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Irrigation Practices and Pumping Systems in Senegal's Niayes Region: Challenges and Prospects for Renewable Energy Adoption

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Abstract

Irrigated agriculture in Niayes region of Senegal is constrained by high energy costs and inefficient water resource management, compounded by climate-related vulnerabilities. This study explores the potential for transitioning from fossil fuel dependence to renewable energy as a pathway to sustainable agricultural systems and improved food security. A comprehensive evaluation of irrigation and water-pumping practices was conducted, focusing on energy sources and the feasibility of renewable energy integration. Data were collected through surveys of 300 market gardeners across the northern, central, and southern zones of the region, with statistical analyses (Chi^2 tests at 5% significance and Cramer's V index) used to identify key drivers of producer choices. Results reveal significant spatial variability in practices: in the northern zone, 61% of farmers employ drip irrigation and 44% utilize solar pumps, while in the southern zone, 38% rely on hose irrigation and 48% on fuel pumps. Energy costs remain a major constraint across all zones, cited by 61% of producers. The findings highlight the critical role of renewable energy, particularly solar, in building climate-resilient production systems and promoting sustainable resource management within the water-energy-food nexus. This study provides actionable insights for policymakers and stakeholders aiming to improve agricultural productivity and sustainability in similar agroclimatic contexts.

Keywords

Niayes Region, Irrigation Practices, Water Pumping, Renewable Energies, Sustainable Management

1. Introduction

Agriculture remains a cornerstone of economic development and sustainability in Africa, employing approximately 55% of the workforce and contributing 23% to GDP [1]. However, the sector's heavy reliance on increasingly scarce water and energy resources, coupled with rising climate-related challenges, threatens its long-term viability. In Senegal, agriculture contributes 9.4% of the national GDP and 62.8% of the added value in the primary sector [2]. Yet, it faces growing vulnerability to climatic variability, marked by rising temperatures, declining and erratic rainfall, and reduced aquifer recharge, all of which exacerbate water scarcity and reduce agricultural productivity [3] [4].

The Niayes region, a key agricultural zone, exemplifies these challenges. In fact, it's a vital agricultural hub in Senegal, and is renowned for its specialization in market gardening, boasting the highest agricultural exploitation rate in the country at 65% [5]. The region's unique geographic and climatic conditions make it an essential area for agricultural productivity and resilience studies, particularly in the context of climate variability and resource management. However, declining rainfall and aquifer overexploitation have severely impacted water availability, threatening vegetable production, which constitutes 60% of Senegal's national output [6]. In addition, agricultural productivity is challenged by the region's low soil fertility, poor water retention, and issues of localized salinity and acidity. These factors not only reduce yields but also lead to the abandonment of cultivation by some producers [7]-[9].

Irrigation has been widely recognized as a solution to bolster agricultural productivity and resilience, with irrigated farming covering over 10,000 hectares [10] [11]. However, irrigation in this region remains predominantly dependent on fossil fuel-powered pumping systems, introduced during agricultural intensification in the 1960s [12]. These systems contribute to environmental degradation and pose significant economic challenges due to high energy costs and saline intrusion in shallow aquifers [13] [14].

Technological advancements, such as the adoption of drip irrigation, offer promising pathways toward sustainable agricultural practices, yet the intensifying impacts of climate change and population growth continue to increase demand for food, water, and energy [15] [16]. In this context, transitioning to renewable energy sources, particularly solar power, presents a viable and scalable solution. Solar-powered irrigation systems can reduce reliance on fossil fuels, enhance water resource management, and strengthen the resilience of agricultural systems to climate shocks. This approach aligns with the principles of integrated resource management and the water-energy-food nexus, addressing critical interdependencies while mitigating environmental impacts [17].

This study aims to analyze irrigation practices and pumping systems in the Niayes region, with a focus on evaluating the effectiveness of current irrigation techniques, assessing the energy sources used for pumping, and identifying key constraints faced by farmers. The findings will provide actionable insights for promoting sustainable agricultural practices, optimizing water and energy use, and informing policy interventions to enhance the resilience and sustainability of farming systems in Senegal and beyond.

2. Materials and Methods

2.1. Site Description

Figure 1 shows the geographic location of the Niayes region, which is located along the northwestern coast of Senegal, between latitudes 14˚55' and 15˚27' N and longitudes 16˚50' and 17˚07' W. The region is bordered by the Saint-Louis region to the north, Dakar to the south, the N2 highway linking Dakar and Saint-Louis to the east, and the Atlantic Ocean to the west.

This narrow coastal band stretches approximately 180 km in length and spans 20 to 30 km in width, covering a total area of 2759 km² [18] [19]. It spans parts of the Saint-Louis, Louga, Thiès, and Dakar regions, playing a critical role in Senegal's agricultural landscape.

