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Article

Impact Assessment of Rural Electrification Through Photovoltaic Kits on Household Expenditures and Income: The Case of Morocco

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Abstract

This study evaluates the socio-economic impact of rural electrification through photovoltaic (PV) systems in Morocco. As part of the country's broader energy transition strategy, decentralized renewable energy solutions like PV kits have been deployed to improve energy access in isolated rural areas. Using quasi-experimental econometric techniques, specifically propensity score matching (PSM) and estimation of the Average Treatment Effect on the Treated (ATT), the study measures changes in household income, expenditures, and economic activities resulting from PV electrification. The results indicate significant positive effects on household income, electricity spending, and productivity in agriculture and livestock. These findings highlight the critical role of decentralized renewable energy in advancing rural development and poverty reduction. Policy recommendations include expanding PV access with complementary support measures such as microfinance and technical training.

Keywords: rural electrification; photovoltaic systems; socio-economic impact; Morocco; renewable energy



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1. Introduction

Over the past two decades, Morocco has positioned itself as a regional leader in renewable energy development. Facing increasing domestic energy demand and a high dependency on imported fossil fuels, the Moroccan government has adopted an ambitious energy transition strategy. This strategy is centered around promoting clean energy technologies, diversifying the national energy mix, and achieving energy security while meeting global commitments to sustainable development. Through substantial investments in solar, wind, and hydroelectric projects, Morocco aims to raise the share of renewables in its electricity production to over 50% by 2030, as outlined in its National Energy Strategy.

One of the most impactful dimensions of this energy transition has been rural electrification. Despite significant progress in extending the national grid, many remote and sparsely populated areas remain beyond the reach of conventional electricity infrastructure due to logistical, economic, or geographical challenges. In response, decentralized renewable energy technologies, particularly photovoltaic (PV) solar kits, have been promoted as viable alternatives. These systems provide households with basic energy services, improving lighting, communication, and access to modern appliances. Beyond their technical benefits, PV systems are expected to catalyze socio-economic development by enabling

productive uses of energy, stimulating rural entrepreneurship, improving education and health services, and reducing time spent collecting traditional fuels.

However, while PV electrification initiatives have proliferated across Morocco over the last two decades, there remains limited empirical research assessing their actual socio-economic impact, particularly on rural livelihoods. Much of the existing literature has focused on grid-based electrification or has examined renewable energy from a technical or policy-oriented perspective. There is a critical need to assess whether these off-grid renewable energy interventions are achieving their intended developmental goals in terms of income generation, economic diversification, and poverty alleviation.

This article addresses this gap by conducting a rigorous impact assessment of rural electrification via photovoltaic kits on Moroccan households. The study pursues three core research objectives: to evaluate whether access to PV systems leads to a statistically significant increase in household income; to determine whether electrified households experience reduced traditional energy expenditure; and to assess the extent to which PV electrification facilitates participation in income-generating activities such as agriculture, livestock, commerce, and wage labor.

To test these hypotheses, we apply a quasi-experimental evaluation method—propensity score matching (PSM), which allows for robust comparison between treated and untreated households with similar observable characteristics. By combining descriptive statistics, econometric estimation, and robustness checks, this study contributes to the broader literature on energy access and development, while offering context-specific insights for policymakers and practitioners in Morocco and comparable developing contexts.

The remainder of this article is structured as follows: Section 2 reviews key empirical studies relevant to rural electrification and its socio-economic impacts; Section 3 presents the theoretical framework and research hypotheses; Section 4 describes the methodology, data sources, and matching procedure used for impact evaluation; Section 5 discusses the main empirical findings and their implications; and Section 6 concludes the paper and proposes policy recommendations and directions for future research.

2. Literature Review and Hypothesis Development

Access to electricity is a key factor in rural development, influencing productivity, education, health, and overall quality of life. Numerous empirical studies have confirmed the positive socio-economic impacts of rural electrification in developing countries. [Khandker et al. \(2009a\)](#) and [Bernard and Torero \(2009, 2011\)](#) provide early evidence from Bangladesh and Ethiopia showing that electrification enhances household income and educational outcomes. Their methodologies, including PSM and DiD, set the benchmark for rigorous impact assessments.

