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SMALLHOLDERS ADOPTION SOLAR IRRIGATION SYSTEM AND CLIMATE CHANGE

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ABSTRACT

The present study aimed at assessing farmers' adoption of irrigation systems on the effect of climate change under the hypothesis of the effect of climate change on small-scale producers. We worked on a sample of 254 vegetable farmers. The analysis shows that the biophysical characteristics of riparian areas are influenced by environmental degradation. The means of transporting water from the source to the garden are favorable thanks to surface water, 60% concerning the well and drilling, this is visible in 35% of the farmers and only 6% are reserved for rainwater. 58% of the farmers are ready to adopt the irrigation by solar system and among this 23.4% already use the solar irrigation system and think that these technologies have a positive impact on the management of the climate change In terms of equipment, 72.4% of the farmers use motorized pumps (gasoline diesel) to transport water from the source to the plot. Thus, only 26.4% have adopted the system of pumps powered by solar energy and 1.2% are satisfied with the winter campaign. In the end, we found that the intensity of farm mechanization increases with farm size and decreases with the increase in family labor. We have formulated economic policy implications tending to make solar equipment more accessible for better performance by small farmers.

Keywords: Irrigation system, smallholders, adoption constraint, acquisition means, access to water.

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Introduction

Socio-economic development in agriculture can help combat poverty. By adopting solar-powered solutions (cost-effective and environmentally sustainable energy) for irrigation in areas without access to electricity, livelihoods can be improved Gallaher and Harvey (2020). Climate change, population growth, urbanization, and increasing demands from agriculture and energy production are several challenges that affect water quality, quantity, and distribution Li and Qian (2018). Speaking of water, its scarcity is a growing global problem that requires appropriate sustainable solutions Zhang et al. (2021). The agricultural sector is a major stakeholder in efforts to achieve global water, energy, and food security, while reducing the causes and impacts of climate change de Amorim et al. (2018), Lefore et al. (2021).

In this dynamic, the government and its partners have initiated actions that have been difficult to implement thanks to the appearance of the Coronavirus, the first case of which was declared on 24 March 2020 in Mali. It was when the disease was considered an epidemic that urgent measures were put into effect by the government. However, with a poorly developed, under-resourced and under-equipped health system, the management of the Coronavirus had become a real headache for Mali INSTAT and DGSHP (2022). The economic impact of the Coronavirus pandemic has been felt particularly at the level of displacement sites that have lost their temporary activities due to the pandemic OCHA (2020). These crises have been an aggravating factor in household consumption and the flow of refugees and displaced persons has increased overnight and is seriously affected by the food crisis Bizimana et al. (2020). The capacity of a system, community or society at risk to resist, absorb, accommodate and recover from the effects of a hazard in a timely and effective manner, including through the preservation and restoration of its essential structures and basic functions UNISDR (2009).

In most developing countries smallholder farmers face multiple constraints, including inefficient water use due to lack of appropriate water management infrastructure and climate change, resulting in low productivity (Fall et al., 2000). Thus, in low-income countries, the adoption of solar energy technologies can be complicated. Lack of information and lack of financial resources or access to financing options are the main barriers to the transition to renewable energy (Energypedia, 2020). In addition to this, the World Bank (2014) has developed the use of technologies to measure the impact and efficiency of irrigation and agricultural water management. Investments in efficient irrigation can also significantly improve the living standards of small-scale farmers who produce the majority of food in developing countries.

The irrigation system is innovative for agriculture and also has an impact on supporting irrigated vegetable seed production Energypedia (2020). Several irrigation options are available in the agricultural sector including manual, gravity or electric (fuel, solar, etc.) systems. Each system

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has weaknesses and strengths, but solar-based irrigation systems have gained increasing interest over the past decade. The vision of the Solar System Innovation Lab is to identify opportunities and pathways to scale up by providing market evidence on irrigation equipment and initial ideas to improve market density and competitiveness for the benefit of smallholder farmers Feed the future (2021).

In the Sahel, droughts in the 1970s and 1980s caused groundwater levels to drop, forcing farmers to switch from manual water extraction to the use of diesel pumps to fetch groundwater from greater depths. The introduction of solar pumping, a technology offered to smallholder farmers, has the potential to foster inclusive growth and play an important role in the realization of farmers' livelihood activitiesFida (2015).