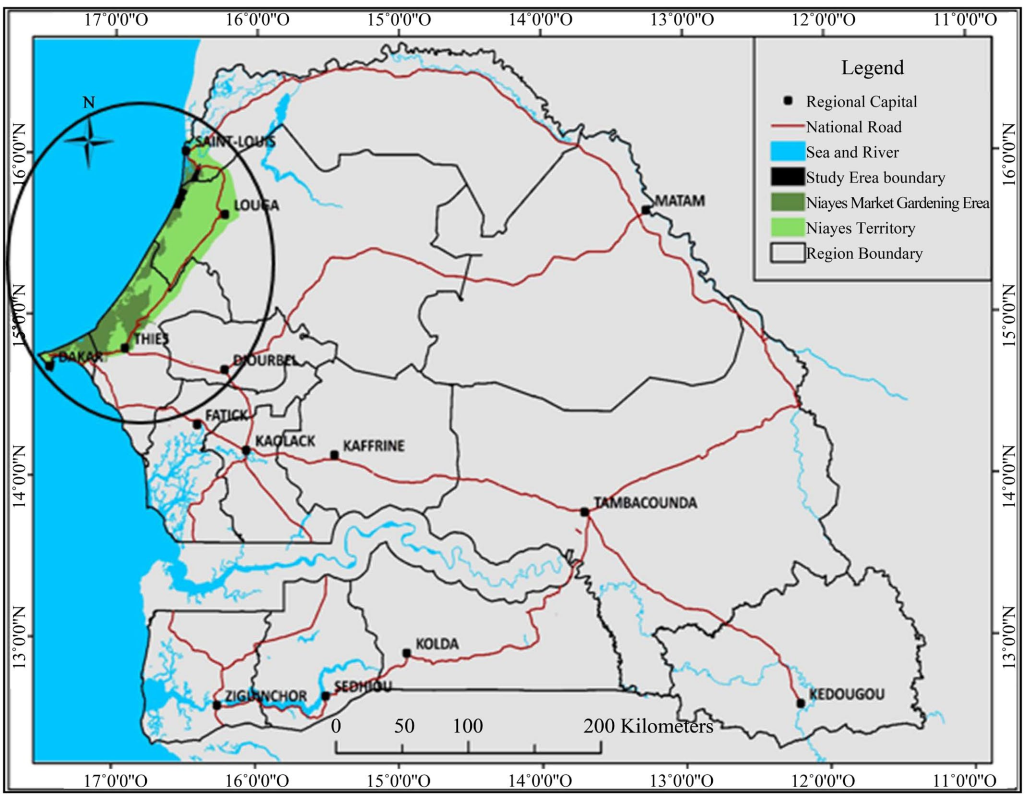

Figure 1. Location of the Niayes region [20].

The Niayes region of Senegal is characterized by a hot and dry Sahelian climate, shaped by the interplay of trade winds, harmattan, and monsoon winds. These winds, with speeds ranging from 2 to 5 m/s, play a pivotal role in the formation and mobility of coastal dune systems [21]. Despite this harsh climate, the region benefits from a unique microclimate induced by maritime trade winds [22], creating conditions particularly conducive to market gardening, especially for onions.

The region experiences a short rainy season with annual precipitation typically below 450 mm [23] and a pronounced dry season. Distinctively, "off-season" rains from December to February are caused by polar air intrusions from temperate regions [24]. During this period, coastal temperatures remain mild, ranging from 20˚C to 27˚C, with minimal diurnal variation [25]. In contrast, the hot and humid rainy season brings temperatures between 30˚C and 35˚C, with relative humidity frequently exceeding 80% [25].

Water resources in the Niayes are predominantly sourced from groundwater, sustained by a complex hydrographic network comprising three primary aquifers recharged by seasonal rainfall and subsurface flows from dune sands [26]. The Quaternary Sand Aquifer (QSA) along the northern coast serves as the principal water reserve, capable of yielding up to 100 m^3/h with less than 10 meters of drawdown [27]. Shallow aquifers are accessed via wells or boreholes, using manual or mechanical methods [28], or through floodwater harvesting during the rainy season [29].

2.2. Target Population and Sampling Framework

This study encompasses the entire Niayes region, with a specific focus on market gardeners and individuals involved in market gardening among other agricultural activities. The delineation of the study area was informed by the August 2014 provisional report from the Directorate of Water Resource Management and Planning (DGPRE), complemented by data from the Association of Niayes Market Gardeners Unions (AUMN). Accordingly, the Niayes region was divided into three distinct sub-regions: Northern, Central, and Southern Niayes, to facilitate targeted analysis and insights.

2.3. Sample Size

Table 1 shows the sampling frame used in this study. In order to ensure statistically robust results while maintaining feasibility in terms of resources (time, personnel, budget), a sample size of 300 producers was selected. This sample size provides adequate representation of the three sub-regions of Niayes and ensures that the diversity of farming practices is taken into account.

To ensure comparability and limit bias due to differences in population size between zones, 100 producers were selected in each zone. Sampling followed a two-stage random approach (village and producer). For village selection (first stage), a sampling rate of 10% was applied to determine the number of villages to be included in each rural commune, resulting in the selection of 80 villages in 13 rural communes. Villages were selected based on two criteria: 1) the presence of horticultural activities, to ensure the relevance of the sample for the study of agricultural practices, and 2) geographical accessibility, to facilitate data collection and reduce logistical constraints. For the selection of producers (second stage), producers were randomly selected within each selected village. The number of producers interviewed in each village was proportional to the total number of villages in each rural commune in order to maintain representativeness within sub-regions.

However, this sampling method may introduce certain biases, such as selection bias, which results in the non-inclusion of certain producers with atypical or marginal farming practices, especially those located in more isolated areas. The inclusion of the geographical accessibility criterion reduced this bias, although it remains a limiting factor.

Table 1. Sample distribution by sub-region.

