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Understanding the Pathways for Adoption of Solar Technologies for Irrigation by Women Farmers, Senegal

Saboury Ndiaye[1,2], Blaise Waly Basse[3], Marame Cissé[2], Laure Tall[2], Djibril Diallo[2], Cheikh Faye[2], Elisabeth Gueye[2], Landing Diedhiou[1*]

[1]Department of Agroforestry, Assane Seck University, Ziguinchor, Senegal
[2]Agricultural and Rural Prospective Initiative (IPAR), Senegal
[3]Department of Economics and Management, Assane Seck University, Ziguinchor, Senegal
Email: *l.d7@zig.univ.sn

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Abstract

In Senegal, like many sub-Saharan African countries, the intensification of irrigated agriculture can help to reduce food insecurity and poverty, but this requires energy to access water. However, women, who comprise the main agricultural workforce, lack access to solar technology for irrigation in agriculture (STI) and therefore rely on diesel pumps, which increase their irrigation costs and contribute to pollution. This paper investigates how and why women horticulturalists in Senegal's Niayes zone adopt solar irrigation technologies. Using survey data from 366 women horticulturists, the authors estimate actual and potential adoption rates with an Average Treatment Effect (ATE) framework and identify determinants through a Probit model. Key findings reveal low current adoption (26%) despite awareness, and highlight decision-making power, secure land tenure, plot size, and marital status as significant drivers. The study also showed that in polygamous households, the fact that the woman is the first wife of the household head increases her likelihood of adopting STIs, unlike the second and third wives. Finally, it has been noted that widowed women are more likely to adopt STIs. The study recommends pairing technology supply with measures that strengthen women's control over land, finance, and on-farm decisions.

Keywords

STI, Adoption, Women, Horticultural, Senegal

1. Introduction

In the agricultural sector, solar technologies of irrigation (STIs: solar pumps and panels) have the potential to reduce hunger, food insecurity, and poverty in Africa, while contributing to climate change mitigation and adaptation [1] [2]. Indeed, research has shown that the use of STIs enables growers to improve agricultural yields and invest in more profitable commercial horticultural crops [1] [3]. In addition, STIs are often viewed as time- and labor-saving solutions for women farmers, with the potential to reduce the drudgery of watering work, thereby freeing up time to attend to other income-generating activities [4]-[6].

Several studies have established a close link between women's participation in decision-making and the adoption of STIs. A study conducted in Ghana found that increasing women's decision-making power in terms of production and income leads to the adoption of irrigation systems [5]. Some authors note that women's limited participation in household and community decision-making often results in lower adoption of irrigation technologies [7]-[9]. Despite the recognized importance of women's participation in decision-making for the adoption of irrigation technologies, it should be noted that the majority of women decision-makers are the wives of household heads. A study conducted in Ghana revealed that, on irrigated plots managed by men, women are still responsible for taking the crops to market and selling them when their husbands request it [5].

Most studies on the determinants of STI adoption focus on the household level [10]-[17]. However, the adoption of a technology at the household level does not necessarily benefit all household members equally, as household structure and gender relations within the household can promote or limit equitable access to technologies [7] [18]. The few studies on the determinants of STI adoption among women farmers focus more on gender relations between women and men [4] [19]-[21]. However, this research does not specifically address the differences between women themselves within a household or between households that may influence the adoption of STIs.

In Senegal, STIs were recently introduced in the 2010s and are a priority in national policies and programs [22]. To encourage the adoption of STIs, the government is putting regulatory and institutional frameworks in place, in addition to financing mechanisms. Although there are several government and non-government projects that support the dissemination of STI, the impact of these interventions on the adoption of solar technologies by women farmers has not been studied. At the time of writing, there were no studies on the link between gender equality and social inclusion and the adoption of STIs in Senegal. It is important to understand the dimensions of gender equality and social inclusion (GESI) of STIs in Senegal, where women are the main source of labor on family farms. The objective of the study is to estimate the adoption rates and factors determining the adoption of STIs among women farmers. This study will help fill this information gap in order to guide decision-making by development actors for better consideration of gender inequalities and inclusion in STI dissemination programs for a just and equitable energy transition that promotes women's economic empowerment.

