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Fueling a Sustainable Future:

The Impact of Financial Inclusion on Green Energy Transition Among Micro- and Small-Sized Firms in Egypt

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Fuelling a sustainable future: the impact of financial inclusion on green energy transition among micro- and small-sized firms in Egypt

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Abstract

This study investigates the role of financial inclusion in driving clean energy adoption among 1,002 Egyptian micro and small enterprises (MSEs) using quasi-experimental methods. Results show that financial inclusion significantly boosts MSEs' intention to use clean energy technologies (8–12% increase) and willingness to pay (WTP; 9–11% increase). Causal mediation analysis reveals that financial inclusion enhances adoption and WTP primarily through direct effects, with behavioural intention and awareness as mediators. The total effect on adoption intention reaches 12%, with behavioural intention factors, notably perceived usefulness and ease of use, mediating approximately 2%. The total effect on WTP is approximately 9%, with indirect effects mediated through behavioural intention ranging from 1% to 3%. Awareness of renewable and clean energy further amplifies these effects, contributing 9–12% to total effects. Theoretically, the findings elucidate how financial resources shape psychological and informational drivers of energy adoption, extending theoretical models of technology acceptance. The results advocate for integrated strategies that combine financial access, behavioural interventions, awareness campaigns, and targeted incentives such as subsidies and low-interest loans to overcome behavioural and informational barriers, and foster a sustainable energy transition among MSEs.

Keywords: Financial inclusion, clean energy, willingness to pay, micro and small enterprises, Egypt

JEL Classification: K32, O13, Q42, P18, P28, P48

1. Introduction

Transitioning from fossil fuels to green energy is a global imperative to minimize environmental degradation, foster sustainable growth, mitigate climate risks, and meet the United Nations' Sustainable Development Goals (Dominković et al., 2018; IPCC, 2022). Developing countries—where most future population growth, urbanization, and economic expansion will occur—are poised to drive the rising global energy demand, significantly shaping both the energy transition and international efforts to curb greenhouse gas emissions (Chen et al., 2022). In response, international frameworks and initiatives, such as the Paris Agreement and Kyoto Protocol, have prompted developing countries to accelerate renewable energy adoption, implement carbon pricing mechanisms, and align economic growth with climate resilience strategies (Van de Putte et al., 2020).

Digital financial inclusion has emerged as a key enabler of clean energy adoption in developing countries, empowering underserved populations and enabling small businesses to access affordable, sustainable energy solutions (Allen et al., 2016; Kuada, 2022). Inclusive financial systems reduce financing barriers and foster low-carbon innovation through tailored instruments like green microfinance and pay-as-you-go equipment leasing, enabling businesses to adopt energy-efficient technologies without burdensome capital requirement and prohibitive upfront costs (Govindan et al., 2024; Hu et al., 2023). Fintech innovations are revolutionizing this space, with mobile banking platforms and decentralized financing models dramatically accelerating clean energy access (Ahmad et al., 2025). Complementary risk-mitigation tools, including inclusive insurance products, address key adoption challenges related to income instability and technology reliability (Yap et al., 2024). Importantly, these digital solutions are displacing precarious informal credit systems while promoting secure savings and efficient financial management (Cama et al., 2024). Together, these mechanisms create a powerful virtuous cycle by strengthening the financial capabilities of small businesses - the engines of local economic growth, while simultaneously driving systemic decarbonization and building climate-resilient communities. This synergy between inclusive finance and clean energy access represents a critical pathway for achieving both equitable development and environmental sustainability.

However, most research on the finance–energy nexus has focused on the Global North, overlooking the distinct socioeconomic and institutional realities of developing countries. This gap is particularly stark in climate-vulnerable regions such as the Middle East and North Africa (MENA), where energy transitions lag amid rising environmental pressures across the Water-Energy-Food-Ecosystem nexus (MedECC, 2024). Despite their growing role in global economic growth, many MENA countries remain locked into fossil fuel-dependent development models, exacerbating environmental degradation (Barua & Aziz, 2022).

A further limitation lies in the prevailing focus on large firms, sidelining micro- and small-sized enterprises (MSEs), despite their significant economic and environmental footprint (Aboelmaged & Hashem, 2019; Sirin et al., 2022). MSEs are critical to climate goals and energy justice, particularly in developing economies where they dominate employment and production (Gennari, 2023; Thomas et al., 2024). Yet, they face structural financial constraints—narrow margins, lack of collateral, and limited credit access that hinder clean energy adoption (Alter & Elekdag, 2020; Hu et al., 2023). Neglecting MSEs excludes essential insights into how grassroots financial mechanisms can drive equitable transitions, leaving a large segment of businesses without the resources to participate in the green economy (Gennari, 2023).

Current research is also constrained by its predominantly macroeconomic orientation, emphasizing aggregate indicators like GDP, employment, and investment (Thomas et al., 2024). While valuable, these studies fail to explain why individual firms adopt or resist clean energy solutions. In particular, they overlook micro-level drivers such as behavioural intentions, cognitive awareness, and perceived benefits, which vary widely by firm size, sector, and governance (Andrews & Johnson, 2016; Apfel

& Herbes, 2021). Without addressing this heterogeneity, policymakers lack the insights needed for targeted, effective interventions.

This study addresses these gaps by examining how financial inclusion influences MSEs' transition to green energy through micro-level behavioural mediators. Drawing on primary data from 1,002 Egyptian MSEs in the 2023 Renewable Energy Survey by the Economic Research Forum (OAMDI, 2024a), we explore: (i) the impact of financial inclusion on MSEs' clean energy adoption intentions and willingness to pay, and (ii) the mediating roles of behavioural intentions and technology awareness. Our empirical approach combines causal mediation analysis with inverse probability weighting and matching estimators, supplemented by robustness checks using partial least squares structural equation modelling. Financial inclusion is measured across access, usage, and quality, while awareness is captured through three firm-level indicators. The study offers actionable insights for designing inclusive, context-specific energy policies that support equitable and effective green transitions.

We proceed by outlining the contextual background relevant to our analysis in Section 2. In Section 3, we provide a description of our data and research methods. Section 4 presents and discusses the empirical results. Section 5 concludes with key insights and policy recommendations.

2. Green transition and financial inclusion for Egyptian MSEs

Egypt exemplifies the challenges many developing countries face in achieving green energy transition goals (Salman & Ismael, 2023). Recent global shocks, including the COVID-19 pandemic and the war in Ukraine have intensified longstanding socioeconomic and environmental vulnerabilities, reinforcing the urgency of Egypt's transition toward a more resilient and sustainable energy system (Abu Hatab & Krautscheid, 2025; UNDP, 2024).

In recent years, Egypt has made substantial strides in integrating renewable energy and sustainability into its national development agenda. The 2014 Constitution¹ mandates environmental protection and low-carbon development, while the Sustainable Development Strategy "Egypt Vision 2030" positions green energy as a cornerstone of inclusive, climate-resilient growth (Abu Hatab & Krautscheid, 2025). This strategy emphasizes scaling up renewable energy projects, improving energy efficiency, and reducing fossil fuel reliance.

To operationalize this vision, Egypt has launched various initiatives to promote green industrial development. The Ministry of Trade and Industry (MoTI) introduced the "Environmentally Friendly Industrial Clusters" initiative in 2016 and the "Green Economy Development Project" in 2020, supporting businesses in clean production, recycling, and green exports (Trinomics, 2020). The establishment of the Supreme Council for Energy and the empowerment of the New and Renewable Energy Authority (NREA) further enabled private sector participation through policies such as Feed-in Tariffs (EBRD, 2016). In partnership with the EBRD, Egypt has also secured green financing to expand solar energy and support firms adopting climate-smart technologies.