Sub-Region	Rural Communes	Number of Villages	Number of Producers
North	Léona	13	36
	Ndiébène Gandiol	7	30
	Thieppe	8	34
Central	Darou Khoudouss	8	28
	Diokoul Ndiawrigne	5	20
	Kab Gueye	7	28
	Méouane	5	24
South	Diender	6	18
	Kayar	3	13
	Keur Moussa	6	18
	Taiba Ndiaye	3	12
	Notto Gouye Diama	6	24
	Mont-Rolland	3	15
Total	**13**	**80**	**300**

2.4. Field Data Collection

Semi-structured interviews were conducted using questionnaires designed to gather information exclusively on market gardening activities. The questionnaire was divided into three sections: irrigation techniques, water pumping systems, and the different energy sources used and their constraints. Data collection was conducted in the selected villages in February 2023, with three survey teams assigned to each zone to ensure efficient coverage.

2.5. Data Analysis

The collected data were initially recorded in the Sphinx Plus2 (V5) software, which streamlined database processing. The data were then imported into Excel 2019 for preprocessing. All analyses and graphical representations were performed using R Studio version 4.4.1. Descriptive statistics were generated using frequencies and relative frequencies, while a Chi-squared test at a 5% significance level was applied to assess potential dependencies between variables (irrigation techniques, water capture methods, energy sources, and geographical zones). The aim of this test was to identify correlations between variables and to determine whether the choice of irrigation and pumping practices was influenced by the producers' geographical location. The strength of the association between significant variables ($p < 0.05$) was quantified using Cramér's V index.

3. Results

3.1. Irrigation Techniques

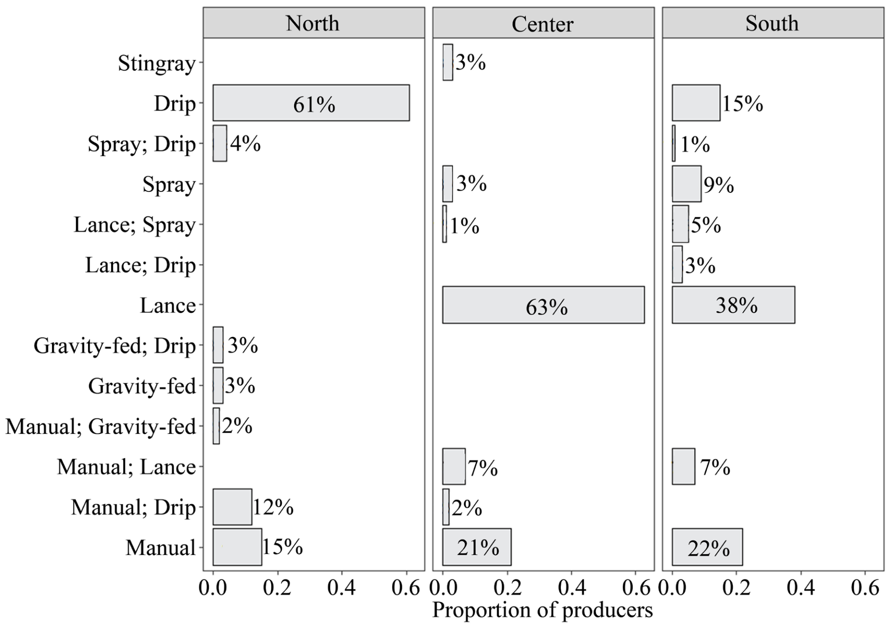

Figure 2. Distribution of irrigation techniques in the Niayes region.

Figure 2 illustrates the distribution of irrigation techniques employed by producers across the Niayes region. Its case be seen that many producers use a combination of techniques to irrigate their crops. The most common combination is manual irrigation with drip irrigation, used by 12% of producers in the northern zone. In the central and southern zones, manual irrigation combined with lance irrigation is employed by 7% of producers. Drip irrigation alone is the most prevalent method, used by 61% of producers in the north, compared to only 15% in the south and 2% in the center, where it is typically used in conjunction with manual irrigation. Conversely, the lance irrigation technique, when used individually, is more widespread in the center and north, with 63% and 38% of producers, respectively, while it is almost unused in the south. Manual irrigation, however, remains the sole technique used across all three zones, with 15%, 21%, and 22% of producers in the north, center, and south, respectively, relying solely on this method or using it in combination with other techniques. The results also show a significant geographic influence on the choice of irrigation techniques, with a p-value < 2.2e-16 and a Cramér's V of 0.6, indicating a strong association between irrigation methods and the producer's location.

3.2. Water Pumping Systems for Irrigation

3.2.1. Water Capture Methods

Figure 3 shows that, as with irrigation techniques, some producers in the Niayes region combine different water collection methods, although only 5% use this practice. Across the region, the majority of producers rely on mini-wells (44%) and boreholes (27%) for their water supply. Wells represent 16% of water collection methods, while Sen'Eau services, which manage the distribution of drinking water in urban and peri-urban areas of Senegal, are used by 5% of producers, mainly in the central and southern zones.