2. Materials and Methods

2.1. Study Area

The study was carried out in the Niayes area (**Figure 1**), located along the northwest coast of Senegal, between latitudes 14˚55' and 15˚27'N and longitudes 16˚50' and 17˚07'W. It is bordered by the Saint-Louis region to the north, Dakar to the south, Route N˚2 linking Dakar and Saint-Louis to the east, and the Atlantic Ocean to the west [23]. It's a narrow coastal strip some 180 km long and 20 to 30 km wide, with a total surface area of 2759 km^2. Administratively, the Niayes area straddles four of the country's regions (Saint-Louis, Louga, Thiès, and Dakar). Thanks to its favorable agroecological conditions, the Niayes zone plays a major role in the country's agriculture, supplying over 60% of the country's market garden production [17] [24].

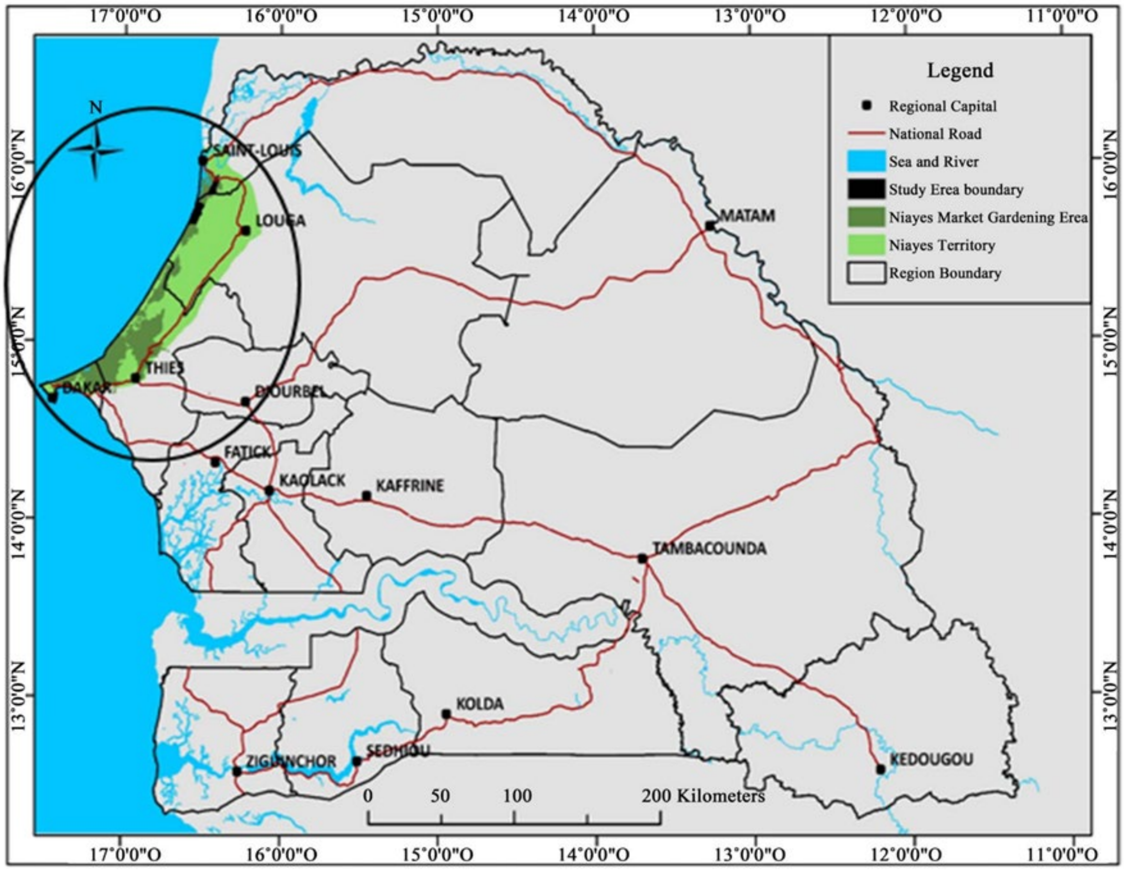

Figure 1. Location map of the study area [16].

The area is characterized by cool temperatures ranging from 27.5˚C to 28.1˚C, with rainfall averaging 450 mm per year. Water resources come mainly from accessible groundwater, with a deep-water table ranging from 5 to over 12 m [25].