Despite these efforts, implementation gaps persist. Challenges include limited financing, bureaucratic inefficiencies, weak institutional coordination, and infrastructure constraints (Hegazy et al., 2017; Abu Hatab & Krautscheid, 2025). One of the most significant barriers is low financial inclusion among micro and small enterprises (MSEs), which account for 98% of businesses and 73% of non-public employment (Assaad & Krafft, 2024; CIB, 2020). These firms are critical not only for economic output but also for social development, particularly in underserved communities (Khairy, 2019).

Greater financial inclusion could empower MSEs to invest in green technologies, enhance energy efficiency, and formalize operations, thereby boosting resilience and competitiveness while supporting climate goals (Abouaiana & Battisti, 2025; Sabry, 2024). Recognizing this, the

¹ The Egyptian constitution <https://sschr.gov.eg/en/the-egyptian-constitution/>

government has introduced reforms to expand MSEs’ access to finance. Led by the Central Bank of Egypt, initiatives include mandated bank lending quotas (25% of portfolios), digital financial services expansion, and supportive regulatory frameworks such as the 2018 leasing and factoring law (CBE, 2025). These efforts have raised financial access significantly, with account penetration rising from 10% in 2011 to 33% in 2017 (ElDeeb et al., 2021).

Nonetheless, empirical evidence on how financial inclusion facilitates green energy adoption among MSEs remains limited. While existing studies highlight the role of finance in improving credit access and business resilience (Bhattacharyya et al., 2023; Brixiová et al., 2020), few examine its environmental implications. Moreover, research rarely incorporates behavioural dimensions to assess the mechanisms through which financial inclusion drives clean energy uptake (Le et al., 2025).

Given Egypt’s rapidly evolving digital finance landscape and the pressing need to align economic development with environmental sustainability, this study seeks to fill these gaps. It explores how financial inclusion can accelerate the green transition among MSEs, contributing to broader national goals of poverty reduction, job creation, and climate resilience.

3. Conceptual framework

The analysis of this study is grounded in the theoretical foundations of the Technology Acceptance Model (TAM) (Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). As illustrated in Figure 1, these models provided a robust framework for variables’ identification to understand how financial inclusion drives the adoption of clean energy technologies among MSEs, while also capturing the behavioural factors that mediate this relationship.

TAM emphasizes two core constructs influencing technology adoption: perceived usefulness and perceived ease of use. Perceived usefulness reflects the degree to which MSEs believe clean energy technologies can improve operational efficiency, lower costs, or support environmental goals (Zumofen et al., 2025). Perceived ease of use indicates how straightforward and effort-free MSEs find the adoption process (Wong et al., 2024). Specifically, MSEs’ usage of financial tools, such as payment systems, is expected to streamline the acquisition and implementation of green technologies, thereby increasing perceived ease of use. Indeed, perceived ease of use is contingent on prior “access” to enabling technologies and financial services. For instance, access to credit or savings accounts reduces cost barriers, simplifying the adoption process and enhancing perceived usefulness by alleviating upfront investment burdens (Dou et al., 2023). Furthermore, the “quality” of financial inclusion, *i.e.*, the reliability and suitability of financial products, further strengthens MSEs’ confidence by providing tailored solutions for transitioning to clean energy (Gupta & Kumar, 2024).

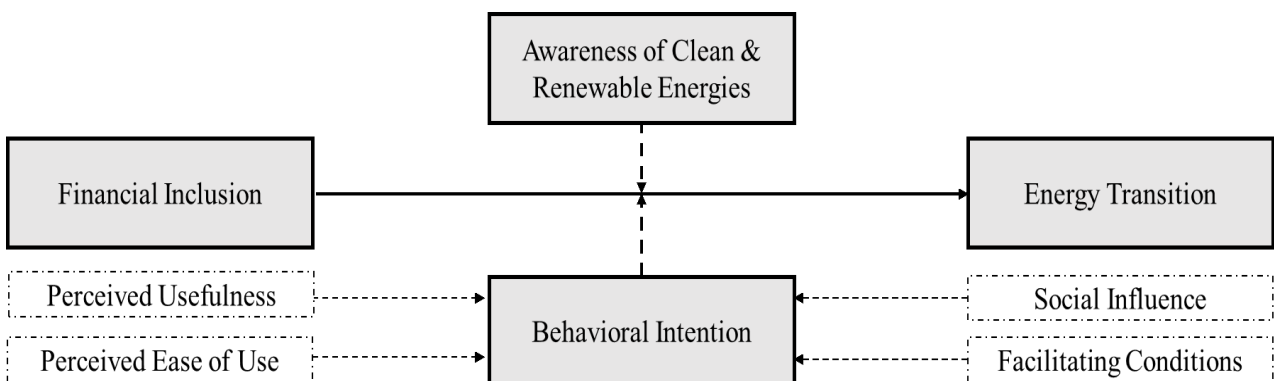


Figure 1: Conceptual links between financial inclusion, behavioural intention, awareness and energy transition

Source: Authors’ own construct

UTAUT extends TAM by incorporating performance expectancy (similar to perceived usefulness), effort expectancy (akin to perceived ease of use), social influence, and facilitating conditions. These additional constructs are particularly relevant in the Egyptian context, where social norms and resource availability significantly influence technology adoption. Social influence captures the motivation firms derive from stakeholders such as peers, regulators, or customers to adopt clean energy technologies(He et al., 2020). Social influence can explain how Egyptian MSEs may respond to industry trends, government incentives, or societal expectations to embrace green practices, especially when financial inclusion empowers them to act on these pressures. Facilitating conditions refer to the resources, infrastructure, and support systems that enable adoption (Dwivedi et al., 2022). In this context, financial inclusion acts as a key facilitating condition by equipping firms with the necessary financial resources to invest in clean energy systems(Koloseni & Mandari, 2024). For example, affordable credit or flexible payment plans can close the gap between intention and action. Moreover, high-quality financial services, such as transparent loan terms or accessible banking platforms, boost firms' confidence in managing the financial aspects of adopting sustainable technologies.

At the heart of TAM and UTAUT lies the mediating role of behavioural intention and awareness, which connect financial inclusion to clean energy adoption(Yawised et al., 2025). Behavioural intention represents a MSE's readiness to adopt clean energy technologies, influenced by perceived usefulness, ease of use, social influence, and facilitating conditions. Financial inclusion enhances this intention by alleviating financial constraints and reinforcing firms' belief in the practicality of green investments(Krah et al., 2024). Awareness, the second mediator, is crucial in Egypt, where MSEs often lack knowledge about renewable and clean energy options. Greater awareness fosters positive perceptions of clean energy's usefulness and ease of use, further strengthening behavioural intention(Yang et al., 2018).

4. Data and Method

We leverage cross-sectional data² from the 2023 Renewable Energy Survey in Egypt, covering 1,002 firms, to address gaps identified in the literature(OAMDI, 2024a). The survey targeted Egyptian businesses with fewer than 100 employees that were established before 2023, excluding those founded in that year. For a probability sample, a comprehensive sampling frame listing all eligible businesses with their contact details is ideal. However, since no such list existed in Egypt, data were sourced from the Egypt Yellow Pages, which included approximately 288,712 businesses across diverse sectors. Using this directory, a sampling frame was created with business names, addresses, and phone numbers. Although the frame's coverage could not be verified due to the lack of official statistics, its size and diversity enabled robust multi-sectoral analysis(OAMDI, 2024b).