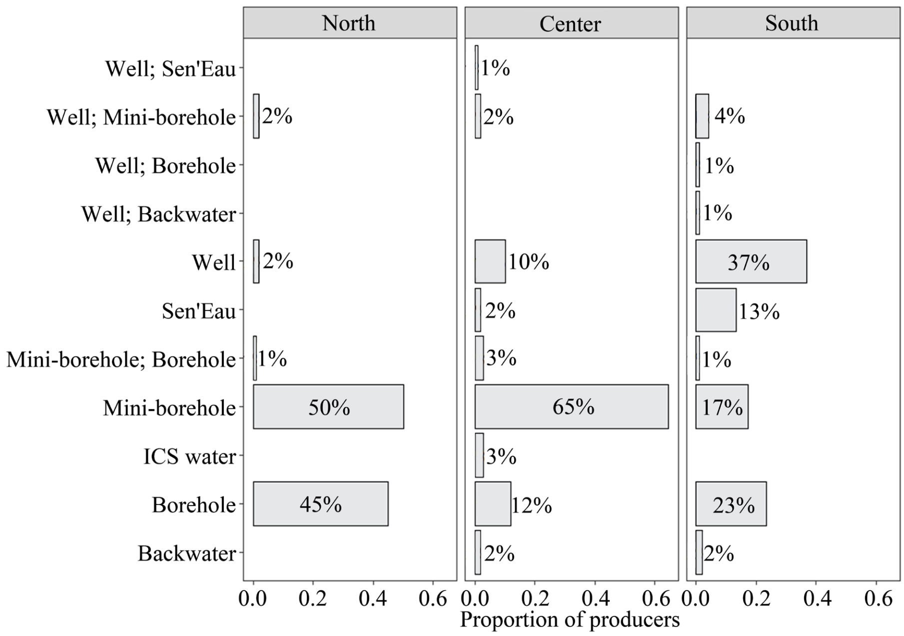

Figure 3. Distribution of water capture methods in the Niayes region.

A unique finding is that only producers in the central and southern zones (2.3%) use surface water for irrigation, specifically from ponds and water sourced from the Senegalese Chemical Industries (ICS), for irrigation. This highlights a clear difference in water capture practices between the different regions within the Niayes.

This distribution highlights the dependence on groundwater sources, especially mini-wells and boreholes, which provide a stable water supply for irrigation throughout the year. The use of surface water and services like Sen'Eau reflects localized solutions for water access, influenced by the proximity to urban infrastructure and available natural resources.

The distribution of water capture methods in the Niayes region shows notable variation across the different zones. Producers in the northern zone primarily rely on mini-wells (50%) and boreholes (45%), with very few using wells. In contrast, producers in the central and southern zones exhibit a greater diversity in their water capture methods. In the central zone, mini-wells are the most common (65%), followed by wells (10%) and boreholes (12%). The southern zone shows a more balanced mix of techniques, with a significant proportion of producers using wells (37%), mini-wells (17%), and boreholes (23%). Additionally, water from the Sen'Eau network is predominantly used by producers in the south, where 13% of producers depend on it.

The statistical analysis confirms a strong dependence between the choice of water capture method and the geographical location of the producers. The Chi-squared test (p-value = 2.2e-16) and Cramér's V (0.46) both indicate a statistically significant relationship. This relationship is particularly evident in the positive gradient of well usage as one moves from north to south, where the use of wells becomes more prominent. Interestingly, the pattern for mini-well usage shows a positive gradient from the north to the center, but a negative gradient from the center to the south, highlighting regional shifts in water capture preferences.

This variation between zones reflects the geographical and infrastructurale differences within the Niayes, with the southern zone having access to urban water distribution networks like Sen'Eau, while the northern zone relies more heavily on groundwater sources.

3.2.2. Water Lifting Techniques

In the Niayes region, groundwater extraction is predominantly motorized, with 94% of producers using pumps for this purpose. This trend is consistent across all three zones, though there are notable differences in the proportion of motorized vs. manual extraction. In the northern and central zones, the use of motorized extraction is nearly universal, with 99% and 98% of producers, respectively, relying on pumps. However, in the southern zone, there is a slightly lower rate of motorized extraction (82%), with 15% of producers still relying on manual extraction methods.

Additionally, while the majority of producers in the center and south use motorized extraction, a small but significant proportion (1.1%) in these zones also make use of the Sen'Eau potable water distribution network. These producers use taps to ensure water availability on their plots, highlighting a shift towards urban water infrastructure in some areas, albeit on a limited scale. This suggests that while groundwater remains the primary source of irrigation water, the presence of modern water distribution systems is beginning to have an influence in some parts of the Niayes region.

3.3. Energy Sources Used

Figure 4(a), **Figure 5(a)** and **Figure 6(a)** present the analysis of energy sources for irrigation and pumping, which involved 262 producers—99 from the north, 94 from the center and 69 from the south—focusing only on those who use energy sources for these activities. Fuel and solar energy sources together account for 83% of the energy used by producers, with a slight preference for fuel.

Fuel pumps are more commonly used in the center and south, with 43% and 48% of producers, respectively, relying on them. In comparison, solar energy is used by 32% of producers in the center and 13% in the south. In the northern Niayes, solar pumping is more common, with 44% of producers using solar energy compared to only 18% using fuel.

Electric pumping, which includes prepaid and postpaid systems, is used by around 17% of producers. Prepaid electricity (woyofal) is more commonly used by producers in the north (17%), while postpaid electricity (paid monthly) is more popular in the south (14%).

The statistical analysis revealed a significant dependence between the energy source used and the producer's geographic zone (p-value = 1.57e-06), with a moderate association (Cramér's V = 0.33). This suggests that the choice of energy source for irrigation is strongly influenced by the zone in which the producer is located.