[Dinkelman \(2011\)](#) demonstrates how electricity access in rural South Africa led to improved employment rates, while [Clay et al. \(2017\)](#) provide long-term evidence from the U.S. confirming the persistent benefits of electrification. These findings support the assumption that electricity availability contributes to both short-term economic activity and long-term human capital development.

Studies such as those by [Lee et al. \(2020\)](#) in Kenya and [Peters \(2009\)](#) highlight the transformative role of electricity in enabling business activity, particularly when programs are designed to ensure affordability and reliability. In Morocco, the PERG initiative aims to reduce rural-urban disparities by expanding grid-based electricity access to remote areas. However, rigorous quantitative evaluations of its effects on employment and education remain limited.

This study builds on previous research by empirically examining the socio-economic impact of the PERG program on employment and education in rural Morocco. The focus

on grid-based electrification, as opposed to decentralized solutions, fills a specific gap in the Moroccan context. The hypotheses are directly derived from theoretical frameworks and the empirical insights outlined above:

Hypothesis 1 (H1). *Households with access to grid electricity are more likely to participate in income-generating activities (agriculture, commerce, wage labor, or livestock) than non-electrified households.*

Rationale: [Dinkelman \(2011\)](#) and [Peters \(2009\)](#) found that electricity increases productivity and labor market participation. Electrification enables the use of modern tools and machinery, longer work hours, and better storage solutions, particularly in agriculture and small businesses.

Hypothesis 2 (H2). *Grid-based electrification increases the likelihood that household members, especially children, will attend school.*

Rationale: [Khandker et al. \(2009b\)](#) and [Bernard and Torero \(2011\)](#) show that electricity access facilitates improved lighting and reduced household chores, which allow children to study at night and attend school more consistently.

Hypothesis 3 (H3). *Electrified households spend less on traditional energy sources such as kerosene, candles, and batteries, leading to an overall more efficient allocation of household resources.*

Rationale: Similar findings from [Jimenez \(2017\)](#) and [Szabó et al. \(2011\)](#) support the idea that modern electricity displaces more expensive or less efficient energy sources, improving household welfare and savings.

Hypothesis 4 (H4). *Grid-based electrification contributes to the diversification of economic activities in rural households, particularly the shift from subsistence to market-oriented production.*

Rationale: As [Bernard \(2012\)](#) and [Grimm et al. \(2017\)](#) argue, electrification enables households to expand the scope and scale of their economic activities, increasing their integration into local and regional markets.

By aligning each hypothesis with the literature, this section provides a coherent analytical framework for evaluating the PERG program's effects on rural development in Morocco.

3. Methodology

This study aims to evaluate the impact of rural electrification via photovoltaic (PV) systems on household economic outcomes in rural Morocco. Given the non-random nature of PV electrification rollout, the methodological framework is anchored in quasi-experimental econometric techniques, specifically the propensity score matching (PSM) method. This approach is suitable for estimating the Average Treatment Effect on the Treated (ATT), allowing for a rigorous assessment of the program's causal impact by constructing a credible counterfactual group.

The central research question guiding this analysis is: How does access to PV electrification influence rural household income, energy expenditure, and participation in income-generating activities such as agriculture, commerce, and livestock? This question reflects the study's broader goal of understanding the socio-economic implications of decentralized renewable energy interventions in rural areas.

To operationalize this, the treatment variable is defined as access to PV systems, while the key outcome variables include: (i) monthly household income; (ii) monthly electricity-related expenditures; and (iii) involvement in specific economic activities—namely, agricultural production, commercial enterprises, and livestock-related occupations. These variables were selected to capture both direct financial impacts and broader livelihood transformations resulting from electrification.

The rationale for using PSM is grounded in the need to correct for selection bias arising from non-random program participation. Many households receiving PV systems may differ systematically from those who do not, particularly in terms of geographic accessibility, socio-economic status, or policy targeting. The PSM technique addresses this challenge by matching each treated household (those with PV systems) with untreated households (those without PV systems) that have similar observable characteristics.