From this database, a systematic random sample of 20,623 businesses was drawn, implicitly stratified by province and sector to ensure wide representation. The distribution of businesses across provinces and regions, detailed in Table A1 in the appendix, shows a higher concentration in Cairo, Alexandria, Giza, and Kaliobeya, while other provinces were categorized into three regions: Lower Egypt (Beheira, Damietta, Kafr El Sheikh, El Daqahleya, Gharbeya, Monofeya, and Sharkeya), Upper Egypt (Assyout, Beni Suef, Luxor, Minya, Qena, Sohag, Aswan, and Fayoum), and Other Areas (Matrouh, Port Said, Suez, Taba, and locations in the Red Sea, Sinai, and North Coast regions)(OAMDI, 2024b).

To achieve balanced representation, sampling weights were applied based on each firm's selection probability. Design weights were calculated as the inverse of the selection probability, given the systematic random sampling approach. Up to three attempts were made to contact unresponsive or busy phone numbers. After these efforts, businesses were categorized by final status, ranging from

² The data used in this analysis is proprietary but available upon request from the Economic Research Forum (ERF) website at <https://www.erfdataportal.com/index.php/catalog/288>

disconnected lines to ineligibility. Excluding non-working numbers and ineligible firms, the response rate was 7.8% of the initial 20,623 businesses, with 1,002 firms ultimately completing the survey—equivalent to 4.86% of the selected sample. This final sample forms the basis for our analysis and discussion(OAMDI, 2024b).

Building on these theoretical insights, the following subsection outlines the specific instrumentation strategies used to measure these constructs. This includes the operationalization of key variables drawn from TAM and UTAUT, adapted to reflect the unique role of financial inclusion in shaping clean energy adoption behaviours among Egyptian MSEs.

4.1. Financial inclusion indicator

The key explanatory variable of interest in this analysis is financial inclusion which has no consistent method of measurement and conceptualization in the literature(Nguyen, 2021). Its measurement depends on the unit of analysis—whether national, firm-level, household, or individual as well as the type of index, be it composite or multidimensional. Irrespective of the method of computation, there is an implicit agreement that financial inclusion index has three dimensions. While access and usage remain key dimensions across most studies, the third dimension vary from availability to quality(Nguyen, 2021). For instance, the Group of Twenty (G20) G20 Financial Inclusion Framework outlines three key dimensions: 1) access to financial services, 2) usage of financial services, and 3) the quality of financial products and service delivery—each supported by specific sub-indicators.

Building on this framework, we construct a Multidimensional Financial Inclusion Index (MFII) encompassing three dimensions: access, usage, and quality. Inspired by the approach for the computation of the global Multidimensional Poverty Index (MPI) (Alkire & Foster, 2011; Efobi & Orkoh, 2017), we assign equal weights to each of the dimensions and their sub-indicators. As presented in Table 1, we assign a weight of 1/3 to the indicator in access dimension, 1/18 to each of the 6 binary-response indicators on the usage dimension and 1/6 to the 2 binary-response questions on quality dimension. Since the overall index is made up of these three dimensions, we assigned a weight of 1/3 to each of them. The product of this weight and the weights of the individual variables were multiplied by the respective variables. The process followed to compute the subcomponents of the index can be functionally expressed as equation 1.

$$\theta_i = \pi_1\chi_1 + \pi_2\chi_2 + \dots + \pi_k\chi_k \quad (1)$$

where θ is the subcomponent (access, usage or quality) of the multidimensional index expressed as a function of the sum of the product of each variable i and its weight π . Each variable was recoded to take the value of 1 (one) if a firm indicates that it was inclusive as far as particular indicator is concerned and zero (0) otherwise. The sum of the weights is represented as $\sum_{i=1}^k \pi_i = 1$. In other words, equation 1 can be simplified as equation 2.

$$\theta_i = \sum_{i=1}^k \pi_i\chi \quad (2)$$

The final stage involved the summation of the product of the weights of each subcomponent to arrive at the multidimensional financial inclusion index, which can be functionally expressed as equation 3.

$$\Gamma_\alpha = \phi_1Y_1 + \phi_2Y_2 + \dots + \phi_dY_d = \sum_{\alpha=1}^d \phi_\alpha Y \quad (3)$$

where Γ is the index expressed as a function of the sum of the product of each subcomponent Y and its weight ϕ (1/3). The index ranges from 0 (completely excluded) to 1 (fully included). However, for ease of interpretation, it is multiplied by 100. The minimum threshold for inclusiveness is referred to as the inclusiveness cut-off (Orkoh & Efobi, 2024). A firm is classified as financially inclusive if it meets or exceeds the cut-off in all indicators and non-inclusive if it falls below the threshold. A firm is considered multidimensionally inclusive if its total weighted financial inclusion score reaches at least half (50%) of the maximum possible inclusion score of 100%.

Table 1. The Financial inclusion indicators, deprivation cut-offs, and weights

| Dimension | Indicator | Deprivation cut-off definition | Weight |
|------------------|--------------------|--|---------------|
| Access | Internet access | Inclusive if the firm has access to internet | 1/3 |
| | Bank account | Inclusive if the firm has a checking or savings account | 1/18 |
| | Loan | Inclusive if the firm has a line of credit or a loan from a financial institution | 1/18 |
| | Mobile money | Inclusive if the firm uses mobile money to send/receive money | 1/18 |
| Usage | Online transaction | Inclusive if the firm sells/buys any products online | 1/18 |
| | Mobile banking app | Inclusive if the firm receives payment for online sales through mobile banking app | 1/18 |
| | Mobile E-Wallets | Inclusive if the firm receives payment for online sales through E-Wallets | 1/18 |
| Quality | Collateral | Inclusive if the firm's financing/line of credit did not require a collateral | 1/6 |
| | Credit challenges | Inclusive if access to credit was not a problem for the firm | 1/6 |

4.2. Energy transition indicators

Additionally, we define three binary variables to measure firms' awareness of renewable energy, awareness of clean energy, and awareness of both energy sources. Each of the variables takes the value 1 if a firm or its representative provides a "Yes" response to the question on their awareness of renewable energy, clean energy or both. We further compute two indicators of energy transition: firms' intention to adopt clean energy and their WTP for clean energy. The first variable equals 1 if a firm has considered using clean energy sources (such as solar or wind power) for its operations and 0 otherwise. The second variable equals 1 if a firm is willing to purchase a solar energy system through at least six-monthly instalments, at a cost equivalent to its current electricity expenses at the time of the survey, and 0 otherwise. Capturing intention and WTP provides valuable insights into the process of green transition and the adoption of green technologies among micro- and small-sized firms. Specifically, these factors influence the adoption of sustainable energy solutions and the overall success of green policies.

On the one hand, intention is often a strong predictor of actual behaviour (Sheeran, 2002). Intention reflects a firm's motivation or readiness to adopt green technologies, and helps account for drivers (e.g., cost savings, regulatory pressure, environmental values) and barriers (e.g., high upfront costs, lack of information, technical challenges) that influence the decision-making process. On the other hand, WTP reveals the financial commitment a firm is prepared to make for green technologies. This helps assess whether cost is a significant barrier and how firms prioritize green investments relative to other business expenses. Generally, small firms often operate with limited budgets, making cost considerations crucial. WTP is shaped by factors such as expected return on investment, government

incentives, and financing options. If WTP is low, it may indicate that firms perceive green technologies as too expensive or not economically viable without subsidies or incentives.

4.3. Behavioural intention and awareness (mediating) indicators

As mediating variables, we construct composite indices for perceived usefulness, perceived ease of use, social influence, and facilitating conditions, along with an overall index for behavioural intentions. The perceived usefulness index is derived from four ordinal variables measured on a 5-point Likert scale ranging from 'strongly disagree' to 'strongly agree'. Responses to these questions were aggregated and divided by the maximum possible score to calculate the Perceived Usefulness Index. A similar approach was employed in calculating the indices for perceived ease of use and social influence, each comprising two items (questions) as well as the index for facilitating conditions which also comprise four items. The overall index of behavioural intention is computed by adding all the sub-indicators of the four variables and divided by the maximum possible score. For ease of interpretation, each of the indices is scaled to 100%. Awareness, as the second set of mediating variables, was measured using binary indicators: a value of 1 was assigned if a firm or its representative reported being familiar with the term 'clean energy' or 'renewable energy,' and 0 otherwise.