As a result of Xie et al. (2021) and Lefore et al. (2021), Solar PV is a promising alternative for irrigation development in Africa. Solar-based irrigation systems are climate-smart solutions that can facilitate access to irrigated agriculture for smallholder farmers and enhance productivity to achieve the Sustainable Development Goals on poverty and hunger Terlau (2018). However, Mali is a continental country located in West Africa where agriculture is the main activity. The agricultural sector (including fishing and livestock) contributes 33% of PIB, employs 79% of the working population and provides 20% of the country's export earnings (https://agriculture.gouv.fr/mali). However, this sector remains largely dependent on climatic conditions. This strong dependence on climatic conditions means that the sector is strongly affected by the impact of climate change on agriculture and reduces the State's economic capacity for action. Makougoum (2020).

The Food and Agriculture Organization of the United Nations Fao (2018), estimates that only 5.3% of the agricultural area was irrigated in 2011. Thus, a single plot of land can provide two or three irrigation-conditioned crops in a year Angeliaume-Descamps et Oballos (2009). Any faith Kane et al. (2018) showed that the use of the manual irrigation system in Mali is not economically reliable in the production of potatoes, shallots and tomatoes, as confirmed by a low benefit-cost ratio of less than unity, while the average ratio of California, drip, sprinkler and gravity canal (drainage) irrigation systems in production are all greater than unity. There is general consensus that small-scale irrigation can improve production performance in Mali, but adoption of solar-powered pumps remains low.

The preference of farmers for the use of equipment adapted to the irrigation system is a concern of most farmers. The expansion of agriculture has been one of humanity's greatest impacts on the environment. It has transformed habitats and is one of the largest activities of humanity Fao (2018). Small-scale irrigation was identified and tested on approaches to strengthen water access

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constraints and support irrigated vegetable seed production already in existence in Mali Feed the future (2021).

However, Mali has conducted several studies in the field of irrigation. The development of the Irrigated System to support inclusive agricultural growth and the market gardening sector becomes an analysis of profitability and economic sustainability at the farm level. However, our central question is: What is the impact of the adoption of solar irrigation systems in small scale farms? The objective of our study is to analyze the application of solar irrigation systems on the effect of climate change.

Literature review

In line with the new institutional economics, the nature of the efforts made to develop institutional arrangements can be measured using transaction cost analysis Ostrom et al. (1993); Imperial (1999) suggest that at least three types of transaction costs should be considered when evaluating procedural institutional arrangements, namely information costs, coordination costs and strategic costs. It is only in a second step that the interactions between these ecological systems and social systems" and their respective resilience Adger (2000).

The individual resilience approach leads to an immediate focus, instead, on social sustainability, the livelihood approach, or the capability approach. As Diagne (2013) et De-Haan (2000)point out, resilience is the degree of adaptation that manifests itself through the confrontation between risk and protective factors, that the processes of social inclusion and exclusion remain the focus of development studies, the interaction between actors and structures.

According to the Fida (2015) conducted in the Sahel have emphasized the resilience that comes from investing in improved natural resource management. If water resources are used more efficiently, groundwater will be able to replenish and act as a buffer during periods of drought. Barker et al (2001) estimate that over-irrigation of land can result in losses of up to 10%. According to Lin (2003), the WUA was able to gain the confidence of users through the restoration work it undertook in its early years of operation. Now, confident in the reliability of their source of supply, farmers agree to price their water consumption according to the water needs of their crop, rather than according to the availability of water. Thus, farmers do not irrigate their land only when it is needed, in an amount that matches the plants' needs. According to Devendra and Sevilla (2002), for Asia, improving the productivity of smallholder farmers should be a priority given their diversity and accumulated empirical knowledge, especially regarding the genetic material used for plants and livestock.

According to authors such as Apollin and Christophe (2013), it is not a matter of conducting detailed technical studies on the irrigation system but first identifying the main weaknesses

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related to the infrastructure and prioritizing them according to their importance. Kergna et Dembele (2018) adds that many small-scale irrigation technologies are used in Mali. These technologies include manual watering and mechanical watering including the pedal pump (Nafasoro), wind pump, electric pump, and motor pump. Water is delivered to plots by gravity irrigation, the California system, the sprinkler system, drip irrigation and manual watering, with results showing negative gross and net margins. Inrae (2018), has established that agricultural irrigation techniques are the primary benchmarks for water savings.