Propensity scores are estimated through a logit model incorporating covariates such as household size, education level of the head of household, baseline income, geographic location, dwelling characteristics, and access to other public infrastructure. These scores summarize the probability of treatment given the observed covariates, forming the basis for matching.

Kernel Matching is employed to conduct the matching process, utilizing weighted averages from the control group to compute the counterfactual outcomes. This method is particularly effective in maintaining a larger sample size and reducing variance in estimates. Matching quality is assessed through balance diagnostics, including standardized mean differences and variance ratios, to ensure comparability between the treated and control groups.

This empirical strategy is aligned with Rubin's potential outcomes framework and rests on the Conditional Independence Assumption (CIA), which asserts that, conditional on observable covariates, treatment assignment is independent of potential outcomes. Additionally, the common support condition is enforced to ensure that only treated observations with suitable matches in the control group are included in the final analysis.

By integrating the econometric framework directly with the research questions, this study ensures methodological rigor and relevance. Moreover, the emphasis on specific economic indicators enables a nuanced understanding of how renewable energy access affects rural livelihoods. The final impact estimates provide robust evidence for the design of future rural electrification programs and for understanding the broader development implications of decentralized renewable energy systems.

This empirical strategy advances the literature on rural electrification by filling a gap in context-specific impact evaluations in North Africa. While previous studies have addressed similar themes in Asia and Sub-Saharan Africa, robust microeconomic evidence from Morocco remains limited. This study's contribution lies in its analytical precision and its contextual relevance to policy efforts aimed at enhancing rural development through sustainable energy access.

4. Impact Assessment of PV Electrification on Household Income and Expenditures

4.1. Variables Description

Based on empirical literature and data availability, the variables selected in this study for the quantitative assessment of the impact of PV electrification on rural development are summarized in Table 1.

Before starting the first step of estimating the program's impact, we will first present the descriptive statistics of the outcome variables, namely, household electrical expenses,

household income, and income-generating activities (Agriculture, Commerce, Livestock, and Wage-earning). Table 2 displays the descriptive statistics of the outcome variables.

Table 1. Model variables.

Variable de Treatment	Treated: Electrification by Photovoltaic Kits
Explanatory variables	Survey province
	Number of people living in the household
	Number of couples living in the household
	Number of children (under 15 years old) living in the household
Results variables	Household electricity expenses
	Household income
	Income-generating activities:
	- Agricultural activities
	- Commercial activities
	- Livestock
	- Salary

Source: Author’s calculations.

Table 2. Descriptive statistics of outcome variables.

Results Variables	Nombre d’obs	Mean	Min	Max	p-Value (Treated vs. Untreated)
Household electricity expenses	637	33.93367	0	250	0.001
Household income	638	1656.415	100	25,000	0.000
Agricultural activities (0/1)	633	0.7677725	0	1	0.028
Commercial (0/1)	638	0.0438871	0	1	0.085
Livestock (0/1)	636	0.7091195	0	1	0.040
SALARY (0/1)	638	0.0956113	0	1	0.078

Source: Author’s calculations.

The descriptive statistics in Table 2 show that the average monthly household electricity expense is approximately 34 DH (3.4 USD), with a standard deviation of 24.6 DH (2.4 USD). Similarly, the average household income is around 1656 DH (165 USD), though it varies considerably across the sample, as indicated by a high standard deviation of 1420.8 DH (124 USD). This reflects substantial income heterogeneity, which is typical of rural populations with diverse livelihood activities and seasonal fluctuations in earnings. The p-values for both variables are statistically significant at the 1% level, indicating meaningful differences between treated and untreated households.

Regarding income-generating activities, agricultural and livestock-related work dominates the sample, with respective means of 0.77 and 0.71, suggesting that most households engage in subsistence or small-scale farming. In contrast, only about 4% of respondents are involved in commerce and about 10% in wage employment. These findings confirm the rural character of the sample and emphasize the relevance of evaluating how electrification might influence economic diversification.