The to assess the internal consistency of the variables used to compute the composite indices of financial inclusion, energy transition and behavioural intention was assessed using the Cronbach's alpha. Cronbach's alpha measures how closely related items are and is widely used to assess scale reliability (Tavakol & Dennick, 2011). An acceptable alpha typically ranges from 0.65 to 0.80 or higher, while values below 0.50 are considered poor (Orkoh et al., 2024). In this analysis, Tables A2 and A3 in the appendix show an alpha value of 0.64 and an inter-item correlation of 0.20 for the financial inclusion index and corresponding values of 0.88 and 0.38 for the behavioural intention index.

4.4. Covariates

In addition to the key variables of interest, we incorporate several control variables that have been both theoretically and empirically identified as significant determinants of firms' energy transitions and their adoption of efficient energy sources. These include firm size, measured as a categorical variable with three levels: micro (less than 5 employees), small (5-19 employees), and medium-to-large (20 or more employees); and firm age, represented as a continuous variable indicating the number of years in operation. Certification status is included as a binary variable, taking the value 1 if the firm holds an internationally recognized certification, and 0 otherwise. Formality is similarly captured as a binary variable, equal to 1 if the firm is formally registered for tax purposes, and 0 otherwise. To account for gender dynamics, we include a binary variable indicating the gender of the top manager, where 1 represents a male and 0 a female. The geographical location of the firm is also considered, measured as a binary variable that takes the value 1 if the firm is located in an urban area and 0 if in a rural setting. Managerial experience is measured as a continuous variable, ranging from 0 to 99 years, with an average of 17 years. Finally, we include the share of highly educated workers in the total workforce, measured as a categorical variable that takes the value 1 if the share is 25% or less, 2 if between 26% and 50%, 3 if between 51% and 70%, and 4 if the share exceeds 75%. The descriptive statistics of the variables are presented in Table 2.

Table 2. Definition and descriptive statistics of variables included in the analysis

| Variable | Definition | Obs. | Mean | Std. dev. |
|--------------------|--|-------|-------|-----------|
| FI | Multidimensional financial inclusion index | 1,002 | 0.573 | 0.495 |
| Willingness to pay | SMEs' willingness to pay for clean energy | 1,002 | 0.636 | 0.481 |
| Clean energy | SMEs' intension to use clean energy | 979 | 0.220 | 0.414 |

| | | | | |
|-------------------------|---|-------|--------|--------|
| Ease of usefulness | Index of perceive usefulness of clean energy | 1,002 | 74.406 | 17.777 |
| Perceive ease of use | Index of perceive ease of use of clean energy | 1,002 | 70.679 | 19.297 |
| Social influence | Index of social influence on the use of clean energy | 1,002 | 71.058 | 19.145 |
| Facilitating conditions | Index of facilitating conditions of the use of clean energy | 1,002 | 65.210 | 18.194 |
| Behavioural intention | Overall index of usefulness, ease of use, social influence, and facilitating conditions | 1,002 | 70.161 | 14.907 |
| Size | Firms' size | 1,002 | 1.394 | 0.624 |
| Firm age | Firms' years of operation | 931 | 9.960 | 13.857 |
| Certification | Firms' ownership of international certification | 971 | 0.133 | 0.340 |
| Tax ID (formality) | Firms' registration for tax id as form of formality | 1,002 | 0.695 | 0.461 |
| Gender | Gender of the top manager | 1,002 | 0.671 | 0.470 |
| Urban | Geographical location of firm | 1,002 | 0.898 | 0.303 |
| Experience | The years of experience of the top manager | 1,002 | 16.694 | 18.964 |
| Higher education share | Share of Highly educated workers in the total workforce | 1,002 | 2.230 | 1.273 |

4.5. Estimation Techniques

In an ideal, confounder-free setting, a randomized controlled trial would be the optimal method for assessing the impact of firms' financial inclusion on their intention and willingness to adopt clean energy in Egypt. However, confounding is inherent in observational data due to non-random assignment and selection bias. If unaddressed, it can lead to biased estimates of the true effect (Chesnaye et al., 2022). To address the challenge of confounding in observational data, previous studies have employed quasi-experimental methods such as inverse probability weighting, matching estimators, and causal mediation analysis. This analysis integrates these approaches to achieve the objectives of paper. The inverse probability weighting (IPW), implemented in two steps. First, the propensity score $\hat{p}(CV_i)$, is estimated this represents the conditional probability of receiving the treatment (being financially included) given the firm's characteristics. As shown in Equation 1, this probability is modelled as a function of a firm's characteristics CV .

$$Prob (FI_i = 1|CV_i) = \beta_0 + \beta_i CV_i + \mu_i \quad (4)$$

FI in equation 4 represents financial inclusion of firm i , CV is a vector of the covariates, β_0 is the constant term, β_i is a vector of the coefficients of the covariates, while μ is the error term. Equation 4 is the estimated version of Equation 1 where $\hat{p}(CV_i)$ is the estimated propensity score.

$$\hat{p}(CV_i) = Pr(FI_i = 1|CV_i) \quad (5)$$

After estimating the propensity score, the next step in the IPW method is to calculate each firm's weight as the inverse of the probability of their actual exposure. The estimated propensity score weights observations using $1/\hat{p}(CV_i)$ for the treated group (financially included) and $1/1 - \hat{p}(CV_i)$ for the control group (financially excluded). As a result, observations with high $\hat{p}(CV_i)$ receive lower weights when treated and higher weights when untreated, with the reverse applying to those with low $\hat{p}(CV_i)$. The estimator can be adjusted so that weights within each group sum to one, enhancing finite sample performance (Abadie & Cattaneo, 2018).

$$\hat{\varphi}_{ATE} = \frac{1}{n} \sum_{i=1}^n \frac{FI_i ET_i}{\hat{p}(CV_i)} - \frac{(1-FI_i) ET_i}{1-\hat{p}(CV_i)} \quad (6)$$

$\hat{\varphi}_{ATE}$ in Equation 6 is the IPW estimator. The causal equation for the estimated average treatment effect (ATE) of financial inclusion is specified as Equation 7 to Equation 9.

$$\widehat{ET}_i = E(ET_{i1} - ET_{i0} | FI_i = 1) \quad (7)$$

$$= E\{E\{ET_{i1} - ET_{i0} | FI_i = 1, \hat{p}(CV_i)\}\} \quad (8)$$

$$= E\{E\{ET_{i1} - ET_{i0} | FI_i = 1, \hat{p}(CV_i) - E\{ET_{i0} | FI_i = 0, \hat{p}(CV_i)\}\}\} \quad (9)$$

The subscript i represents a firm; φ is the average treatment effect; while D is a binary variable, which takes the value 1 if the firm is financially included, and 0 otherwise. The ET represents the outcome variable (energy transition). The propensity score, $\hat{p}(CV_i)$, captures the probability that a firm would be financially included given the covariate (CV). A covariate should only be included if it simultaneously influences both financial inclusion and energy transition. Additionally, variables must not be confounded (Caliendo & Kopeinig, 2008), and the outcome must be independent of the treatment, conditional on the propensity score (Angrist & Kuersteiner, 2011). To ensure consistency of the estimated effects, we present the results for different estimators of the IPW. We begin with regression adjustment (RA), followed by standard inverse probability weighting (IPW), inverse probability weighted regression adjustment (IPWRA) and augmented inverse probability weighting (AIPW). IPWRA and IPWRA estimators have the double robustness property compared to the other estimators. The IPWRA method employs quasi-likelihood methods, weighted by the inverse of the instrument's propensity score making it have appealing small sample properties (Sloczynski et al., 2022). Additionally, the quality of matching was evaluated using weighted standardized differences to assess covariate balance across the full sample and subgroups. As shown in Table A4 in the appendix, the covariates exhibit standardized differences close to zero and variance ratios near one, indicating that the weighting effectively achieved conditional exchangeability on observed covariates.