2.2. Data Collection and Treatment

For data collection, surveys were carried out in 2022 in the Niayes area. The KoboToolbox platform (version 2.022.44) was used to develop the questionnaire, which was then deployed on the KoboCollect application (version 2022.4.4) to ensure effective data collection. Interviewers with extensive knowledge of data collection administered the questionnaire to women horticulturalists. The data collection was funded as part of the project entitled "Energy transition for women's economic empowerment through the horticultural value chain in a post-COVID-19 context in Senegal", implemented by "Initiative Prospective Agricole et Rurale" (IPAR) and financed by the International Development Research Centre (IDRC).

The sample size was determined on the basis of a cross-referencing of data from the general census of population, agriculture, and livestock conducted by the National Statistics and Demography Agency in 2013 [26] and those of the Ecological Monitoring Center (CSE) on agroecological zones. This made it possible to identify all the villages and neighborhoods in the "Niayes" area. Next, mapping work was carried out through resource persons in the various localities to identify localities where women are active in horticultural production and where solar technologies are used. A two-stage stratified sampling approach was used to better meet the study objectives. The strata are made up of the three Niayes sub-zones: South, Centre, and North. Within each stratum, the sample was drawn in two stages. In the first stage, a sample of villages was drawn at random from each commune. Then, in the second stage, a list of horticultural households using or not using solar technology irrigation (STI) was drawn up for each village selected. A total of four villages were selected per commune, and in each of them, ten households were surveyed, divided equally between five households that used solar energy and five that did not. Overall, the survey involved 366 female horticulturalists, including 182 STI users and 184 non-users.

Collected data were corrected using Excel spreadsheets before being exported for processing to the STATA/SE-17.0 statistical tool (StataCorp, 4905 Lake Way Drive, College Station, TX 77845, USA).

2.3. Data Analysis

2.3.1. Socio-Economic Data

Descriptive statistics (mean, frequency, headcount) were generated using frequencies relative to STI-adopting and non-adopting female horticulturists. For qualitative and quantitative socio-economic variables, correlation analyses according to STI adoption status were performed using the Chi-square and Pearson tests, respectively. Before this, a multi-colinearity test was performed on the same socio-economic variables using the variance inflation factor (VIF). The results of the multi-colinearity test indicate an average VIF value of 1.34, which is less than 1.0, allowing us to say that there are no problems of multi-colinearity between the socio-economic variables involved in our model.

2.3.2. Method for Estimating STI Adoption Rates

This study is based on the theory of random utility, which states that economic agents are rational beings who tend to pursue options that maximize their utility.

Consequently, the utility (U) derived from the choice alternative can be considered to consist of a deterministic component, V, and a stochastic component, ε, which follows a predetermined distribution, as illustrated in Equation (1). This means that individual i will choose alternative j from a set of choice alternatives (J) given that the choice maximizes his utility. The probability (P) that the individual will choose alternative j can be illustrated by Equation (2).

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (1)$$

$$P_{ij} = P_r\left(U_{ij} > U_{ij}\right)\forall_j \neq j \quad (2)$$

In the literature, to estimate technology adoption rates, most studies use classical methods such as Tobit, Probit, or Logit [27]. However, these methods give a biased estimate of true adoption rates, as they assume that knowledge of the technology disseminated is universal in the population. In reality, the diffusion of a technology is rarely complete, and consequently, not all of the population is fully exposed to the technology. The result is a non-exposure bias, due to the fact that a population that has not been exposed to the technology cannot adopt it [27]. The presence of this bias often results in an underestimation of the potential adoption rate in the population. Similarly, calculating the adoption rate among the subpopulation that has been exposed to the technology is not a robust estimate of the actual adoption rate in the population. This adoption rate suffers from a positive selection bias due to the fact that the choice of the beneficiary population is not random. In general, the population targeted for testing or disseminating a new technology is the one most available or most committed to accepting it [28].

In this study, we therefore use the Average Treatment Effect (ATE) method of [27]. The ATE model appropriately controls for non-exposure and positive selection biases in order to robustly estimate true adoption rates. The conceptual framework of the ATE estimation model is based on Rubin's causal model [29], which is generally suited to analyzing the situation in which a treatment may or may not be administered to an individual. In the context of STI use, treatment status corresponds to STI exposure status. Exposure is defined as knowledge of STIs, made possible by the information and awareness-raising on STIs provided by development actors (NGOs, technical services, projects, private promoters).