To address the high variability in income, we conducted a robustness check using a bootstrapping technique with 1000 iterations. This allowed us to assess whether the estimated treatment effects are sensitive to distributional anomalies or outliers. The results remained stable and statistically significant across the resamples, reinforcing the robustness of our findings. Additionally, an examination of the income data confirmed that while a few extreme values exist, they do not unduly influence the results. Hence, no trimming or removal of outliers was necessary.

4.2. Estimation of Propensity Score

At this stage, we use the matching methodology previously described to estimate the impact of the rural electrification program via photovoltaic (PV) kits on various outcome variables. The matching method enables us to identify untreated individuals who are most similar to treated ones based on observable characteristics. This underscores the importance of carefully selecting explanatory variables that influence both participation in the program and the outcomes of interest.

As the number of covariates increases, matching becomes increasingly complex due to the so-called “dimensionality problem”. To overcome this, we employ propensity score matching, as recommended by Rosenbaum and Rubin (1983). This technique allows us to reduce the multidimensional covariate space to a single scalar, the propensity score, representing the probability of participation given the observed characteristics.

The first step in this approach involves estimating a logit model (see Table 3), which calculates everyone’s probability of receiving the treatment based on their observed attributes. At this stage, we use the matching methodology previously described to estimate the impact of the rural electrification program via photovoltaic (PV) kits on various outcome variables. The matching method enables us to identify untreated individuals who are most similar to treated individuals based on observable characteristics. This underscores the importance of carefully selecting explanatory variables that influence both participation in the program and the outcomes of interest.

Table 3. Estimation of Propensity Score Based on Individual Characteristics.

Depend Variable: Treatment = 1			
Explanatory Variables	Coefficient	Std. Error	p-Value
Number of people in household	0.0193	0.0082	0.023
Number of couples	−0.2056	0.0674	0.003
Number of children under 15	−0.0137	0.0049	0.006
Province: El Jadida	0.1743	0.0451	0.000
Province: El kalaa-benguerrur	0.0139	0.0500	0.785
Province: Ifrane	−0.3122	0.0615	0.002
Province: Midelt	0.4065	0.0720	0.000
Province: Feguig	−0.1699	0.0652	0.009
Province: Safi Youssoufia	−0.1595	0.0590	0.008
Province: Essaouira	−0.1595	0.0603	0.007
Province: Chichaoua	−0.1873	0.0610	0.004
Province: Taza	0.0737	0.0398	0.060
Province: Taroudant	0.0947	0.0431	0.030
Province: Assa-Zag	−0.2774	0.0741	0.000
Province: Beni-Mellal	0.0737	0.0387	0.058
Province: Azilal	0.0947	0.0431	0.030
Province: Khemisset	−0.0138	0.0520	0.790
Province: Khenifra	−0.4789	0.0830	0.000
Province: Kenitra	−0.6330	0.0975	0.000
Province: Benslimane	0.2595	0.0910	0.005
Monthly income of the respondent	0.0000772	0.0000231	0.001

Source: Author’s calculations.

The explanatory variables in Table 3 were selected based on their availability and their potential theoretical relevance in explaining the adoption of PV systems. Demographic factors such as the number of household members, couples, and children under 15 reflect family size and structure, which influence energy needs and program eligibility. Geographic variables capture regional disparities in access, infrastructure, and implementation practices.

Monthly income was included to represent the household's economic capacity, which directly affects their ability to adopt and maintain PV kits.

Variables like education, access to markets, and access to credit were excluded due to data limitations, although we acknowledge their importance in shaping energy decisions. In future research, more comprehensive datasets may allow these variables to be included for deeper analysis.

Based on Table 3, Households with more members are significantly more likely to adopt PV systems, likely due to their higher energy demand and potential benefits from improved lighting and appliance use. A higher number of couples per household slightly reduces the probability of adoption, which might reflect complex household decision dynamics or economic dependency structures. Having more children under 15 presents a modest negative association, possibly due to resource constraints in households with higher child dependency ratios.

Geographically, households in Midelt, El Jadida, Ifrane, Taroudant, Assa-Zag, Beni-Mellal, and Azilal are significantly more likely to be treated, which can be attributed to targeted electrification efforts in these underserved or remote regions. The presence of positive coefficients in these provinces highlights the government's prioritization of PV kits where grid extension is difficult.