While inverse probability weighting (IPW) offers strong causal insights, it is sensitive to large differences in covariates between groups. When some individuals have propensity scores close to 0 or 1, the resulting extreme weights can inflate variance and widen confidence intervals—particularly in cases of rare exposure. To address this, common approaches include outlier removal, weight stabilization, and truncation (Chesnaye et al., 2022).

As a validation of the consistency of the results, we apply matching techniques—specifically propensity score matching (PSM) and nearest neighbor matching—which reduce reliance on extreme weights by pairing treated and control individuals with similar characteristics. These methods identify comparable non-participants based on observable traits such as age, education, and gender (Abadie & Cattaneo, 2018). Like IPW, PSM begins with estimating the propensity score via logistic regression, modelling the probability of being financially inclusive based on observed covariates.

As indicated in the introduction, the second objective of this paper is to assess the extent to which behavioural intention and awareness mediate the relationship between financial inclusion and firms' adoption of clean energy. This objective is addressed using the causal mediation analysis (CMA), specified as equation 10. CMA decomposes the total causal effect into direct and indirect effects (Imai et al., 2010). The direct effect measures the impact of financial inclusion on intention to use and willingness to pay for clean energy, while the indirect effect captures the mediating role of behavioural intention and awareness of clean energy this relationship. In Equation 10, intention to use and willingness to pay for clean energy are modelled as a function of behavioural intention and awareness, a vector of control variables, and an error term.

$$ET_i = \beta_0 + \beta_1 FI_i + \beta_1 BIA_i + CV_i \gamma + \varepsilon_i \quad (10)$$

Where BIA_{it} represents the mediator—behavioural intension and awareness in this case—alongside the financial inclusion FI_i , covariates, and the error term. In equation 8, adoption of clean energy is specified as a function of the behavioural intension and awareness, a vector of covariates and an error term. The mediators are specified as a function of financial inclusion because they are intermediate variable that transmits part (or all) of the effect of financial inclusion on clean energy adoption. Omitting the mediator as a function of the treatment variable breaks the causal chain and misrepresents the mediation process. This can lead to overlooking indirect effects and overstating the direct impact of financial inclusion.

$$BIA_i = \alpha_0 + \alpha_1 FI_i + X_i \delta + \varepsilon_i \quad (11)$$

Based on both equations, we estimate the natural indirect effect (NIE), natural direct effect (NDE) and total effects (TE) of financial inclusion as follows:

$$\delta(FI) \equiv E[ET_i(FI, BIA(1))] - E[ET_i(FI, BIA_i(0))] \quad FI \in \{0, 1\}$$

$$\gamma(i) \equiv E[ET_i(1, BIA_i(FI))] - E[ET_i(0, BIA_i(FI))] \quad FI \in \{0, 1\}$$

$$\tau \equiv E[ET_i(1)] - E[ET_i(0)] = E[ET_i(1, BIA_i(1))] - E[ET_i(0, BIA_i(0))]$$

While causal mediation analysis establishes pathways and quantify how much of an effect is mediated by another variable, it relies on indices (like a mediator variable) that are typically observed or pre-defined variables—often single scores or constructs that are already computed. In this analysis, the mediator variables (behavioural intension and awareness) and financial inclusion were computed from a set of observed variables. Although the Cronbach’s alpha is used to assess the internal consistency of the variables constituting the indices, we further use partial least squares structural equation modelling (PLS-SEM) to validate the robustness of the results. In PLS-SEM, indices (constructs) are typically latent variables not directly observed but inferred from multiple indicators (items/questions). PLS-SEM is a versatile and powerful analytical tool for predicting relationships, particularly in studies with small sample sizes. It is highly effective for handling non-normal data and modelling complex constructs (Venturini & Mehmetoglu, 2019). Widely applied in fields such as psychology, social sciences, and economics, PLS-SEM accounts for measurement error and enhances interpretability. It is especially useful for theory development and prediction, with minimal assumptions about data distribution and sample size (Hair et al., 2019).

The postestimation analysis of the validity of the results are presented in the appendix. Table A5 in the appendix presents the standardized loadings of the measurement model and the respective parameters including the Cronbach’s alpha values while Table A6 shows the discriminant validity test parameters. In Table 4, the model-based reliability estimate (ρ_A) which lies between Cronbach’s alpha and composite reliability fall within the acceptable range of 0.60 and 0.95 for both financial inclusion and behavioural intension variables (Hair et al., 2019). Although the corresponding values for energy transition are lower, they are intuitively understandable, given the fact that the index is constructed from two observable variables. Furthermore, to assess whether the latent constructs sufficiently account for the variance in their associated indicators, the Average Variance Extracted (AVE) values ranged from 0.32 to 0.82. The constructs related to energy transition and awareness exceeded the recommended threshold of 0.50, while those for behavioural intension and financial inclusion approached this benchmark. These results support the conclusion that the measurement model demonstrates acceptable levels of validity and reliability.

5. Results and Discussion

5.1. Intention to use clean energies

The results in Table 3 show that financial inclusion significantly increases the likelihood of MSEs’ intention to adopt clean energy technologies, with an estimated increase ranging from 7.5 to 12 percentage points across various estimation methods. The Regression Adjustment (RA) method estimates an Average Treatment Effect (ATE) of 0.075 ($p < 0.05$), reflecting a moderate yet

statistically significant impact. The Potential Outcomes Mean (POmean) indicates that 58% of MSEs lacking financial inclusion express an intention to use clean energy. The Inverse Probability Weighted Regression Adjustment (IPWRA) method produces the highest ATE of 0.12 ($p < 0.01$). The consistent positive and statistically significant ATEs, predominantly at the 1% significance level across methods, highlight the robust influence of financial inclusion on MSEs' intentions to embrace clean energy technologies. These findings align with prior research emphasizing the role of financial access in enabling sustainable practices and facilitating businesses' adoption of energy-efficient technologies (Allen et al., 2016; Cama et al., 2024; Hu et al., 2023; Kuada, 2022).

Table 3. MSEs' financial inclusion and intent to use clean energies

| Indicators of financial inclusion | Estimation methods | | | | | |
|--|---------------------|---------------------|---------------------|---------------------|--------------------|---------------------|
| | RA | IPW | IPWRA | AIPW | PSM | NNM |
| <i>Intention to use clean energy</i> | | | | | | |
| Average treatment effect (ATE) | 0.075** (0.037) | 0.097*** (0.038) | 0.116*** (0.037) | 0.110*** (0.038) | 0.080* (0.048) | 0.120*** (0.044) |
| POmean | 0.582*** (0.030) | 0.591*** (0.030) | 0.577*** (0.029) | 0.582*** (0.031) | | |
| Observations | 908 | 908 | 908 | 908 | 908 | 908 |
| <i>Willingness to pay for clean energy</i> | | | | | | |
| Average treatment effect (ATE) | 0.114*** (0.030) | 0.097*** (0.033) | 0.091*** (0.033) | 0.091*** (0.035) | 0.088** (0.039) | 0.112*** (0.037) |
| POmean | 0.178*** (0.022) | 0.172*** (0.026) | 0.178*** (0.025) | 0.178*** (0.027) | | |
| Observations | 887 | 887 | 887 | 887 | 887 | 887 |

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5.2. Willingness to pay for clean energy technologies

The results for the indicator of WTP for clean energy technologies further confirm the positive influence of financial inclusion, with ATEs ranging from 0.088 for the PSM method to 0.114 for the RA method estimates (Table 3). The ATEs are highly significant across all methods, with most at the 1% level, indicating that financial inclusion substantially enhances the willingness to pay for clean energy among MSEs. The POmean estimates suggest that around 17% of MSEs without financial inclusion are willing to pay for clean energy. These results corroborate studies like Asante et al. (2021), Prashar and Sunder M (2020), and Rahbauer et al. (2018), which indicate that financial inclusion tools encourage clean energy investments by reducing financial barriers.