The irrigation efficiency of different systems using an irrigation scenario analysis and optimization tool defines the origins of water drainage loss due to too much water applied to an area. It concludes that water losses (reduction of wind drift, direct evaporation, or soil evaporation) are reduced by changing the irrigation system or technology, but also by changing the irrigation management, including piloting, to provide the right amount of water at the right time. Water losses are reduced not only by change in the irrigation system or technology (reduction of wind drift, direct evaporation or soil evaporation), but also by a change in irrigation management, notably through piloting, which aims at bringing the right amount of water at the right time.

According to (Fao, 2018), solar-powered irrigation systems are now among the green and affordable technologies for small and large farms in developing countries. It emphasizes that they must be well managed and regulated to avoid the risks of unsustainable water use. Irrigation boosts agricultural production while ensuring that water is not captured without a proper management plan and promotes crop variety that can help improve production. She also adds that solar-powered irrigation systems are capable of reducing greenhouse gas emissions by more than 95% for each unit of energy used to pump water, compared to fuel-based alternatives.

When it comes to agriculture-based livelihoods, one of the main obstacles is the seasonality of the production process, which forces the farmer to "invest" even if the agricultural season is short. When rainfall conditions allow only one agricultural season, and when the seasons give a precise rhythm to the possible agricultural seasons, as in the Sahel countries or in India, with the monsoon season. This type of barrier, although known, is still poorly accounted for by Devereux, Wheeler and Longhurst, (2011). Its impact has been reinforced by the disappearance of marketing boards, agricultural development banks, and the reduction of agricultural development projects from 1980 onwards, for the World Bank (2014). Climate variability has a direct impact on agricultural production, as farming systems depend in part on the nature of the climate Mertz et al. (2010).

This irrigation system is credited with good technical efficiency Kane et al. (2018). The system developed by pipes buried in the plot and standpipes are installed in the upper parts of the plot

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via solar radiation as the use of diesel or fossil fuel electric networks. In the study of Kergna et Dembele (2018), he shows that this type irrigation system seems to have a higher technical efficiency for the production of many vegetables that is used for market gardening in urban areas (Fao, 2018), Choosing the right irrigation technology for a combination of physical and socioeconomic conditions, regardless of the method used, depends on complex and sometimes conflicting factors. Irrigation by modern methods has the same potential advantages, as it allows for frequent application of a small volume of water and the injection of fertilizer into the water. In addition, these systems can be easily adapted to farmers' conditions and development patterns by reducing the size of the system to make it more suitable for the generally small plots to be irrigated.

Brouwer et al (1990), believe that the farmer should choose an irrigation method that adopts the most suitable method for the local conditions of his farm. He also adds that the farmer must be able to know the advantages and disadvantages of the different methods he adopts for his farm. According to Brouwer, sprinkler and drip irrigation techniques are more complex than those used for surface irrigation. Investment costs per hectare are high and maintenance work requires "know-how" and expertise at hand. He concludes that the equipment adopted for surface irrigation systems, and particularly for small-scale irrigation projects, is simpler and easier to maintain, unless water has to be pumped. Kergna et Dembele (2018) prove that producers realize a loss of about 20% of these investments so the production is insufficient to support the costs of implementing the technologies.

According to a study conducted by Inrae (2018), he believes that with the increase in the share of market gardening in agricultural production, the number of women working in agriculture has significantly increased and they have been able to improve their incomes. Serra-Wittling, Molle, et Cheviron (2019), overestimated the potential water saving capacity on the plots by modernizing the irrigation systems. Modernization of irrigation management equipment, reduction of drainage, residual water in the soil after harvest). It therefore appears more important to support investments in innovative equipment by improving farming practices.

All beliefs conceptualize the processes of scaling up agricultural innovation as an integral part of a systems approach to innovation, paying particular attention to the possible consequences of scaling up efforts as an integral part of a systems approach to innovation. This looping and cyclical process of systematically and repeatedly identifying what works, what fits, and who is responsible Wigboldus et al. (2016), it was found that in some locations, improved water distribution systems were less well adapted than traditional systems due to high groundwater salinity that caused pipes to become clogged.

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Several reviews have been written in the field of irrigation and solar system promotion, but ours will be particularly devoted to the introduction of solar pump-based irrigation systems.