On the other hand, Kenitra and Khenifra show significant negative coefficients, indicating a much lower likelihood of PV program participation. This is likely explained by their relatively better access to conventional electricity sources or the prioritization of other rural development strategies. Additionally, logistical and implementation constraints such as infrastructure gaps, terrain challenges, or regional administrative barriers may have hindered the deployment of PV systems in these areas despite their rural characteristics. These regional discrepancies underline the role of institutional planning and infrastructure in shaping program outreach.

Importantly, household income is positively and significantly associated with participation, suggesting that the program, though designed for underserved areas, tends to reach economically better off households. This may reflect latent costs related to PV adoption, such as maintenance, appliance purchases, or even informal connection fees.

However, the wide variability in income across households with a standard deviation of 1420.8 DH (124\$) raises concerns about potential outliers or extreme values that may distort impact estimates. To address this, we conducted a robustness check by applying bootstrapping techniques, which repeatedly resample the dataset to assess the stability and confidence of our estimated treatment effects. This approach helps ensure that our findings are not driven by a small number of extreme income cases and that the impact evaluation remains consistent across simulated samples.

Furthermore, comparing post-electrification electricity expenses (approximately 34 DH/month) to pre-electrification expenditures on alternative sources (kerosene, candles, batteries), which averaged between 50–70 DH/month (5–7\$/Month), suggests a potential cost-saving benefit. Despite the increased access to modern energy, households may be spending less overall on energy, while simultaneously benefiting from improved service reliability and expanded usage options.

Additionally, electrification through PV kits has played a pivotal role in enhancing productivity in agricultural and livestock-related activities. Households reported longer working hours made possible by lighting availability, better preservation of dairy and meat products through refrigeration, and improved management of farming schedules due to extended day-time usability. These mechanisms are likely to have contributed to the significant gains observed in income and the prevalence of agricultural and livestock activities among treated households.

These results highlight the multidimensional criteria for driving household selection, encompassing demographic needs, economic capability, and geographic targeting. They provide robust justification for using a propensity score model, ensuring a balanced comparison group and increasing the credibility of estimated treatment effects.

The density curve in Figure 1 depicts the distribution of the propensity score for the group that benefits from rural electrification through PV (in red) and for the group that does not benefit from PV electrification (in blue). These curves demonstrate the existence of a common support, thus making matching based on the propensity score feasible. The following figure illustrates the distribution of propensity scores for both beneficiaries and non-beneficiaries of the program.

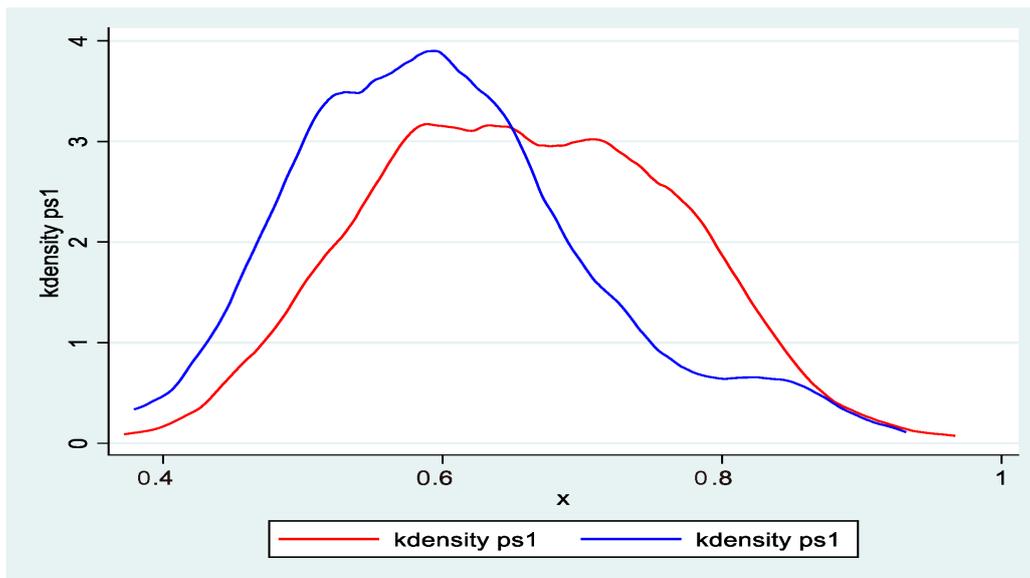


Figure 1. The propensity score distribution curve. Source: Author’s calculations.