5.3. Causal mediation results

The results of the causal mediation analysis, presented in Table 4, show that financial inclusion influences MSEs' intention to use and WTP for clean energy technologies through behavioural intention predictors—perceived usefulness, perceived ease of use, social influence, facilitating conditions. By decomposing the effects into natural indirect, natural direct, and total effects, the results provide insights into the mechanisms driving clean energy adoption among Egyptian MSEs.

5.3.1. The mediating role of predictors of behavioural intention

Specifically, across all models, the total effect is statistically significant at the 1% level, suggesting that financial inclusion increases the probability of intending to adopt clean energy by approximately 11.5–11.8 percentage points. The natural direct effect, which captures the impact of financial inclusion independent of behavioural predictors, is consistently significant at the 1% level, ranging from 0.085 for the overall index to 0.117 for facilitating conditions. This indicates that financial inclusion directly fosters adoption intentions, with facilitating conditions exhibiting the strongest direct influence. The natural indirect effect, reflecting mediation through behavioural predictors, varies in magnitude and significance. Perceived usefulness shows a robust indirect effect of 0.031 ($p < 0.01$), suggesting that financial inclusion enhances the perception of clean energy’s benefits, thereby boosting adoption intent. Perceived ease of use has a moderate indirect effect of 0.012 ($p < 0.05$), implying that financial access makes clean energy technologies seem more manageable. In contrast, social influence and facilitating conditions have weaker indirect effects, with estimates of 0.009 ($p < 0.1$) and 0.002 ($p > 0.1$), respectively, indicating limited mediation through social norms or external support. The overall index yields a combined indirect effect of 0.021 ($p < 0.05$). Notably, the direct effect dominates the total effect across models, underscoring that financial inclusion’s primary influence bypasses behavioural mediators, particularly for facilitating conditions.

With regard to willingness to pay, the total effect remains significant at the 1% level, ranging from 0.085 to 0.090, indicating that financial inclusion increases the likelihood of WTP by 8.5–9.0 percentage points (Table 4). The natural direct effect is significant across all models, ranging from 0.064 (overall index) to 0.085 (facilitating conditions), reinforcing the direct role of financial access in enabling WTP. The natural indirect effect is most pronounced for perceived usefulness, with an estimate of 0.026 ($p < 0.01$), suggesting that financial inclusion enhances WTP by highlighting clean energy’s economic benefits. Other predictors show limited mediation: perceived ease of use and social influence have non-significant effects of 0.008 and 0.005, respectively, while facilitating conditions yield a marginally significant but negligible effect of 0.000 ($p < 0.1$). The overall index produces a moderate indirect effect of 0.014 ($p < 0.05$). Similar to the intention results, the direct effect outweighs the indirect effect, with perceived usefulness as the primary mediator. The slightly smaller sample for WTP likely reflects minor data attrition, but the robust standard errors and consistent significance levels ensure the findings’ reliability.

Overall, these findings resonate with the TAM and UTAUT, offering theoretical insights into clean energy adoption in resource-constrained settings. The strong indirect effect of perceived usefulness aligns with TAM’s core premise that perceived benefits drive technology acceptance (Raj et al., 2024), suggesting that financial inclusion equips MSEs with resources or knowledge to recognize clean energy’s productivity or cost-saving potential. However, the weaker mediation by perceived ease of use indicates that financial access does not fully alleviate technical complexities, possibly due to limited training or infrastructure. This challenges TAM’s applicability in contexts where external barriers persist, suggesting a need to integrate structural factors into the model.

Table 4. Financial inclusion and MSEs’ intention to use and WTP for clean energy

| Indicators of financial inclusion | Predictors of behavioural intention | | | | Overall index |
|--------------------------------------|-------------------------------------|-----------------------|---------------------|-------------------------|---------------------|
| | Perceived usefulness | Perceived ease of use | Social influence | Facilitating conditions | |
| <i>Intention to use clean energy</i> | | | | | |
| Natural indirect effect (NIE) | 0.031*** (0.009) | 0.012** (0.006) | 0.009* (0.005) | 0.002 (0.006) | 0.021** (0.009) |
| Natural direct effect (NDE) | 0.085*** (0.031) | 0.106*** (0.031) | 0.110*** (0.031) | 0.117*** (0.031) | 0.094*** (0.031) |
| Total effect (TE) | 0.116*** (0.031) | 0.118*** (0.031) | 0.118*** (0.031) | 0.118*** (0.031) | 0.115*** (0.031) |
| Observations | 1,002 | 1,002 | 1,002 | 1,002 | 1,002 |

| <i>Willingness to pay for clean energy</i> | | | | | |
|--|---------------------|---------------------|---------------------|---------------------|---------------------|
| Natural indirect effect (NIE) | 0.026*** (0.009) | 0.008 (0.005) | 0.005 (0.004) | 0.000* (0.000) | 0.014** (0.006) |
| Natural direct effect (NDE) | 0.064*** (0.025) | 0.079*** (0.026) | 0.082*** (0.026) | 0.085*** (0.026) | 0.076*** (0.025) |
| Total effect (TE) | 0.090*** (0.026) | 0.087*** (0.026) | 0.087*** (0.026) | 0.085*** (0.026) | 0.090*** (0.026) |
| Observations | 979 | 979 | 979 | 979 | 979 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The strong indirect effect of perceived usefulness (0.031 for intention, 0.026 for WTP) mirrors UTAUT's performance expectancy, suggesting that financial inclusion enhances MSEs' belief that clean energy technologies improve productivity or profitability, driving adoption. This aligns with UTAUT's emphasis on performance benefits as a primary adoption driver in organizational contexts (Apfel & Herbes, 2021). The moderate indirect effect of perceived ease of use (0.012 for intention, non-significant for WTP) corresponds to effort expectancy, indicating that financial access partially reduces perceived technical barriers, though complexities may persist due to limited training or infrastructure (Hrnjica & Veselinović, 2025; Lin & Lee, 2024). The weak indirect effect of social influence (0.009 for intention, 0.005 for WTP) challenges UTAUT's assertion that social norms significantly influence adoption, particularly in collectivist cultures like Egypt (Muwanga et al., 2024). This suggests that economic constraints overshadow peer or community pressures for MSEs, necessitating a contextual adaptation of UTAUT. Similarly, the negligible indirect effect of facilitating conditions (0.002 for intention, 0.000 for WTP) highlights a limitation in UTAUT's application, as external resources like infrastructure or subsidies are critical but not addressed by financial inclusion alone. The dominance of the direct effect over mediated pathways suggests that financial inclusion acts as an economic catalyst, directly shaping adoption intentions beyond UTAUT's behavioural constructs. This finding advocates for extending UTAUT to incorporate economic access as a direct determinant in resource-scarce settings, offering a theoretical contribution for low-income entrepreneurial contexts. Future research could explore additional UTAUT moderators, such as experience or gender, to refine its application to MSEs.