Materials and method

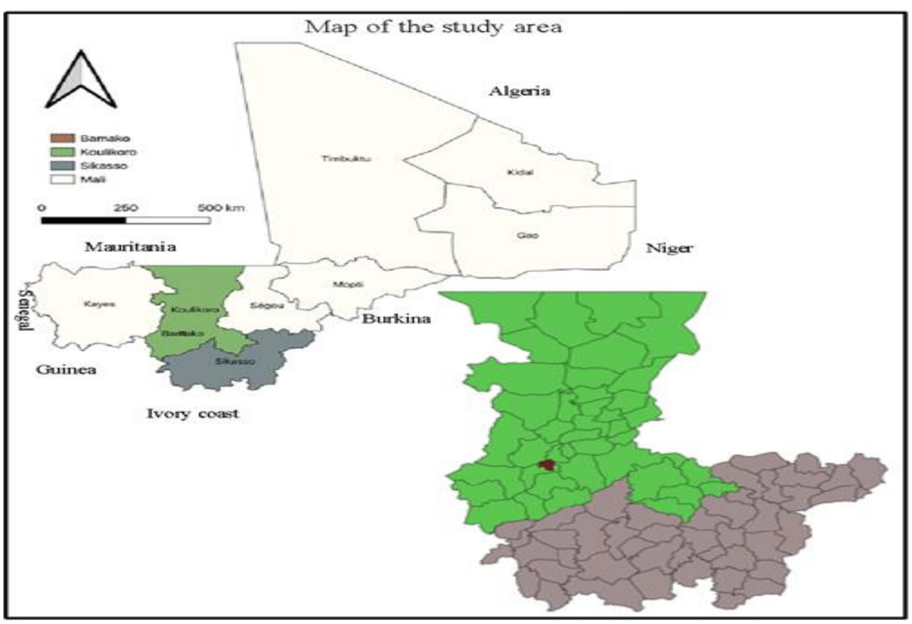
- **Materials**

This study was conducted in the regions of Bougouni, Koulikoro and Bamako. These regions are favorable for vegetable seed production due to climatic conditions and availability of agricultural labor and are located in Mali.

This study was conducted in the regions of Bougouni, Koulikoro and Bamako during the period of December 17-30, 2021. These regions are favorable for the production of vegetable and market garden crops because of the climatic conditions and the availability of agricultural labor. The state of roads, infrastructure, local vegetable market share, and prices relative to the national level allowed these areas to access the market system in their region.

We worked with a sample of 254 vegetable farmers. The information was collected from the farmers using a digitized questionnaire and saved in the KoBoToolbox platform. The deployment on smartphones allows the use. In offline mode for data collection. The process and analysis were done by the software STATA. It concerned the descriptive analyses simple mean and standard deviations.

Figure 1 show the disign Map of the study area



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Data analysis methods

– **Methods and descriptive analysis**

Different concepts have been used in different contexts to describe the data collected in the literature in an interpretable model, often in the form of a frequency analysis. For example, arithmetic models are used to measure the central tendency, the frequency. For a statistical series whose values are given by: $x_1, x_2, \dots, x_n (1)$, and the frequency is given by $f_1, f_2, \dots, f_n$, (2) the average is : $\underline{x} = f_1 x_{1+f_2 x_2} + \dots + f_n x_{n\,.}$ (3)

Knowing that $f_i = \frac{n_i}{n}$, we were that the calculate of average from the frequencies can be considered as a weighted arithmetic average: $\underline{x} = \sum_{i=1}^{n} f_{1x_1=} \sum_{i=1}^{n} \frac{ni}{n} x_i = \frac{1}{n} \sum_{i=1}^{n} n_i x_i = \frac{n_1 x_{1+} n_2 x_{2+\dots} + n_n x_n}{n} = \frac{n_1}{n} x_1 + \frac{n_2}{n} x_2 + \text{---} + \frac{n_n}{n} x_n = f_1 x_{1+f_2 x_2} + \dots + f_n x_{n\,.}$ (4)

$\underline{x} = f_1 x_{1+f_2 x_2} + \dots + f_n x_{n\,.}$ (5)

The final output of a descriptive analysis is considered the true state of the research field. It reduces and simplifies a large volume of data to accurately describe a population of studies Yang and Tate (2012). Thus, the standard deviation is the square root of the variance is an indicator of dispersion that is : $\sigma = \sqrt{V} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} * (x_i - \underline{x})^2} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} * {x_i}^2 - \underline{x}^2}$ (6)

The standard deviation is homogeneous with the variable being measured, i.e., if by a change of unit, all values are multiplied by a coefficient α > 0, the standard deviation will be multiplied by the same coefficient. In contrast, the standard deviation is additively shift invariant; if a constant is added to all recorded values, it does not change the standard deviation, the main variables used in descriptive statistics are intended to improve the quality of data collection.