Let t be a binary variable determining exposure status to STI: $t_i = 1$ means that the female horticulturist has been exposed to STI (and therefore knows about STI), and $t_i = 0$ means that she has not been exposed to STI. Exposure is assumed to affect the adoption of STIs, which is a result variable. Based on Rubin's causal model [29], we consider that there are two potential outcomes of adoption corresponding to the situation of a female horticulturist under each of the alternatives, *i.e.*, if the female horticulturist adopts the STI $y_i = 1$, and if she does not adopt it $y_i = 0$. These two levels of STI adoption are never observed at the same time for the same female horticulturist, as it is impossible to be both an adopter and a non-adopter of STI. Therefore, for a female horticulturist who has been informed, made aware, or trained about the STI, Y_1, corresponding to the adoption of the STI, is observed, while Y_0, corresponding to the non-adoption of the STI, is unknown, and vice versa. The value corresponding to the result of non-adoption of STI by the female horticulturist, which would have been obtained if she had not been informed, trained, or made aware, is called "counterfactual" in the econometric literature on impact assessment [29]. The observed result of STI adoption, Y, can be written as a function of the two potential adoption outcomes Y_1 and Y_0, and the exposure status, t, as follows (Equation (3)).

$$Y = TY_1 + (1-T)Y_0 \tag{3}$$

In the case of our study, where the outcome of adoption is a binary variable taking the value 1 if the female horticulturist adopts STI or 0 otherwise, then the expected value corresponding to the average outcome of STI adoption is simply the probability corresponding to the measure of the adoption rate (proportion of adopters in the population). The different treatment effects can therefore be written as follows:

ATE: Average Treatment Effect on the population, which represents the potential adoption rate of STI for all female horticulturists in the study area:

$$\text{ATE} = E(TY_1) = P(Y_1 = 1) \tag{4}$$

ATE1: Average effect of the treatment on the population of women horticulturists who are aware of STI, *i.e.*, the rate of adoption of STI among women horticulturists who have been informed, sensitized, or trained on STI.

$$\text{ATE1} = E\left(\frac{Y_1}{T} = 1\right) = P\left(Y_1 = \frac{1}{T} = 1\right) \tag{5}$$

ATE0: Average Treatment Effect on the sub-population of female horticulturists who have not been exposed to STI, *i.e.*, the potential adoption rate of STI among female horticulturists who have not been informed or sensitized, *i.e.*, who are unaware of STI. In other words, this is the potential adoption rate of these female horticulturists if they had been informed about STIs.

$$\text{ATE0} = E\left(\frac{Y_1}{T} = 0\right) = P\left(Y_1 = \frac{1}{T} = 0\right) \tag{6}$$

JEA: Joint Exposure and Adoption: if $Y_0 = 0$, the expression of the observed outcome of use as a function of the potential outcome of adoption and exposure status reduces to: $y = Ey_1$. This expression shows that the observed outcome variable of adoption is a combination of that of STI exposure and the potential outcome of STI adoption.

$$(\text{JEA}) \cdot E(Y) = E(TY_1) \tag{7}$$

GAP: The adoption gap (GAP) is the average difference between the JEA and ATE, which provides information on the demand for STIs. This GAP is given by the Equation (8).

$$\text{GAP} = E(Y) - E(TY_1) \tag{8}$$

The difference in mean between ATE and ATE1 is called positive selection bias

(PSB), given by Equation (9):

$$\text{PSB} = E\left(TY_1\right) - E\left(\frac{Y_1}{T} = 1\right) \quad (9)$$

The ATE estimation procedure is based on the following Equation (10) which identifies ATE(*X*), which underlies the conditional independence assumption. This assumption states that the treatment status is independent of the potential outcomes $y_i = 1$ and $y_i = 0$ conditional on an observed set of covariates x [27]:

$$\text{ATE}\left(X\right) = E\left(y_1 \mid x\right) = E\left(y \mid x, t = 1\right) = g\left(x, \beta\right) \quad (10)$$

where g is a known (non-linear) function of the vector of covariates x, and the parameter β must be estimated using the least squares (LS) or the maximum likelihood estimation (MLE) method using the observations $\left(y_i, x_i\right)$ concerning the subpopulation familiar with the solar device, with y as the dependent variable and x the vector of explanatory variables. With an estimated parameter ($\hat{\beta}$), the predicted values $g\left(x_i, \hat{\beta}\right)$ are calculated for all observations i in the sample (including observations in the subpopulation that did not adopt) and ATE, ATE1, and ATE0 are estimated by taking the average of the predicted values $g\left(X_i, \hat{\beta}\right) = 1, \cdots, n$ across the entire sample (for ATE) and the respective subsamples (for ATE1 and ATE0) in Equations (11) to (13).