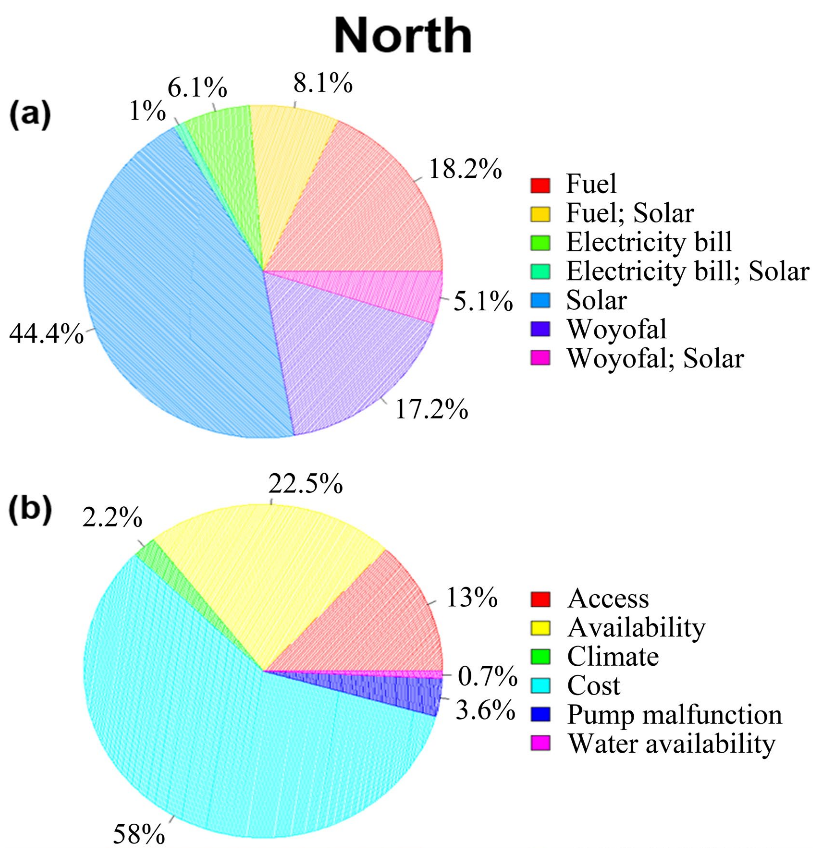

Figure 4. (a) Energy sources and (b) the constraints associated in north zone.

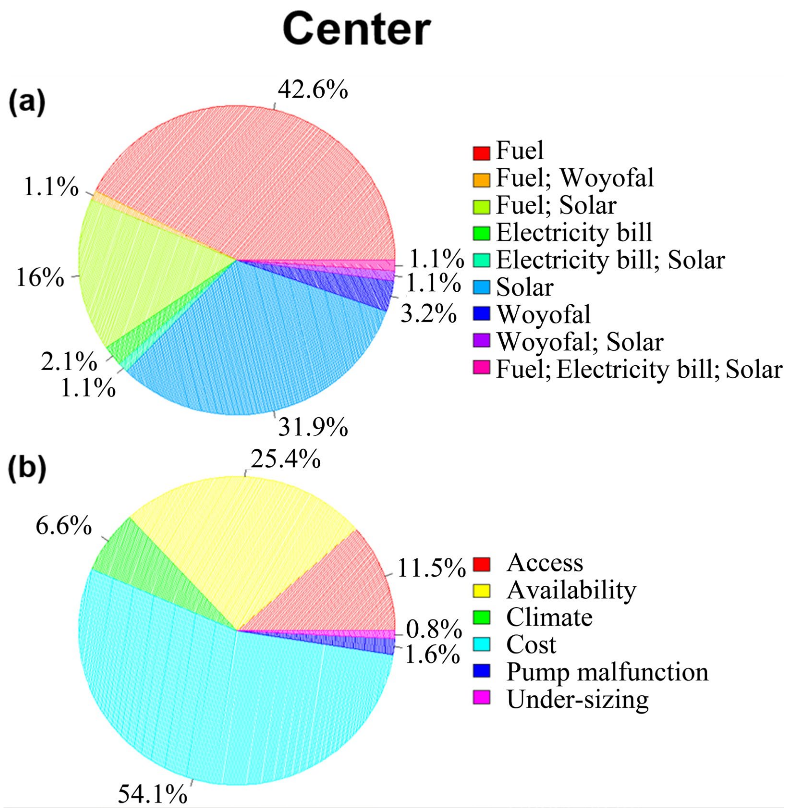

Figure 5. (a) Energy sources and (b) the constraints associated in central zone.