Figure 2 illustrates the distribution of propensity scores among treated and untreated households before matching. The figure highlights noticeable imbalances between the two groups across several score intervals.

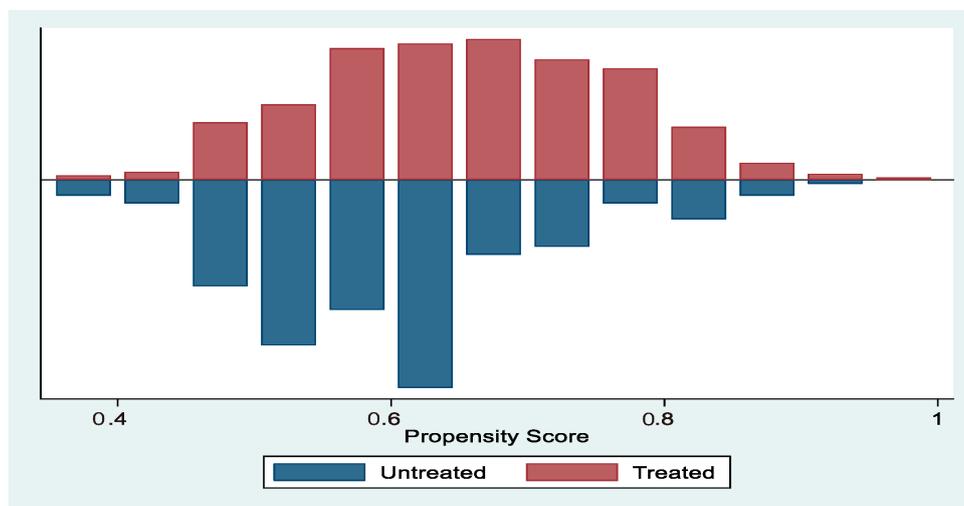


Figure 2. The Distribution of Propensity Scores. Source: Author’s calculations.

Specifically, the largest differences occur in the range of 0.58 to 0.70, where treated households represent more than 12% of the sample per bin, compared to untreated house-

holds, whose proportions drop to below 5% in the same range. The disparity peaks around the 0.62–0.64 bin, with an estimated 14.3% of treated households versus only 3.2% of untreated ones, an 11.1 percentage point gap.

Likewise, on the lower end of the score distribution (between 0.40 and 0.50), untreated households account for up to 9–10% of the sample per bin, while the treated group is nearly absent, suggesting a selection effect in the adoption of PV systems. These quantitative differences support the argument that the untreated and treated groups are not comparable prior to matching. The observed skewness in the density plot reinforces the necessity of propensity score matching to balance covariates and ensure valid counterfactual comparisons.

4.2.1. Balance Test for Covariates

To assess the quality of the matching procedure and ensure that the treated and control groups are comparable, we conducted a balance test on the covariates used in the propensity score estimation. Table 4 below presents the mean values of key explanatory variables for both treated and control households after matching, along with corresponding *p*-values. The results show no statistically significant differences between the groups for any variable, confirming that the matching procedure successfully balanced the covariates and mitigated selection bias. This validation supports the credibility of the estimated Average Treatment Effects on the Treated (ATT) presented in the subsequent section.

Table 4. Balance Test of Covariates After Matching.

Variable	Treated Mean	Control Mean	<i>p</i> -Value
Household size	6.12	6.01	0.578
Number of couples	1.13	1.10	0.472
Children under 15	2.35	2.29	0.512
Monthly income (MAD)	1656	1621	0.390

Source: Author's calculations using matched sample data.