– **Empirical model**

Empirical research methods serve to help integrate theoretical research with practice. Traditional knowledge or superstition has been endorsed for too long. In the interest of this study, we will use the multiple linear regression model where there are several explanatory variables to model the variable to be explained $Y = \beta_1 + \beta_2 X_{2i} + \cdots\cdots + \beta_K X_{Ki} + \mu_i$

With$i = 1,2,\cdots\cdots n = \underline{1,n}$ **et** $\beta_{j\,(j=1,2,\cdots,k)}$, μ is the residual.

If we apply to our consumption model we will have

β_i = factor associated with each equipment used by the farmers

Xi_1 = type of equipment used by farmers

Y = is the exploitable area per farmer

As can be seen from the equation, the application of ordinary least squares is well suited to this study, and we will estimate the parameters of this model.

The model can be explained by different sources of random errors, including:

- The existence of measurement errors in the variables
- The existence of explanatory variables that are not included in the relationship
- Total number of food groups consumed by household members takes the sum of the values of the 12 food categories, i.e. **« 0 »** or **« 1. »**

Let the model be: $Y = \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_K X_K + \mu$

$$Y = (Y_1 Y_2 \ldots Y_N) X = (1 X_{21} \ldots X_{K1} 1 X_{22} \ldots X_{k2} \ldots\ldots\ldots\ldots\ldots\ldots 1 X_{2n} \ldots X_{kn}) \beta = (\beta_1 \beta_2 \ \cdots \ \beta_K) \mu = (\mu_1 \mu_2 \ \cdots \ \mu_n)$$

We seek to estimate, frame and test the values of the coefficients β_1**et** $\beta_1 \ldots \ldots \beta_k$ as well as the common variance σ^2 of hazard. $Y = X\beta + \mu$

It is assumed that the X are non-random data so the only source of variation for Y comes from the random term **u: E(X'u) = 0**

- The random factor u is introduced into the model to consider the influence of various "errors" that allow the identification and testing of causal relationships between access and individual and environmental factors.
- The measure of the dependent variable Y is given by the (Area harvested during the season) and the table 1 given the independent variable attributed by each Xi_1 used

Table 1: Description of the different independent variables of the model

Variables	Definitions	Expected signs
Manual use from a basin (tap)	1 if yes, otherwise	+
Use of gravity channels	1 if yes, otherwise	+

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Drop by drop	1 if yes, otherwise	+
Watering can	1 if yes, otherwise	+
Aspersion	1 if yes, otherwise	+
Lack of agricultural equipment	1 if yes, otherwise	+
Equipment not available at local level	1 if yes, otherwise	+
Lack of financial resources	1 if yes, otherwise	+
Lack of training on irrigation methods	1 if yes, otherwise	+
Solar energy method is economically beneficial	1 if yes, otherwise	+
Positive impacts of solar energy method on environment	1 if yes, otherwise	+
Negative impacts Solar energy method on environment	1 if yes, otherwise	+
Adopted the solar irrigation system	1 if yes, otherwise	+

Thus, after the mathematical steps, we find a $\beta = (X'X)1^{-1} * X'Y$**.** This result is subject to the number of assumptions and including that the matrix X is of rank **k <n : rank (X) = rank *(X' X)* = k and** $(X'X)^{-1}$ is generally the number of observations is greater than the number of parameters to be estimated and there is no linear combination of Xi that is zero. For the estimation of the vector b, we have to make some assumptions on the observations and on the distribution of u_i. These assumptions are either structural or stochastic.