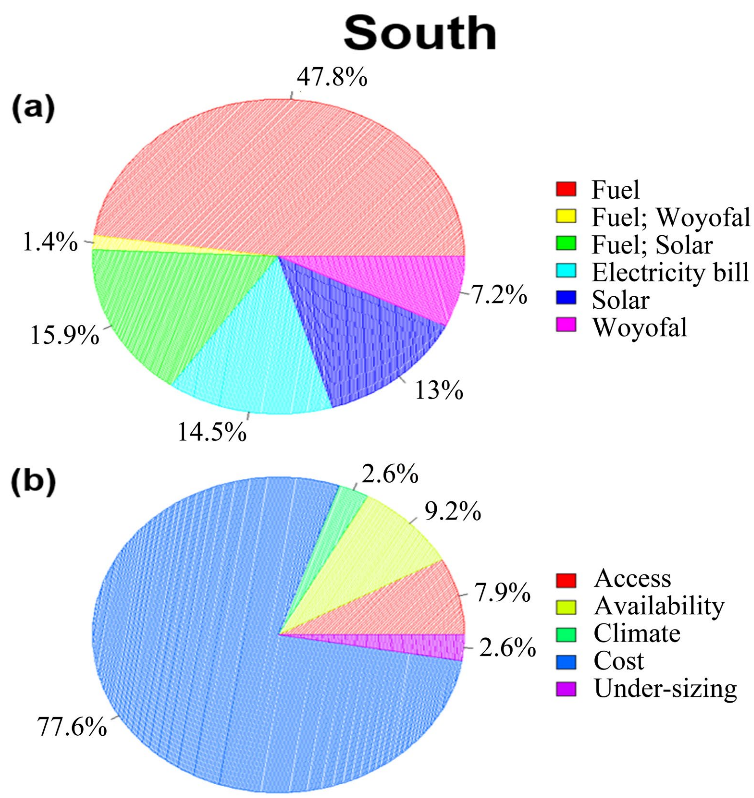

Figure 6. (a) Energy sources and (b) the constraints associated in south zone.

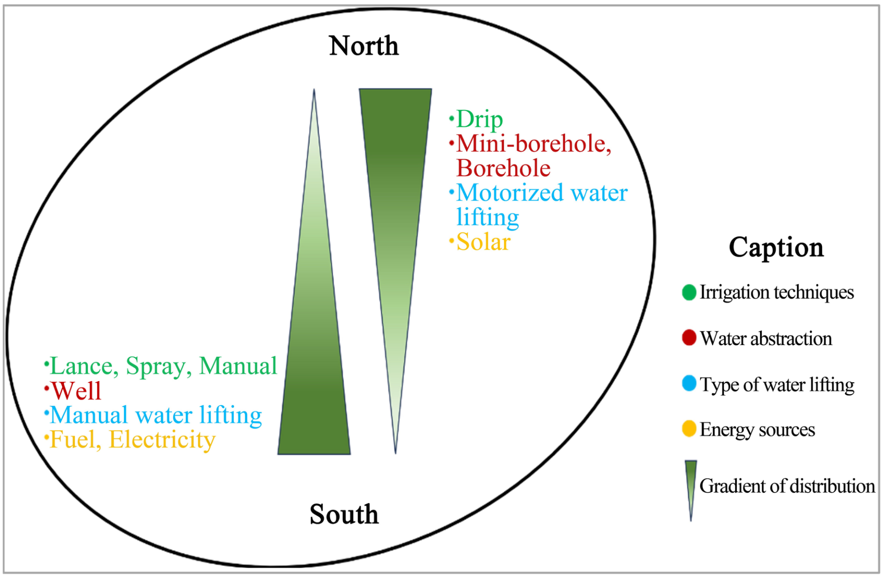

Figure 7. Gradient of distribution of irrigation techniques, water catchment methods, and energy sources in the Niayes region.

Figure 7 illustrates the impact of the variability in water table levels between zones in the Niayes region, which is closely linked to rainfall patterns and has significantly influenced farmers' choice of irrigation and pumping practices. The figure shows that farmers in the northern zone have a clear preference for adopting innovative technologies, such as drip irrigation and solar pumping systems. This shift toward innovation reflects a broader movement toward sustainable agricultural practices that better manage water and energy resources.

In contrast, the central zone serves as a transition zone, where producers adopt a mixture of practices from both the northern and southern zones. This results in a more diversified approach to irrigation and water management, driven by the zone's geographic and climatic characteristics, which share similarities with both the north and the south.

As one moves from the south to the north of the Niayes, there is a noticeable trend of transitioning from traditional irrigation practices towards more modern and efficient systems, reflecting a growing emphasis on sustainability and resource conservation.

3.4. Constraints Related to Energy Sources

Figure 4(b), Figure 5(b) and Figure 6(b) highlight the main constraints faced by producers in the Niayes regarding energy sources, which are primarily related to access, availability, and cost. For the region as a whole, 61% of producers report high costs associated with energy use, and this percentage exceeds 50% in all three zones. Specifically, 58% of producers in the north, 54% in the center, and 78% in the south report high energy costs.

In addition to the high costs, producers also face challenges with the availability and access to energy sources. Specifically, 22% of producers in the north, 25% in the center, and 9% in the south face issues with availability. Similarly, access to energy sources is reported as a constraint by 13% of producers in the north, 11% in the center, and 8% in the south. These constraints collectively hinder the adoption of more sustainable and efficient irrigation and water pumping practices, particularly in the southern zone where the impact is most pronounced.

Table 2. Expenditures related to the use of different energy sources.

	Energy cost				
	Under 500,000 F CFA	500,000 - 1,000,000 F CFA	1,000,000 - 1,500,000 F CFA	Over 1,500,000 F CFA	Don't know
Electricity bill	**50%**	5%	10%	35%	0%
Fuel	**47%**	23%	11%	17%	1.9%
Solar	16%	22%	21%	**40%**	0.9%
Woyofal	**43%**	23%	20%	10%	3.3%

Table 2 shows that of the four energy sources, solar energy users are the only group whose expenditure exceeds 1,500,000 CFA, with 40% of them reporting such high costs. In contrast, users of other energy sources, such as fuel and electricity, generally spend less than 500,000 CFA. This cost discrepancy is primarily attributed to the elevated initial investment necessitated for solar energy installation, as opposed to the recurrent operational expenses that predominate the costs of alternative energy sources throughout production campaigns. Some producers, particularly those in the southern zone, conduct up to two irrigation campaigns per year, which leads to ongoing energy costs for pumping water. Despite the higher initial cost of solar energy, its long-term sustainability and reduced operating costs may offer an advantage for producers who can afford the initial investment.