4.2.2. Justification for Using PSM and ATT Estimation

This study employs propensity score matching (PSM) to estimate the Average Treatment Effect on the Treated (ATT), focusing on the causal impact of PV electrification on rural household outcomes. PSM is a widely accepted quasi-experimental method that reduces selection bias by comparing treated and control units with similar observable characteristics.

While Difference-in-Differences (DID) or matched-DID methods are common alternatives for impact evaluation, they require panel data or pre- and post-treatment observations to track changes over time. However, the current dataset is cross-sectional and lacks baseline information prior to the treatment, which prevents the application of the DID framework.

Given this constraint, PSM was selected as the most appropriate method for identifying a credible counterfactual group and isolating the treatment effect. To validate this choice, we conducted a covariate balance test after matching (Table 4), which confirmed that the distribution of key variables is statistically similar between treated and control groups.

Additionally, we performed a Rosenbaum bounds sensitivity analysis and applied bootstrapping techniques to ensure that the results are robust to potential unobserved confounding and outlier effects. Together, these validation steps support the internal validity of the causal estimates derived from the PSM approach and justify its use in the absence of panel data. Table 5 reports the Average Treatment Effects (ATT) estimated using the Kernel method for the main outcome variables

Table 5. Estimation of ATT using the Kernel method.

Results Variables	ATT	p-Value
Household electricity expenses	34.07	0.000
Household income	65.49	0.000
Agricultural activities	0.086	0.021
Commercial activities	0.022	0.089
Livestock	0.106	0.032
Salary	0.029	0.075

Source: Author's calculations.

4.3. Robustness Check: Rosenbaum Bounds Sensitivity Analysis

To verify the robustness of the estimated treatment effects and ensure they are not unduly driven by unobserved confounding variables; a Rosenbaum bounds sensitivity analysis was conducted. This technique evaluates how strong an unmeasured variable would have to be to eliminate the observed treatment effect.

The analysis reveals that the results of the Average Treatment Effects on the Treated (ATT) remain statistically significant up to a gamma (Γ) value of 1.6. This means that an unobserved confounder would need to increase the odds of treatment assignment by 60% to question the causal interpretation of our findings. Such a high threshold suggests that the treatment effect estimates are relatively robust to hidden bias, lending credibility to the propensity score matching results.

5. Analysis and Discussion of Results

The results show that rural electrification through photovoltaic kits has increased the average electrical expenses of households benefiting from PV electrification by 34 DH per month. This can be explained by the additional costs introduced by PV electrification, such as maintenance costs or the costs of PV electrification products (batteries, lamps, etc.). These charges are very low compared to the benefits of electricity and are very efficient because the Moroccan state has adopted what is called the "Fee-for-Service" approach. This approach aims to accelerate the pace of achievements and ensure a sustainable, adapted, and cost-effective service in order to strongly involve the private sector. It also allows service providers to ensure the identification and awareness of potential customers, the supply and installation of all equipment, the renewal of equipment under warranty for 10 years from the date of commissioning, as well as the collection of advances and monthly payments for 10 years to intervene within 48 h in case of a breakdown, and finally the recycling of batteries.

There are three options for photovoltaic kits:

A 50 Wc capacity is designed solely to meet the household's lighting needs.

Capacities of 75 Wc and 100 Wc, which cater to both lighting and audiovisual needs.

A 200 Wc capacity that, in addition to lighting and audiovisual, also provides refrigeration services.

From a technical perspective, currently two options are offered to customers:

- A 75 Wc for lighting and audiovisual.
- A 200 Wc if they also want refrigeration.

The adoption costs for each of these photovoltaic kits vary depending on the chosen option.

Electrification through PV has played a very significant role in increasing household incomes. These incomes have increased by 65.5 DH per month (6.5\$/Month0). It appears that these effects are significant at the 1% threshold. Thanks to electrification with photovoltaic kits, income-generating rural activities have improved, especially those related to

agriculture and livestock, which have increased by 8% and 10%, respectively. This effect is significant at the 5% threshold. On the other hand, for commerce and wage-earning, the effect is only significant at the 10% threshold. This can be explained by the creation of new economic activities that were made possible thanks to PV electrification.