$$\widehat{\text{ATE}} = \frac{1}{n} \sum_{i=1}^{n} g\left(X_i, \hat{\beta}\right) \quad (11)$$

$$\widehat{\text{ATE1}} = \frac{1}{ne} \sum_{i=1}^{n} T_i g\left(X_i, \hat{\beta}\right) \quad (12)$$

$$\widehat{\text{ATE0}} = \frac{1}{n - ne} \sum_{i=1}^{n} \left(1 - T_i\right) g\left(X_i, \hat{\beta}\right) \quad (13)$$

2.3.3. Method for Estimating the Determinants of STI Adoption

As a reminder, a woman farmer will only adopt STI if the benefits she expects to gain are greater than if she does not. However, in addition to knowledge of STI, several socio-demographic and socio-economic factors can influence a horticultural woman's decision to adopt STI or not. These include observable factors such as age, education, farm size, and income, as well as unobservable factors such as the perceptions and motivations of female horticulturalists Takleword et manda….

In this context, when the female horticulturist has only one choice, *i.e.*, whether or not to adopt STI, standard binary empirical models of the Logit and Probit type are used, instead of models based on ordinary least squares. Both Logit and Probit models are similar and generate almost identical predicted probabilities, but the Logit model uses the logistic cumulative distribution function, whereas the Probit model assumes a normal distribution. For similar studies, [10] [19] and [30] used the Logit model, while [11] and [12] applied the Probit model. To choose between the two models (Probit and Logit), we apply the quality test of a statistical model proposed by Hirotugu Akaike in 1973, better known as the Akaike Information Criterion (AIC). According to Akaike, between two models, choose the one with the lowest AIC value. After testing, we obtained the smallest AIC value with the Probit model, which justified its choice. The Probit model is estimated as follows in Equations (14) and (15).

$$P_i = F(Z_i) = F + \sum_{i-1}^{m} \beta_i X_i = \frac{1}{1+e^{-zi}} \quad (14)$$

$$Z_i = \alpha + \sum_{i-1}^{m} \beta_i X_i \quad (15)$$

Here: P_i = the probability that a woman farmer adopts STIs; $i = 1, 2, 3, \cdots, m$; e = base of natural logarithms (2.718); m = number of explanatory variables; α = intercept; β_i = coefficient of explanatory variables.

3. Results and Discussion

3.1. Descriptive Analysis

The results in Table 1 show that, depending on the adoption status of STIs, there is a statistically significant difference at the 1 to 10% threshold for several socio-demographic and economic variables. These include marital status, level of education, relationship to the head of household, ethnic group, mode of access to land, cultivated area, irrigation costs, and income before the use of solar energy. For other variables, the difference is not statistically significant regardless of STI adoption status, particularly age group and type of land ownership.

3.2. STI Adoption Rate

Table 2 presents the results of STI adoption rates among women horticulturists.

The results indicate that knowledge of STIs has a positive and significant impact on the adoption of solar energy among women horticulturists. In fact, in the study area, the current adoption rate of STIs among horticulturists who have been informed or made aware of STIs is estimated at 26%. Similar studies have shown a positive and significant relationship between knowledge of solar irrigation technologies and their adoption by farmers. A study conducted in Bangladesh by [31] showed that the adoption of STI increases by 25.1% if the farmer has good knowledge of solar irrigation technologies. [32] showed that in Kenya, knowledge of the technologies increases adoption by 15%. This is confirmed by [31], who notes that if most family members lack the necessary knowledge to understand the benefits of solar irrigation systems, the family may decide not to adopt the technology.

The results also reveal that the potential adoption rate is 32.21%, indicating a 6.07% adoption gap, which represents the difference between the potential adoption rate and the current adoption rate. This relatively low adoption gap shows that awareness of STIs alone is necessary but not sufficient to increase the adoption of STIs in the Niayes area. This is acceptable insofar as other conditions must be met for women to adopt STIs. Indeed, other factors hinder the adoption of STIs among women. This emerged during focus group discussions with women horticulturists who have not adopted solar energy, citing constraints on access to land and the high cost of acquiring STIs as barriers to its adoption.