E(u) = 0, ∀ i = 1, 2, . . ., n or approximately, the positive and negative values of u have a zero sum. Homoscedasticity and absence of autocorrelation of errors $E(uu') = \sigma^2 In$, where **In** is a unit matrix of order n. This writing is a condensed way to formulate a double hypothesis:

$-E(u_i^2) = \sigma^2 \forall i = 1,2,\cdots,n$ the $u_i$have a constant variance, this is the homoscedasticity

- $E(u_i u_j) = 0$Pour $i \neq j$, les $u_i$are not correlated two by two, this is the absence of autocorrelation.
- The law of u_i is a normal distribution. This assumption is necessary to conduct statistical significance tests of the estimators (the **t**, $\chi^2$and F are based on normal distributions) and

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construct the confidence intervals. The estimator $\hat{\beta} \rightarrow N(\beta, \sigma_u^2(X'X)^{-1})$ were σ_u^2 is the variance of u_i.

Testing a hypothesis consists of verifying whether the marginal effect of the factor on the dependent variable is zero or not. By comparing a calculated test statistic to a critical statistic (tabulated) using estimated parameters. It is a question of knowing if the test is said to be two-sided if the hypothesis H0 is opposed to its simple negation as an alternative hypothesis e.g. $H_{0:}$ β=0 versus H_1: β=0 and it will be said multilateral otherwise, e.g. $H_{0:}$ β=0 versus H_2: β >0 and H_3 : β <0.

The null hypothesis versus the alternative hypothesis (H_0=0 versus H_1≠0). Choose the confidence level ε **%** and generally at (5% chance of rejecting the null hypothesis when it is true). The higher this level, the more accurate the test. Calculate the statistic $\frac{\beta_j - \beta_j^0}{SE(\beta_j)} = t$ (Student):

if $|t| \succ t_{\frac{\varepsilon}{2}}(n-k)$ then β_j is distinct de β_j^0, où $\frac{R^2}{1-R^2}\frac{n-k}{k} = F$ (Fisher)

if **F**$\succ$ $F_{\frac{\varepsilon}{2}}(k-1, n-k)$ we will say that the regression is significant or that all β_j are not zero.

Results

Analysis of the data revealed that 19.7% of the farmers were located in the Bougouni region, 12% in Bamako and 67.7% in Koulikoro. Among these farmers, the average size of the gardens is 6.83 m2 and this can reach up to 37 m2. 52.4% of the farmers were women and 47.6% were men, with an average of 5.5 years of experience in market gardening, ranging from 3 to 9 years. The main opportunities offered by solar irrigation systems for farmers are, among others, energy supply and improved access to water for irrigation. The following table shows the average dimensions of the indicators.

Table 2: Determinants of solar irrigation adoption

Indicator	Number	Mean	Ecartype
Area exploited during the campaign	254	6.83	8.40
Economically beneficial methods	254	0.07	0.26
Negative environmental impact	254	0.35	0.47

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Positive environmental impact	254	0.42	0.49
Adopt a solar irrigation system	254	0.15	0.36
Main source of access to water			
Borehole least deep	254	0.86	0.34
Borehole deeper	254	0.07	0.25
Surface (river, lake)	254	0.12	0.32
Rain only	254	0.80	0.39
Method of transporting water from source to garden			
Pump with diesel engine	254	0.72	0.44
Solar powered pump	254	0.26	0.44
Rain only	254	0.01	0.10

Our statistics show that several sources of water supply are the main factors that promote the adoption of solar pumping technologies. Figure 2 shows that the majority of farmers use rainwater and well water to irrigate their gardens, these sources represent the main supply sources. The farmers already know the seasonal crops, almost 72.4% of the farmers use the diesel pump.

The results of this study give an indication of the financial viability of solar pumping, but further economic and financial analysis could provide stronger evidence. In particular, a more thorough evaluation could examine the benefits of this adoption of the new generation technology. During the study, it was found that 58% of farmers are willing to adopt solar irrigation and of these 23.4% are already using solar irrigation and feel that these technologies have a positive impact on climate change management.

The solar pumping offers good opportunities for water savings to the extent that it increases production capacity at lower cost. However, collective management of the pumps has important social benefits, allowing poorer farmers to benefit from technological advances. On the other hand, solar powered systems require higher initial investments but have a longer lifespan than motorized pumps.