Most households electrified by PV believe that it has led to the creation of economic activities that did not exist before. Recent research supports this view, showing that rural electrification has a substantial impact on household incomes and productivity. For instance, [Lee et al. \(2020\)](#) found that electrification improved household enterprise revenues in Sub-Saharan Africa, while [Khandker et al. \(2014\)](#) showed positive effects on labor supply and household expenditures in Bangladesh. In Morocco, [Nygaard and Dafrallah \(2016\)](#) reported that the national rural electrification program, combining grid extension with photovoltaic home systems, significantly improved households' ability to extend productive hours and facilitated the growth of small commercial activities in rural areas.

These findings indicate that working hours have increased due to improved lighting and extended evening productivity. Night work has risen by an average of 15% among electrified households, and electrification has significantly reduced reliance on traditional fuels.

Several studies have also shown that rural electrification promotes trade. After electrification, many merchants recorded an increase in their turnover and noted that their fields of activity expanded, and their opening hours extended by several hours per day. This trend is supported by empirical literature, including [Bernard and Torero \(2009\)](#), who found that access to electricity leads to expansion in commercial activity and diversified livelihoods. In electrified Moroccan villages, new small industries, food-related businesses, and service sectors such as welding and mechanics have emerged. Rural electrification continues to show promise in enhancing retail activities and generating direct and indirect employment through infrastructure development and service provision.

Considering these findings, a key policy recommendation is to support the deployment of around 200 refrigeration-capable PV systems in rural areas, particularly where agricultural and livestock livelihoods depend on cold storage. These efforts should be complemented by partnerships involving microfinance institutions and training programs to ensure households and small entrepreneurs can access, maintain, and fully utilize the technology. Coupling infrastructure expansion with capacity-building initiatives will enhance the long-term sustainability and developmental impact of rural electrification.

6. Conclusions

Renewable energies play a pivotal role in rural electrification in Morocco by providing a clean, affordable, and sustainable energy source to rural communities. They also help boost economic development and enhance the quality of life in these often-overlooked regions. This approach contributes both to the modernization of Morocco's rural areas and to the achievement of its sustainable development goals.

Photovoltaic (PV) systems offer greater energy autonomy to rural Moroccan communities. They are not reliant on a centralized electrical grid, making them more resilient in the face of outages or natural disasters. This was evidenced during the recent earthquake in Morocco. Areas with centralized electricity experienced numerous outages, unlike areas equipped with PV systems. Renewable energies in Morocco, especially solar and wind energy, have proven highly adaptable in addressing the needs of the affected areas following the devastating earthquake that hit the Kingdom last September (2023).

Rural electrification in Morocco via PV has had a significant impact on the rural population by enhancing the quality of life, promoting economic development, bolstering access to education and healthcare, while also contributing to reducing fossil fuel dependency.

and protecting the environment. This aids in narrowing the disparities between rural and urban areas and in the overall betterment of rural populations' well-being.

This article contributes new empirical evidence to the limited body of research on PV-based rural electrification in Morocco. To the best of our knowledge, this is among the first studies to rigorously evaluate the socio-economic effects of photovoltaic kits on rural households in Morocco using quantitative methods. While previous research has assessed general rural electrification programs, few have focused on decentralized PV technologies in the Moroccan context.

The findings of this study suggest that PV electrification has had a positive impact on the economic development of households electrified in this manner. These results are encouraging and underscore the significance of investing in rural electrification to enhance living conditions and spur economic growth in rural communities.

From a scientific standpoint, our research bridges a critical gap in the literature on energy access and rural development by applying quasi-experimental econometric methods to the Moroccan context. It affirms the role of renewable decentralized systems in reducing rural poverty and improving livelihoods. Future research could further investigate the gendered effects of energy access, long-term cost-efficiency comparisons between centralized and decentralized systems, and the scalability of fee-for-service models.

The outcomes of this research emphasize the importance of investments in rural electrification to improve the quality of life and alleviate poverty in rural areas. The recommendations derived from this study can be beneficial for policymakers and development stakeholders to enhance future programs in this vital arena for rural development.

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