Table 1. Descriptive statistics on the adoption status of STI.

Variables		Non-adopting STI woman N (%)	Adopting STI woman N (%)	P-value
Age range	<35 years	222 (74%)	78 (26%)	0.266
	35 - 50 years	254 (69.21%)	113 (30.79%)	
	>50 years	212 (74.13%)	74 (25.87%)	
Marital status	Monogamous	302 (81.62%)	68 (18.38%)	0.000***
	Polygamous 1st wife	99 (77.23%)	111 (52.86%)	
	Polygamous 2nd wife	173 (77.25%)	51 (22.77%)	
	Widowed	17 (53.13%)	15 (46.88%)	
Ethnic group	Wolof	410 (68.91%)	185 (31.09%)	0.048*
	Pular	250 (78.13%)	70 (21.88%)	
	Serere	19 (70.37%)	8 (29.63%)	
Relationship to head of household	She is the household's head	428 (90.87%)	43 (9.13%)	0.000***
	Wife of the household's head	217 (50.58%)	212 (49.42%)	
	Daughter of the household's head	25 (89.29%)	3 (10.71%)	
Education level	No formal education	279 (69.58%)	122 (30.42%)	0.043*
	Primary school	88 (73.33%)	32 (26.67%)	
	College	55 (63.95%)	31 (36.05%)	
	Qur'anic school	266 (76.88%)	80 (23.12%)	
Mode of access to land	Owner/co-owner with administrative document	178 (74.79%)	60 (25.21%)	0.0495*
	Owner/co-owner without administrative documents	308 (72.13%)	119 (27.87%)	
	Borrowing	202 (70.19%)	265 (27.49%)	
Type of land tenure	Individual	323 (75.12%)	107 (24.88%)	0.110
	Familial	163 (69.36%)	72 (30.64%)	
Land area before solar use	<0.1 ha	503 (90.14%)	55 (9.86%)	0.000***
	0.1 - 0.9 ha	97 (43.69%)	125 (6.31%)	
	>s1 ha	88 (50.87%)	85 (49.13%)	
Cost of irrigation before solar use (CFA)	<100,000	567 (79.30%)	148 (20.70%)	0.000***
	100,000 - 300,000	78 (51.19%)	76 (48.81%)	
	>300,000	43 (51.19%)	41 (48.81%)	
Total household income before solar use (CFA)	<500,000	586 (77.11%)	174 (22.89%)	0.000***
	500,000 - 1,000,000	63 (49.61%)	64 (50.39%)	
	1,000,000 - 5,000,000	35 (59.32%)	24 (40.68%)	
	>5,000,000	4 (57.14%)	3 (42.86%)	

Table 2. Current and potential STI adoption rates.

Parameters	Results
ATE: Potential adoption rate of STI in the total population of women horticulturists (%)	32.21***
ATE1: Potential adoption rate of STI in the sub-population of women horticulturists exposed to STI (%)	29.83***
ATE0: Potential adoption rate of STI in the sub-population of women horticulturists not exposed to STI (%)	49.04***
Common rate of STI exposure and adoption (%)	26.13***
STI usage gap (GAP) (%)	−6.07**
PSB: Positive Selection Bias at STI (%)	−0.023**

"We cannot afford to invest in pumps and solar panels for irrigation because we don't have our land."

"If we are lucky enough to benefit from a subsidy or funding, I won't hesitate to use solar energy for irrigation, because we're tired of buying fuel at ever-increasing (…)."

"We use the motor pump, but we can't go on because fuel is too expensive and so is electricity. I'd like to have solar power now."

Similarly, other studies have shown that women's limited access to land is a major barrier to the adoption of solar irrigation technologies [33] [34]. A recent study conducted in the Niayes region showed that the method of obtaining land for agricultural activities is mainly dominated by inheritance, followed by sharecropping [17]. The same study highlights that the reason some producers were unable to invest in solar panels was that the land they farmed did not belong to them, but to members of their family, making it risky to invest in expensive installations, particularly in situations where families disagree on inheritance. Indeed, the initial investment is considered the main perceived constraint to the acquisition of solar pumping systems in the Niayes area [16] [17]. The study by [16] shows that in the Niayes region, the investment cost required to install a solar pumping system varies between €1372.04 (900,000 CFA) and €5488.17 (3,600,000 CFA).

