco, which can involve the promotion of energy sustainability in Moroccan agriculture. The main objectives of the thesis were achieved:

A) Development of new applications to enhance agricultural biomass and especially olive trees in Morocco.

B) Development and proposal of new applications for water management and the production of information in the agricultural sector of Morocco.

C) Proposition for more suitable solution for greenhouses, by using A.I to master the energy supply.

V.2 Reflexion on results

Morocco is a high energy importer country there about 98% of energy. Furthermore, electrification remains a real challenge for the wellness of the rural sphere, and its integration into the new national energy transition. Aware of this situation, this country is diversifying its renewable energy mix, and combining efforts to improve energy efficiency. Despite all this, biomass is still the real forgotten factor in this sustainable transition, and several municipalities are still without electricity or constantly paying the most expensive energy bills.
The analysis of the structure of energy consumption in Moroccan agricultural sector shows that the energy consumption of this sector in 2017 is in the order of 1,561.8 Ktep with an annual increase of 9.5%. These are concentrated on two uses: tractors and agricultural machinery (diesel) with 686.2 Ktep and pumping for irrigation (gas, oil and electricity) 398.6 Ktep, these two consumers account for 69.5% of the overall energy consumption of the sector.

In this respect, the present thesis focuses on the potential of agricultural biomass to produce electricity and the encouragement of photovoltaic irrigation.
First, concerning water management, PV water pumping systems are considered as one of the suitable solutions to replace classic pumps in rural society. Systematically, solar applications are provided as a key step towards sustainable agriculture and more reducing the consumption of conventional energies. Accordingly, to appropriate photovoltaic pumping, the design must consider the local climatic conditions, the crops water requirements and the configuration of the suitable coupling to the system.

Because of this understanding, this modest work aims at capturing, by involving a multi-level perspective, potential drivers and barriers of the solar water pumping in Moroccan agriculture. Systematically, solar applications are provided as a key step towards sustainability by reducing the consumption of conventional energy sources and related greenhouse emissions. The effective design of such systems should consider many variable parameters, including the local climatic conditions, crops water requirements and the configuration of the suitable coupling to the system. Orderly, to gain an in-depth understanding of the conditions influencing the sector's transition towards the best energy management, three investigations are carried out: (i) a case studies analysis, (ii) a comparative cost analysis, and (iii) a Strength-weakness-opportunities-treats analysis (SWOT).

This reflexion is applied for two scenarios using two possible configurations. In the gain to compare two configurations and underline the most performant as an appropriate technology for irrigation in Morocco and Mediterranean region. For this perspective, the first case corresponds to 1 ha of tomatoes adapted for small farmers. The field survey in the region shows that most farmers involved in market gardening have small plots. 70% have farms that do not exceed 6 ha. The second case concerns the irrigation of 6 ha of olive trees in Meknes-Fes, which is the emblematic region of olives in Morocco.

The results show that an increase of 30 % in annual performance and a decrease of 10% of system losses are observed when using MPPT DC converter for medium sized crops. In term of water use efficiency, the second scenario aims to use drip irrigation coupled with the direct coupling; the selected configuration is the best method to save energy and manage water, especially for small crops like tomatoes. In addition, cost comparative analysis revealed that Levelized cost of water (LCOW) of SPVWP is significant, approximately in the range of 0.08US/ m^3, which is very competitive comparing to other sources.

Considering long-term benefits and the high performance in the dry season, photovoltaic systems must be considered as the first choice for farmers in the Sais region to replace unsustainable pumps. According to the recommendations, the slope should be less than 2-5% for furrow irrigation and less than 5-9% for micro-spraying irrigation to avoid wasting water and energy. The correct annual precipitation for PVWP systems was between 300 and 600 mm based on grassland water demand. The annual temperature and sunshine hours should be below 20°C and above 1400 hours, respectively.

The annual ambient temperature stress was related to the effect of temperature on evapotranspiration and thus on grassland water demand. Or Implementation of this methodology in the Fez-Meknes region shows that there are currently more than17.000 solar pumps between 0.7 and 40 kW can be installed. In addition, convert more than 80% of existing butane-powered pumps to PVWP.

Generally, Renewable energies are the treasured key for the agricultural and sustainable development. They make it possible to decarbonize and reinforce the structuring of these sectors and play a positive performance in the rural development and limit energy consumption. Although, sustainability is the Key element to ensure the socio-cultural, ecological and economic utilities of agricultural production and rural world.

The second reflexion was adopted to enhance the use of agricultural. Biomass must be widely used to install sustainability, produce electricity and convert wastes to biofuels. Biomass is less adopted even if plays a major role in supporting renewable energies and their integration in the rural society and industrial processes.
Concerning the energy recovery from biomass in Morocco, very few studies have confronted this subject, and the present study was motivated by this lack of research in the literature and the nonattendance of biomass in the country's energy policy.
Despite the countless benefits and quantities of biomass, Morocco uses only 2% of these potentials. This inoperability of biomass is due to colossal investments and especially to the lack of technical knowledge, to see that there is no integration of biomass in the industrial sector, in particular the agricultural biomass is the key step to weave agro-industrial synergies to valorize the materials and to promote the energy biomass.
There is a significant amount of available biomass in rural areas of Morroco. It's concluded that The biomass can be used as a precious resource of renewable energy. In order to integrate this energy appropriately, it is necessary to estimate the amount of available organic material over the area. The main objective of this work is to valorise agricultural biomass with the integration of CHP technology as a suitable application in Morocco for more sustainability.