Figure 8(a) and Figure 8(b) highlight the various constraints faced by producers using different energy sources in the Niayes region. While cost, availability, and access remain the primary challenges for all energy sources, solar pump users face additional specific issues.

A major problem reported by solar pump users in all three zones is related to malfunctions such as clogging and overheating of the motor, due to inadequate maintenance. These technical issues can significantly impact the efficiency of solar pumps. Additionally, users in all zones highlight problems with the selection and number of solar panels, suggesting that incorrect installations or insufficient panels may lead to suboptimal performance.

These challenges underscore the importance of proper maintenance and optimal installation practices for solar energy systems to ensure their long-term effectiveness. Addressing these issues could help producers maximize the potential benefits of solar pumping systems, especially in areas where solar energy is a preferred alternative to more expensive or less sustainable sources.

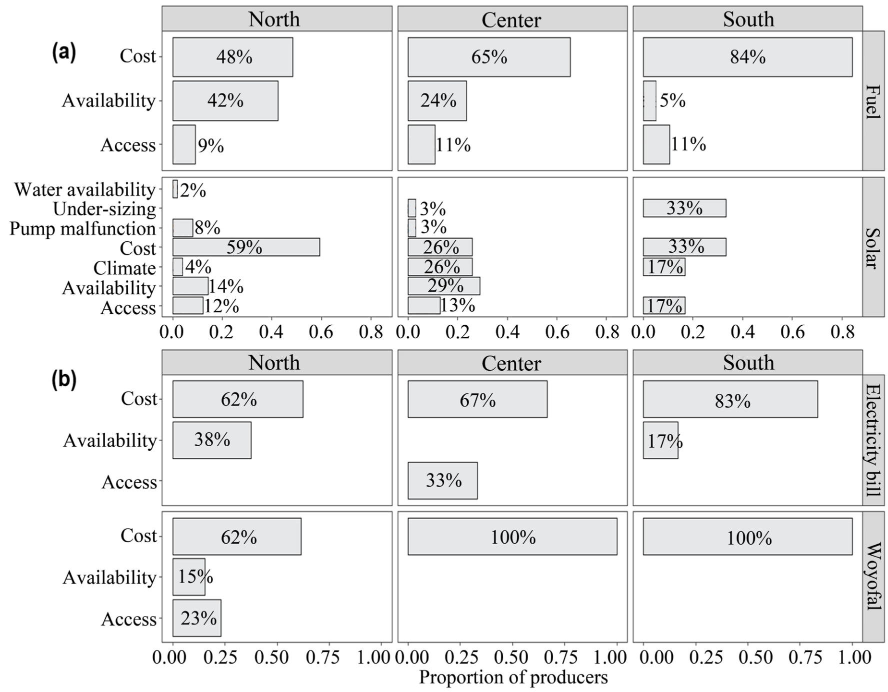

Figure 8. Constraints related to the use of (a) fuel and solar energy and (b) electricity in Niayes region.

4. Discussion

The results from this study provide valuable insights into the irrigation practices and energy usage among producers in the Niayes region, highlighting the geographical variability and the shift toward more sustainable practices. However, the findings also illustrate that fossil fuel-based energy sources and labor-intensive irrigation methods still dominate, particularly in the central and southern zones.

The significant geographical variability in practices is closely tied to the adaptability of farmers to the specific challenges they face in each zone, such as water availability, soil conditions, and economic constraints. In the northern Niayes, farmers have largely embraced more sustainable practices, including solar energy and drip irrigation systems, particularly among wealthier vegetable producers. These producers are better positioned to invest in such technologies, facilitated by their proximity to large capital-intensive farms that provide technical support and equipment. Interestingly, local farmers in these areas have also developed their own solutions using locally available materials, minimizing reliance on expensive imported equipment.

In contrast, in the central and southern zones, challenges such as high iron concentrations in groundwater have limited the adoption of drip irrigation systems. These areas have faced frequent clogging of drip emitters, a problem exacerbated by high ferric oxide deposits, which have led many producers to favor sprinkler irrigation systems instead. While sprinkler irrigation allows for faster water distribution across large areas, it is less efficient due to water wastage, which further underscores the importance of addressing water management issues.

The study also highlights the historical context of irrigation development in Senegal, with motorized pumping systems becoming more widespread following droughts in the 1970s and 1980s. These climatic events reduced rainfall, leading to lower groundwater levels and making water management practices even more crucial. Despite the increasing use of modern irrigation systems, the financial barriers faced by smallholders continue to limit the widespread adoption of more efficient and sustainable practices, particularly in regions with less access to resources.

Overall, while there has been progress towards more sustainable agricultural practices in the Niayes, significant challenges remain, particularly in terms of cost, access to technology, and local environmental conditions. Addressing these barriers could help enhance the sustainability of agricultural production in the region, improve water management practices, and reduce dependency on fossil fuels.

The study provides a comprehensive overview of the water extraction and irrigation practices across different zones in the Niayes region, illustrating the significant role of aquifer recharge, energy sources, and technology adoption in shaping farming practices.