However, the table shows that the adoption rate is 50% among the subpopulation of women who are not exposed to STIs. This would mean that if women horticulturists who are not informed or aware of STIs had been, approximately 50% of them would have adopted STIs. This indicates that there is a more or less significant unmet demand for STIs in the Niayes area, but only if other constraints on access to land and property are removed. The study also shows that the positive selection bias is estimated at 0.023% and is significant, which means that women horticulturists who are aware of or informed about STIs are not as likely to adopt these STIs as any woman horticulturist chosen at random from the population. This is logical insofar as female horticulturalists who are aware of STIs have more information about them, which may encourage them to adopt STIs, unlike those who are not aware of them.

3.3. Factors Determining STI Adoption

Table 3 shows the determinants of IST adoption among women horticulturists.

Table 3. Determinants of STI adoption by women horticulturists.

Variables	Coefficients	Marginal effects
Women's participation in household decision-making		
✓ The adult woman makes the decision	1.359 (0.212) ***	0.307
✓ Husband and wife make joint decision	1.255 (0.208) ***	0.270
✓ Someone else in the household makes the decision	0.106 (0.646)	0.010
✓ The wife and someone else in the household make the decision jointly	0.803 (0.315) **	0.131
✓ The woman makes the decision jointly with someone outside the household	2.628 (0.850) ***	0.770
Mode of access to land		
✓ Purchased	0.226 (0.218)	0.052
✓ Assigned by the town hall	0.786 (0.433) *	0.232
✓ Offered	0.356 (0.264)	0.880
✓ Land in unallocated national domain	0.786 (0.443)	0.409
Age	−0.005 (0.006)	−0.001
Marital status		
✓ First wife of the head of household	0.874 (0.211) ***	0.251
✓ Second wife of the head of household	−0.230 (0.203)	−0.037
✓ Third wife of the head of household	−0.005 (0.272)	−0.0009
✓ Widowed	1.131 (0.375) ***	0.351
Education level		
✓ Primary	−0.163 (0.242)	−0.034
✓ Secondary 1st cycle	0.147 (0.269)	0.036
✓ Qur'anic school	−0.044 (0.178)	−0.0101
Surface area before solar use		
✓ Between 0,1 ha and 0,9 ha	0.951 (0.286) ***	0.238
✓ >1 ha	0.843 (0.317) ***	0.200
Irrigation network maintenance costs		
✓ Between 20,000 and 50,000 CFA	0.346 (0.284)	0.090
✓ >50,000 CFA	0.098 (0.299)	0.022
Total household income before solar use		
✓ Between 500,000 and 1 million CFA	−0.161 (0.224)	−0.036
✓ Between 1 million and 5 million CFA	−0.667 (0.319) **	−0.0113
✓ >5 million CFA	−0.945 (0.664)	−0.134
Number of working hours before using STI		
✓ 2 hours to 5 hours	1.682 (0.324) ***	0.439
✓ More than 5 hours	1.354 (0.307) ***	0.312

The results reveal that women's participation in decision-making in agricultural production positively and significantly increases the propensity of women horticulturists to adopt STIs. This is true regardless of the level of participation in decision-making, particularly when she is primarily responsible for decision-making, participates jointly in decision-making with her husband or another person inside or outside the household. Marginal effects show that participation in decision-making increases the probability of women horticulturists adopting STIs by 30%. Analysis of focus group data shows that women's participation in decision-making is often justified by their strong involvement in agricultural production activities or is limited to consultation, with men having the final say. During the discussions, one male head of household stated:

"It's the two of us who make the decisions (…) I'm the one who buys the seeds and products, but as far as managing our farm is concerned, it's my wife who takes care of that, as I'm busy with other things (…) she's the one who puts the most effort into the fields (…)."

Another male head of household points out: "I always discuss things with my wife and always seek a consensus. With my advanced age, I no longer have the strength to work in the fields, so it's my wife and children who take care of the work in my fields".

Several studies have established a close link between women's participation in decision-making and the adoption of STIs. A study conducted in Ghana found that increasing women's decision-making power in terms of production and income leads to the adoption of irrigation systems [5]. Some authors note that women's limited participation in household and community decision-making often results in lower adoption of irrigation technologies [7]-[9]. Despite the recognized importance of the involvement of women in decision-making for the adoption of irrigation technologies, it should be noted that the majority of women decision-makers are the wives of household heads. A study conducted in Ghana revealed that, on irrigated plots managed by men, women are still responsible for taking the crops to market to sell them when their husbands request it [5].