5.3.2. The mediating role of MSEs' awareness of clean energy solutions

Table 5 presents the results of the mediation analysis of how financial inclusion influences MSEs' intention to use and WTP for clean energy technologies through their awareness of renewable energies, clean energies, or both. The results demonstrate that financial inclusion significantly enhances MSEs' intention to use clean energy technologies. The total effect across all awareness categories—renewable energies, clean energies, and both—is statistically significant at the 1% level, with estimates indicating that financial inclusion increases the probability of adoption intent by approximately 11.8–11.9 percentage points.

The natural direct effect is consistently significant at the 1% level, ranging from 0.097 (clean energies) to 0.106 (both). This suggests that financial inclusion directly fosters adoption intentions, with a slightly stronger effect when MSEs are aware of both renewable and clean energies. The natural indirect effect varies in significance. Awareness of clean energies shows a significant indirect effect of 0.022 (p<0.05), indicating that financial inclusion enhances adoption intent by increasing knowledge of clean energy options. In contrast, awareness of renewable energies and both categories yields insignificant indirect effects, suggesting limited mediation. The dominance of the direct effect over the indirect effect across all models underscores that financial inclusion primarily drives adoption intentions directly, with awareness of clean energies playing a modest mediating role.

For willingness to pay, the total effect is also significant at the 1% level, ranging from 0.088 to 0.095. The natural direct effect is significant for renewable energies (0.051, p<0.05) and both categories (0.043, p<0.1), but non-significant for clean energies (0.030, p>0.1), indicating that direct financial access is less consistently influential for WTP. The natural indirect effect is significant across all

awareness categories, with estimates of 0.044 ($p < 0.01$) for renewable energies, 0.060 ($p < 0.01$) for clean energies, and 0.045 ($p < 0.01$) for both. This suggests that awareness strongly mediates the relationship between financial inclusion and WTP, with clean energy awareness showing the largest indirect effect. Unlike intention to use, the indirect effect is more pronounced for WTP, particularly for clean energies, indicating that awareness plays a critical role in translating financial access into financial commitment.

Table 5. Awareness, financial inclusion and MSEs' use and WTP for clean energy

| Effect of financial inclusion | Willingness to pay | | | Intention to use | | |
|-------------------------------|--|---------------------|---------------------|---------------------|---------------------|---------------------|
| | <i>MSEs' awareness of energy sources</i> | | | | | |
| | Renewable Energies | Clean Energies | Both | Renewable Energies | Clean Energies | Both |
| NIE | 0.013 (0.009) | 0.022** (0.010) | 0.013 (0.010) | 0.044*** (0.010) | 0.060*** (0.012) | 0.045*** (0.010) |
| NDE | 0.105*** (0.032) | 0.097*** (0.033) | 0.106*** (0.032) | 0.051** (0.024) | 0.030 (0.024) | 0.043* (0.025) |
| TE | 0.119*** (0.031) | 0.118*** (0.031) | 0.119*** (0.031) | 0.095*** (0.025) | 0.090*** (0.026) | 0.088*** (0.026) |
| Observations | 979 | 979 | 979 | 979 | 979 | 979 |

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

These findings engage with the broader literature on clean energy adoption and financial inclusion, particularly in developing economies. Studies like those by Khan et al. (2024) highlight that financial barriers are a primary obstacle to clean energy adoption among small enterprises in developing countries, a finding corroborated by the significant total effects observed here. However, the literature often emphasizes infrastructure and cost as dominant factors, with less focus on awareness as a mediator. The significant indirect effect of clean energy awareness for WTP aligns with research by Bernat et al. (2024) and Aliano et al. (2024), which suggests that knowledge of environmental benefits increases financial commitment to sustainable technologies. The weaker indirect effect for intention to use contrasts with findings from Akpan et al. (2022) and Ghobakhloo et al. (2022), which argue that awareness drives adoption intent in small businesses. This discrepancy may reflect Egypt's context, where financial constraints overshadow informational barriers for MSEs, as evidenced by the dominant direct effect. The stronger mediation for WTP suggests that awareness campaigns could be particularly effective in encouraging financial investment, a nuance less explored in prior studies focused on adoption behaviour alone.

5.4. Robustness analysis

As presented in Table 6, the results of the robustness analysis using PLS-SEM confirm the observed estimates of the causal mediation analyses, although the magnitudes of the estimates are comparatively higher. Financial inclusion has a significant impact on both behavioural intention (0.198) and awareness (0.156), which in turn promote the energy transition. The indirect effects (0.054 and 0.041), though modest, are statistically significant at 5% level, indicating partial mediation in both paths. The indirect effect through behavioural intention accounts for approximately 21% of the total effect (0.054 out of 0.252), indicating a moderate mediating role. Similarly, the indirect effect through awareness accounts for approximately 16% of the total effect (0.041 out of 0.251). This suggests that behavioural intention and awareness serve as equally important channels through which financial inclusion influences the adoption of clean and renewable energy. Overall,

the findings support a dual-path mediation model, where financial inclusion contributes to the energy transition both directly and indirectly. Enhancing financial inclusion may therefore be an effective strategy to accelerate clean energy adoption, particularly when paired with efforts to raise awareness and influence behavioural change.

Table 6. Partial least squares structural equation modelling (PLS-SEM) estimates

| Structural path | Behavioural intention | | | Awareness | | |
|--|-----------------------|----------|----------|-----------|----------|----------|
| | Direct | Indirect | Total | Direct | Indirect | Total |
| Financial inclusion-> Behavioural intention/Awareness | 0.198*** | | 0.198*** | 0.156*** | | 0.156*** |
| Behavioural intention/Awareness-> Energy transition | 0.273*** | | 0.273*** | 0.263*** | | 0.263*** |
| Financial inclusion-> Energy transition | 0.198*** | 0.054** | 0.252*** | 0.209*** | 0.041** | 0.251*** |

Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Note: Standard errors were estimated using the bootstrapping method with 500 replications to assess the stability and significance of the PLS-SEM path coefficients

6. Conclusion, policy implications, and limitations

This study used primary data from 1,002 Egyptian micro- and small-sized enterprises (MSEs) and employed robust analytical methods, including causal mediation analysis and structural equation modelling, to examine the impact of financial inclusion on the green energy transition among MSEs. The results show that financial inclusion significantly enhances the adoption of clean energy technologies among MSEs, with robust effects on both intentions to use and willingness to pay (WTP). Specifically, financial inclusion increases the likelihood of intending to use clean energy by 7.5–12 percentage points. The Potential Outcomes Mean (POmean) indicates that 58% of MSEs without financial inclusion intend to adopt clean energy, while WTP is boosted by 8.8–11.4 percentage points, with only 17% of non-included MSEs willing to pay. The mediation analysis shows that perceived usefulness is the primary mediator, with significant indirect effects, while perceived ease of use, social influence, and facilitating conditions play limited roles. MSEs' awareness of clean energies significantly mediates WTP, but less so for intention, underscoring the dominance of direct financial access. Theoretically, these findings align with the theoretical frameworks of TAM and UTAUT, which stress the interplay between cognitive factors and facilitating conditions. The findings extend TAM and UTAUT by emphasizing economic access in resource-scarce settings, advocating for integrated models that address both financial barriers and cognitive and perceptual factors to promoting green energy adoption.

From a policymaking perspective, the significant direct effects in our results underscore the need to expand financial inclusion through microcredit, grants, or green financing, to further enable MSEs to invest in clean energy technologies. Awareness campaigns, emphasizing clean energy's economic and environmental benefits, should target MSEs with limited financial literacy, leveraging cooperatives or business associations for outreach, particularly to boost WTP. Structural barriers, evidenced by the negligible mediation of facilitating conditions, necessitate investments in reliable electricity grids and clean energy supply chains. Flexible payment models, such as pay-as-you-go systems or micro-leasing, could address affordability constraints, bridging the gap between intention and WTP. Complementary policies addressing behavioural intention—such as leveraging social influence through regulatory incentives or peer networks—could further motivate MSEs to adopt sustainable practices. These measures would not only support Egypt's green economy initiatives, but also advance energy justice and economic resilience, ensuring MSEs contribute meaningfully to a sustainable energy transition.