The findings emphasize that aquifer recharge is heavily influenced by rainfall and hypodermic runoff from the sandy dunes, with a significant gradient in recharge between the northern and southern zones. The southern zones benefit from higher recharge rates, with 70 mm of annual recharge compared to just 13 mm in the northern Niayes, as reported by [30]. This variation in groundwater availability has prompted farmers in different zones to adopt various irrigation and water extraction methods. In response to declining water levels, some farmers have invested in motor pumps and cement wells with water retention basins, facilitating large-scale irrigation and multiple cropping cycles [12]. However, this over-exploitation of the water resource has led to the need for more innovative solutions, such as mini-well installations, particularly in the northern and central zones.

In terms of energy source usage, solar energy is more commonly adopted in the northern Niayes due to the inefficiency of motor pumps in handling declining water table levels. These technologies are increasingly being promoted as they have the potential to transform agricultural systems and increase household resilience and well-being while reducing greenhouse gas emissions [31]. Despite the higher installation costs associated with solar pumping, farmers have increasingly turned to solar technology because it enables them to pump water from greater depths and automate irrigation, thus reducing labor and fuel costs. In fact, the operational costs of a solar-powered pump can be lower than those of a fuel-powered pump over time [32]. In fact, their results show that the cost of running a fuel-powered motor pump for 2.5 irrigation seasons would be enough to finance the purchase of a solar generator with a lifespan of up to 20 years. What's more, the depreciation cost of solar pumps can be up to 91% of the total cost of water production, making this technology a more economical option than electric or fuel-powered pumps.

On the other hand, in the southern Niayes, the adoption of solar pumps faces several obstacles. The high upfront costs of solar systems and the financial barriers associated with loan repayments are significant challenges. Farmers often rely on bank loans, but repayment terms are challenging, and delays can lead to the repossession of equipment, causing losses in production. These findings are in accordance with those of [33], who reported that difficult access to agricultural technologies, limited information on their use and low financial resources limit their adoption by small-scale producers. Additionally, the lower power of solar panels used in these systems, compounded by lower sunlight levels during cooler months, further limits the effectiveness of solar pumping in this region. As a result, fuel-powered pumps remain the preferred choice, with some farmers adopting a hybrid approach by using solar pumps for water extraction and fuel pumps for irrigation.

This hybrid approach, where farmers use a combination of techniques, reflects their adaptability in managing water resources and addressing the economic constraints they face. Solar pumps are used to fill retention basins, and when needed, fuel-powered pumps are employed for irrigation. This strategy mitigates the risks associated with relying solely on a new technology and allows farmers to ensure water availability for their crops while managing costs effectively.

In summary, the study underscores the variability in irrigation practices across the Niayes region, driven by geographic, climatic, and economic factors. While solar energy and drip irrigation are becoming more prevalent in the northern Niayes, the southern and central zones continue to rely on motor pumps due to technical limitations and financial constraints. The adoption of hybrid systems and the careful management of energy sources demonstrate the resilience of farmers in the face of environmental and economic challenges.

5. Conclusions

This study provides a detailed analysis of irrigation practices and water pumping systems in the Niayes region, emphasizing the challenges and opportunities of adopting renewable energy, particularly solar power, in the context of climate change and agricultural modernization.

Key findings indicate that declining water table levels, exacerbated by climatic events and agricultural intensification, have significantly impacted the Niayes region. As a result, vegetable farming in the region has seen the introduction of various innovations, with adoption rates differing across zones. In the northern zone, farmers have increasingly embraced modern innovations like drip irrigation and solar-powered pumping systems, which are beneficial due to their ability to reduce operational costs, provide access to deeper water sources, and increase agricultural productivity.

In contrast, the central and southern zones are encountering challenges to the adoption of these innovations. Water quality constraints have led farmers to prefer sprinkler systems to drip irrigation. The high initial costs of solar pumping systems, the low power of solar panels available, and the relatively low solar radiation in the south have hampered the widespread adoption of solar energy in these areas.

Despite these challenges, some farmers have adopted hybrid systems that integrate new technologies with traditional practices such as solar pumps for water extraction and fill retention basins, while fuel-powered pumps for irrigation when necessary.

The study emphasizes the necessity of adapting agricultural policies to local circumstances, recommending the differentiation of strategies according to geographical zones and the proposal of targeted subsidies for solar equipment, with priority support for small-scale farmers with limited financial resources. It further recommends the establishment of maintenance centers to ensure the sustainability of installations and the training of farmers in the installation and maintenance of solar pumps. The study further recommends that financial institutions offer low-interest loans with staggered payments to facilitate the acquisition of solar equipment and that they encourage participatory financing and/or cooperatives to pool investment costs. Additionally, it is suggested that a gradual transition to renewable energies via hybrid systems would limit the risks associated with high initial costs. Finally, the study calls for regular monitoring of public policies and adaptation of support mechanisms to ensure effective and sustainable adoption of new agricultural technologies.

Future research could focus on optimizing land and water resources through innovative approaches such as agrivoltaics systems that integrate agriculture and solar energy production, the combined use of aquaculture and vegetable farming to improve sustainability, and the development of AquaCrop models to simulate and improve water productivity in these integrated systems.

In summary, the study highlights the complex interplay between water management, agricultural innovation, and energy adoption in the Niayes region. By addressing the specific challenges and opportunities in each zone and supporting farmers with tailored policies and financial mechanisms, the transition to sustainable, renewable, energy-powered irrigation systems could be significantly accelerated.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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