The study shows that the mode of land acquisition through deliberation by the town council has a positive and significant influence on the adoption of STI by women horticulturalists. Marginal effects show that obtaining a legal document attesting to land ownership increases the probability of women adopting STIs by 20%. Indeed, securing land tenure gives women control over resources and prevents them from being evicted from the land, thus creating the right conditions for investment to increase agricultural productivity. According to the World Bank [35], land ownership encourages investment and conditions equal opportunities - and in particular women's bargaining power, but also parents' ability to invest in their children's material and economic well-being and to overcome agricultural risks. Also, in the opinion of [21], securing women's land rights can have profound repercussions on household income, food security, investment in education and health, as well as on children's well-being, and reduce gender-based violence.

Other studies have shown that constraints on women's access to land are a major brake on the adoption of solar irrigation technologies [33] [34].

Concerning marital status, in a polygamous household, being the first wife positively and significantly increases the probability of adopting STI, unlike being the second or third wife, which is negatively favorable to the probability of adopting STI. This is because first wives generally have more decision-making power with their husbands than second and third wives. Also, the study reveals that being widowed is positively and significantly correlated with the propensity to adopt STIs. One of the explanatory reasons could be that widows are often the head of household, making decisions alone or with children, but also that their vulnerability may benefit from positive discrimination in the targeting criteria of social programs.

The study also showed that the adoption of STI by women horticulturalists increases positively and significantly with the size of the plot farmed. This is understandable, given that investment in STI is so costly that it is necessary to have a large enough area to expect a return on investment. In many cases, women horticulturalists have very small acreages, which is an obstacle to the adoption of STIs. Consequently, to facilitate access to STI for women horticulturists, it is necessary to allocate them sizeable plots of land. On the other hand, a study carried out in India as part of the national subsidy program for solar irrigation pumps showed that the probability of receiving solar pumps starts to decrease for farmers with more than 1.8 hectares, which seems to demonstrate positive discrimination against farmers with smaller landholdings during the selection process [20]. However, the study indicates that marginal farmers were more likely to receive subsidies from the solar irrigation pump, as this result is representative of farmers who were able to apply for the program [20].

The study also showed that as working time increases, female horticulturists are more likely to adopt STI. This is explained by the fact that the manual irrigation generally practiced by women horticulturists remains a significant workload, both tedious and time-consuming. Since STI is often accompanied by drip or sprinkler irrigation, this avoids the need for manual watering. According to [21], access to solar-powered irrigation pumps would reduce women's workload by reducing the time they spend irrigating or collecting water with buckets. During the focus groups, women horticulturists stressed that manual dewatering is the most strenuous and time-consuming task, and that solar power would relieve them of the burden and drudgery of manual dewatering and pond filling.

"Solar power has reduced my workload. Today I just switch on the machine to feed my ponds, before it was manual labor that tires the women a lot. If before I did 4 hours, with solar, you can do it in 1 hour."

On the other hand, the study showed that an increase in overall household income had a negative and significant impact on the adoption of STI by female horticulturalists. This may be because, although the high cost of irrigation, those who are high income can afford it, and therefore do not feel the need to turn to STIs.

This result also highlights the importance of raising awareness.

4. Conclusion

The objective of this study was to evaluate the adoption of solar irrigation technologies by women horticulturists and the main associated influencing factors in the Niayes region of Senegal. It was noted that information on STIs is an important and necessary element, but not sufficient to promote the effective adoption of STIs by women horticulturists in the Niayes zone. It is therefore crucial to consider other factors, such as access to financing and secure land tenure. To improve the adoption of STIs by women horticulturists, it is important to know that the determinants of adoption must be taken into consideration. These include the size of the production plot. Women who cultivate larger areas tend to feel a greater need to adopt solar irrigation technologies because of the difficulty of manual irrigation. There are also other factors, such as the marital status of the women. Because the respondents who were the first wife in a polygamous household were more inclined to adopt solar irrigation technologies. Widows were also more open to the prospect of adopting STIs, as they are often not constrained by household limitations in terms of initiatives. This study highlights the importance of combining awareness-raising with both land tenure security and financial support to promote the effective adoption of STIs.

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Conflicts of Interest

The authors declare no conflicts of interest.

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