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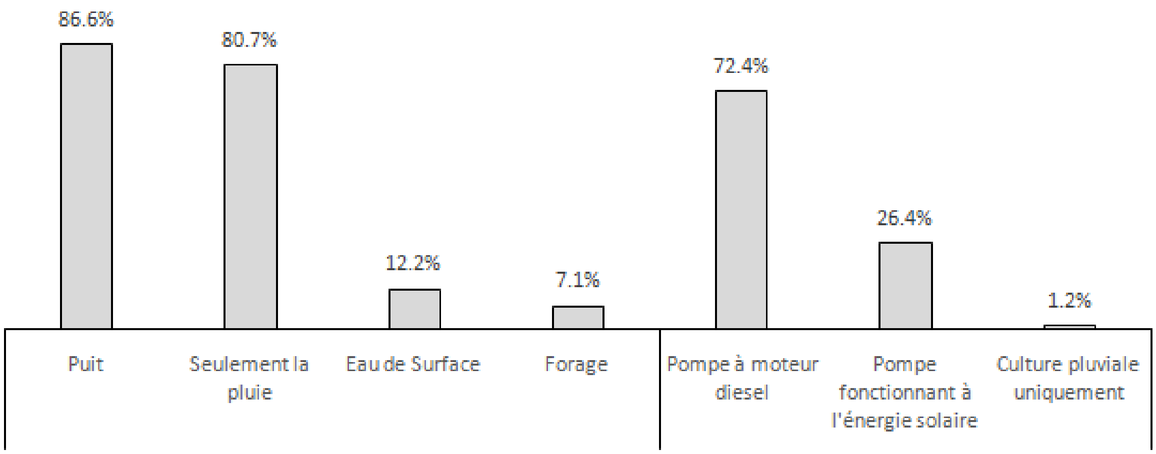
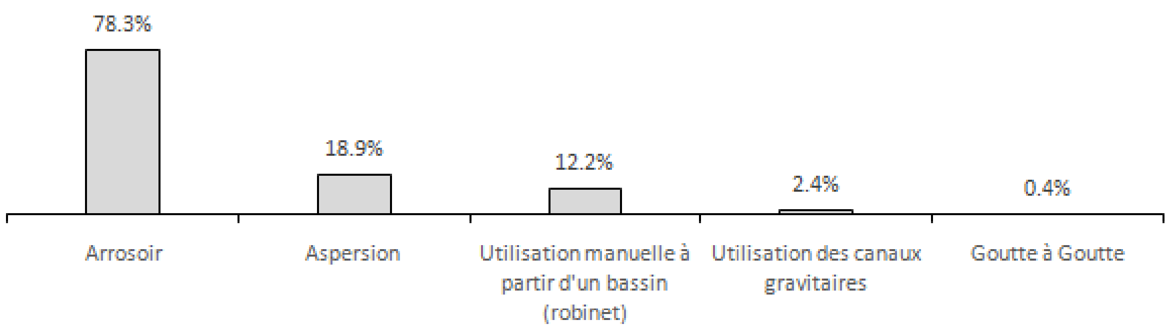
Figure 2: Main source of water supply and transport



The figure 3 shows the evolution of irrigation methods adopted by farmers to improve farmer resilience and food security. Farmers have sought to adopt alternative coping strategies to address the problems associated with the scarcity of primary resources. The high initial investment has made the demand for the solar pump a barrier for poor farmers. Therefore, farmers should have access to savings and credit mechanisms to facilitate this type of investment.

Figure 3 Use of irrigation methods



In an environment increasingly subject to various climatic hazards, adaptation appears to be a necessity for producers. However, reading this table shows that the regression model is significant at 1%. The effect or result expected by producers by adopting the simplest or most complex of the possible adaptation strategies is to maintain their profit level.

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Table 3: Determinant of the irrigation profile

Explanatory variables	Coefficients	Std Error	t student	Probability
Manual use from a basin (tap)	1.971	1.149	1.72	0.088
Use of gravity canals	4.033	2.552	1.58	0.115
Drop by drop	5.591	6.396	0.87	0.383
Watering can	4.691**	2.256	2.08	0.039
Sprinkler	3.727	2.346	1.59	0.113
Lack of agricultural equipment	3.496	2.373	1.47	0.142
Equipment not available at local level	13.170***	2.443	5.39	0.000
Lack of financial resources	14.434***	2.147	6.72	0.000
Lack of training on irrigation methods	-4.067	2.996	-1.36	0.176
Solar energy method is economically beneficial	-7.922***	1.987	-3.99	0.000
Positive impacts Solar energy method on environment	5.941***	1.130	5.26	0.000
Negative impacts Solar energy method on environment	-7.941***	1.595	-4.98	0.000
Adopted solar irrigation system	-4.670*	1.808	-2.58	0.010
Consistency	-3.163	2.232	-1.42	0.158
Number of observations	254			
Fisher's F-statistic	22.23*** (ddl1=13; ddl2=240; P=0.0000)			
R^2	0.54			
*** p<0.01; ** p<0.05; * p<0.1				