As a result of our findings: at the scale of the agricultural pole of Fes-Meknes, which has a particular agricultural potential, we have the possibility of recovering more than 4,22 million tons of waste and organic residues, which is equivalent to more than 0.5 MTep/ year.

Furthermore, the utilization of olive residues in the province of Fez-Meknes, has the highest annual energy production, about 2828.11 GWh / year with the annual capacity factor of 82.5%. Accordingly, the average real and nominal LCOE is estimated at 17.23 and 15.03 ¢/kWh respectively, which is very competitive. Over and above that, a sensitivity analysis is carried out to explore the sensitivity and parametric analysis of performance and LCOE of the CHP plant. Moreover, the results indicate that LCOE is strongly sensitive to feedstock price and financial rates.
Moreover, Morocco has a large capacity in olive growing, for example the city of Meknes, produces more than 4,000 tons of olives/day; it should be noted that 2 kg of olive stones represent the equivalent of one litter of gas oil, almost 10 kW, which is a very interesting figure to value this biomass

This biomass could in particular be of interest for energy production in rural areas where end-users are located near the farm producing biomass. It is an alternative solution to fill the national energy deficit and represent an undeniable environmental and economic benefits for this sector ".

For Morocco it's a real asset with huge benefits:

- Reduction of greenhouse gas emissions.
- Possibility of creating territorial dynamism through jobs and synergies.
- Access to energy independence for farmers and agricultural fellowship
- Integrate social population in the heart of the national energetic transition.
- Adopt new technologies and Artificial intelligence to promote sustainability in Moroccan agriculture.

V.3 Recommendations for strategy and synergistic development in remote societies.

The outcomes of this work can be concerned to boost sustainability of energy and water efficiency in remote communities. The highlighted recommendations are suggested to experts and policy makers in Morocco and comparable areas:

- Policies to promote renewable energy development should expand to include not only thermal and wind energy, but also for biomass and large scale integration of photovoltaics. By taking into account rural and agricultural constraints, a better understanding of the opportunities can be generated. This transition must also take into account the large increases in electricity demand, due to population growth and socio-economic progress.

- Energy transition in Morocco requires substantial levels of public and private investments to reduce high financing costs, and encourage rural as the urban population to adopt sustainable systems.

- Energy efficiency in remote communities and sustainable agriculture ought to be the main elements of the future energy transition. Efficiency and productivity must be aligned with the distribution and consumption of energy. Such considerations can protect the vulnerable population from the volatility of prices.

- Hybridization between systems can reduce production costs (LCOE), and consumption, thus mitigating environmental impacts. For example, in situations with diesel generators, it is better to consider hybridization with solar panels.

- Biomass can be a significant energy resort for rural communities given its local supply and carbon neutrality. It can be turned to electricity and stream through many conversion technologies. Air pollution from biomass exploitation must be neatly managed.

- Technological advancement can often overtake the development of the institutional framework, which can lead to slow integration or sub-optimal functioning of these renewable solutions. So it is necessary to update national policies institutional contexts and market protocols.

- Considering the development of electricity production and demand, the substantial extension of transmission lines and the use of VHDL connexions to recuperate cleaner energy is expected in all the 2030-2040 scenarios. In order to connect the remote villages and the southern region of the country.

V.4 Perspectives

The Laboratory of innovative technologies (LTI)-USMBA, aware of the vital importance of energy for our country, and a healthy management of the water resources, has for several years, made its modest contribution to the institutional operators. In this Optics, we have set ourselves the objective of a better understanding of the dynamics of our ecosystems and the evaluation of the impact of agricultural pollution, in order to propose a renovation of irrigation techniques and the rural use of abundant biomass. Many researches are currently carried out in parallel by our laboratory, in collaboration with administrations, national offices, regional communes of Fez, communities. Different efforts contribute to the realization of these axes of research which mainly address:

- Water climate interaction
- Renovation of agricultural habits
- Integration of R.E in rural practices
- Dimensioning rural metabolism.

To conclude on this thesis work, we will suggest ways of improving this development but also avenues for reflection for future research. Supply chain examination and optimization of agricultural biomass as an alternative energy resource.

- Adoption of A.I for optimization of hybrid systems and manage the predictivity of production.
- Feasibility and sustainability of On-grid connected greenhouses
- Pv/biogas systems for covering all greenhouses need and attain Zero CO^2 emissions.
- Biogas quantification and promotion for small and medium scale uses.
- Agro-industrial ecology approach and creation of flow and information synergies in agriculture.
- Inclusion of solar cooling, as an expansion in the energy-water-food nexus.

V.5 Concluding remarks

The research presented in this thesis aims to integrate renewable energies and sustainability in Moroccan agriculture through the integration of renewable energies, water supply, and the digitization of agricultural practices.

The results of this research may be useful to community developers, aid agencies, and policymakers as a model for thinking about new perspectives for the agricultural economic sector and above all for reducing the vulnerability of family farming. However, the results and concepts proposed are based on the Moroccan context but may be applicable in other regions and countries that rely on agriculture in their economies.

Finally, it is hoped that the general public can realize that technologies are available to guarantee sustainability and socio-economic progress, in order to create a new nexus between man and his mother nature, science and vulnerable, and above all integrate academic laboratories at the heart of the social mission.