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Discussion

Market gardening in the Bamako, Bougouni and Koulikoro areas is an activity that is predominantly carried out by women. In terms of equipment, 72.4% of farmers use motorized pumps (diesel) to transport water from the spring to the plot. Only 26.4% have adopted the solar-powered pump system and 1.2% are satisfied with the winter campaign. On average 42% of the farmers think that the use of solar powered pump systems can have positive effects on the environment but they believe that the equipment is very expensive for small farmers. The use of watering cans was statistically significant at 10%. However, at the local level equipment not available or lack of financial resources is statistically significant at 1% and farmers already agree that it has a positive impact on the solar method on the environment.

According to the farmers, the solar energy method is economically beneficial for the farmers, statistically significant at 1%. Indeed, in studying perceptions and adaptations to climate change and variability in the Limpopo Basin of South Africa, Gbetibouo (2009) noted that although farmers perceive the effects of climate change, not all of them adopt adaptation strategies. This situation is the result of the existence of factors limiting adaptation.

About 37% believe that these solar methods are economically beneficial, 42% also say that they can have positive effects on the environment (water use, soil conservation or climate change), more than 68% think that it can favor the increase of erosion and 7% find that the irrigation techniques use a lot of water.In addition, although not widely adopted in the study area, farmers' constraints in moving water from the source to the plant are too diverse, however, the analysis confirmed that farmers lack financial resources 100% of which 65% need equipment and 31% seek training and or information on technologies.

The adjustments made by producers have variable effects on the elements of the operating account. However, the results of the regression model indicate that only the irrigation system and the diversification of farming methods have significant effects on producers' profits. The positive effect on the use of irrigation system methods supports the adoption of the solar irrigation system is statistically significant at 10% with a negative effect because farmers have a strong need for financial resources and accessibility of the technology. Also, the farmers are more likely to use the most profitable equipment for vegetable production and less sensitive to climatic risks.

On average 88% of the farmers produce the following crops: chili, eggplant, green beans, cabbage, bell pepper, lettuce, onion, carrot, beet, celery, turnip, parsley, strawberry. The increase in the production rate of a crop depends on its demand in the consumer goods market. Increased yields and income have occurred when manual labor has been reduced in combination with better time management.

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Conclusion and recommendation

In the end, we found that the intensification of agricultural mechanization increases with farm size and decreases with the increase in family labor.

In addition, drought increases the chances of agricultural mechanization. Based on the data collected, we hypothesized that the adoption of the solar system would reduce the effect of climate change. The constraints to move water from the source to the plant is too diverse and remains a problem for farmers. The difficulty of access and the cost of purchase are to be reviewed.

The hypothesis has been validated under the conditions in terms of the involvement of economic policies tending to make solar equipment more accessible for a better yield of small farmers and to reduce the operating costs in hydrocarbons or even cancel them. Thus, based on the analysis of climate change adaptation, the factors that dictate climate change adaptation, and the perception of climate change by farmers in Mali, different policy options can be suggested. These policy options include raising awareness of climate change and adaptation methods and mainstreaming climate change issues. Specifically, these include:

- Accompanying the extension of alternative equipment to the decline in water levels due to climate change.
- Valorization of groundwater through renewable energy equipment (solar, wind, etc...)
- Request the integration of the subsidy of renewable energy equipment in the framework of the climate fund in view of the limited financial capacity of the operators.
- Promote the manufacture of renewable energy equipment.

Lack of training on irrigation methods. There is a need to adopt an application to facilitate local implementation among farmers and promote solar systems that are adopted for irrigation. Furthermore, drought increases the chances of mechanization of agriculture. We have formulated economic policy implications tending to make solar equipment more accessible for better performance of smallholder farmers.

AUTHORS' CONTRIBUTION

The two PhD students were responsible for data collection, analysis and interpretation of the interpretation of the data. They were research assistants and teachers at school.

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