Despite the contributions of this study, it has limitations that warrant consideration. First, the cross-sectional design limits our ability to capture dynamic changes in MSEs' green transition behaviours

over time. Longitudinal studies could better elucidate how financial inclusion influences adoption trajectories, particularly amidst Egypt's evolving policy landscape. Second, our sample is restricted to Egyptian MSEs, which may limit generalizability to other MENA countries with different socioeconomic and institutional contexts. Comparative studies across MENA could reveal regional variations in the finance-energy transition nexus. Third, although accounted for behavioural mediators, other unobserved factors, such as cultural or institutional influences, may also play a role. Future research should incorporate these variables to provide a more holistic understanding. Future research could also explore the role of digital financial inclusion (e.g., fintech innovations) in greater depth, given its rapid rise in Egypt, and investigate how sector-specific factors (e.g., agriculture vs. manufacturing) shape MSEs' green transition behaviours.

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Appendix

Table A1: Sample distribution of businesses and selected sample by province and region

| Provinces/regions | Businesses in sampling frame | Businesses selected |
|-------------------|------------------------------|---------------------|
| Cairo | 122046 | 8718 |
| Alexandria | 22955 | 1640 |
| Giza | 75912 | 5422 |
| Kaliobeya | 18099 | 1292 |
| Lower Egypt | 36060 | 2577 |
| Upper Egypt | 358 | 4993 |
| Other provinces | 616 | 8647 |
| Total | 288712 | 20623 |

Source: Estimates based on Renewable Energy Egypt: Sampling design and survey weights report

Table A2: Test of internal reliability of the financial inclusion variables

| Item | Obs | Sign | correlation | correlation | correlation | alpha |
|---|------|------|-------------|-------------|-------------|-------|
| Have a checking or savings account | 1002 | + | 0.5898 | 0.383 | 0.192 | 0.588 |
| Have a line of credit or a loan from a financial institution? | 1002 | + | 0.4058 | 0.163 | 0.241 | 0.655 |
| Use mobile money to send/receive money | 1002 | + | 0.5736 | 0.363 | 0.197 | 0.595 |
| Sell/buy any firm products online | 1002 | + | 0.7841 | 0.649 | 0.141 | 0.497 |
| Receive payment for online sales through mobile banking account | 1002 | + | 0.5354 | 0.315 | 0.207 | 0.610 |
| Receive payment for online sales through E-wallets | 1002 | + | 0.592 | 0.386 | 0.192 | 0.587 |
| Other means of receiving payment for online sales | 1002 | + | 0.4435 | 0.206 | 0.231 | 0.643 |
| Test scale | | | | | 0.200 | 0.640 |

Table A3: Test of internal reliability of the behavioural intention variables.

| Item | Obs | Sign | Item-test | Item-rest | Average interitem | alpha |
|--|------|------|-------------|-------------|-------------------|-------|
| | | | correlation | correlation | correlation | |
| Renewable energy technologies would improve our energy efficiency | 1002 | + | 0.647 | 0.564 | 0.379 | 0.870 |
| The use of renewable energy technologies would enhance our daily operations | 1002 | + | 0.690 | 0.614 | 0.373 | 0.867 |
| Renewable energy technologies would make a positive impact on the environment | 1002 | + | 0.631 | 0.545 | 0.381 | 0.871 |
| Renewable energy technologies would reduce our energy costs | 1002 | + | 0.706 | 0.633 | 0.370 | 0.866 |
| Our staff finds renewable energy technologies easy to understand and operate | 1002 | + | 0.693 | 0.618 | 0.372 | 0.867 |
| The installation and maintenance of renewable energy technology seem hassle-free | 1002 | + | 0.716 | 0.645 | 0.369 | 0.865 |
| Recommendations would encourage us to adopt renewable energy technologies | 1002 | + | 0.725 | 0.655 | 0.368 | 0.865 |
| Government incentives and policies that support the adoption of renewable energy | 1002 | + | 0.613 | 0.524 | 0.384 | 0.873 |
| We have access to the necessary infrastructure to adopt renewable energy technology | 1002 | + | 0.666 | 0.586 | 0.376 | 0.869 |
| The cost of implementing renewable energy tech. is within our financial means | 1002 | + | 0.626 | 0.539 | 0.382 | 0.872 |
| We're aware of government policies that support renewable energy technology adoption | 1002 | + | 0.647 | 0.563 | 0.379 | 0.870 |
| The availability of renewable energy tech. providers in our area is sufficient | 1002 | + | 0.503 | 0.399 | 0.399 | 0.880 |
| Test scale | | | | | 0.378 | 0.879 |

Table A4: Standardized difference of covariates before and after matching

| | Standardized differences | | Variance ratio | |
|-------------------------------|--------------------------|----------|----------------|----------|
| | Raw | Weighted | Raw | Weighted |
| Small-sized firm | 0.592 | 0.057 | 2.336 | 1.071 |
| Medium-large firm | 0.265 | -0.067 | 2.816 | 0.816 |
| Firm age (years of operation) | -0.038 | 0.059 | 0.519 | 0.754 |
| International certification | 0.272 | -0.060 | 1.913 | 0.889 |
| Formality (Tax ID) | 0.529 | 0.130 | 0.665 | 0.901 |

| | | | | |
|---|--------|-------|-------|-------|
| Gender of top owner | -0.054 | 0.171 | 1.037 | 0.901 |
| Urban | 0.236 | 0.350 | 0.540 | 0.436 |
| Manager's experience | -0.055 | 0.108 | 0.885 | 1.226 |
| Share of educated employees- 26% to 50% | 0.131 | 0.029 | 1.264 | 1.051 |
| Share of educated employees- 51% to 75% | 0.231 | 0.022 | 1.865 | 1.056 |
| Share of educated employees- > 75% | 0.347 | 0.051 | 1.421 | 1.048 |

Table A5: Measurement model - standardized loadings

| Variables | Behavioural intention | | Awareness | |
|--|---------------------------------------|---|-------------------------------------|---------------------------------------|
| | Reflective: Financial inclusion | Reflective: Behavioural intention | Reflective: Energy transition | Reflective: Financial inclusion |
| Renewable energy technologies would improve our energy efficiency | | 0.727*** (0.024) | | |
| The use of renewable energy technologies would enhance our daily operations | | 0.766*** (0.019) | | |
| Renewable energy technologies would make a positive impact on the environment | | 0.692*** (0.024) | | |
| Renewable energy technologies would reduce our energy costs | | 0.726*** (0.021) | | |
| Our staff finds renewable energy technologies easy to understand and operate | | 0.707*** (0.023) | | |
| The installation and maintenance of renewable energy technology seem hassle-free | | 0.708*** (0.025) | | |
| Recommendations would encourage us to adopt renewable energy technologies | | 0.723*** (0.026) | | |
| Government incentives and policies that support the adoption of renewable energy | | 0.572*** (0.034) | | |
| We have access to the necessary infrastructure to adopt renewable energy technology | | 0.598*** (0.036) | | |
| The cost of implementing renewable energy tech. is within our financial means | | 0.549*** (0.039) | | |
| We're aware of government policies that support renewable energy technology adoption | | 0.558*** (0.040) | | |
| The availability of renewable energy tech. providers in our area is sufficient | | 0.351*** (0.048) | | |
| Have a checking or savings account | 0.671*** (0.038) | | 0.690*** (0.042) | |
| Have a line of credit or a loan from a financial institution? | 0.416*** (0.062) | | 0.333*** (0.071) | |
| Use mobile money to send/receive money | 0.595*** (0.043) | | 0.564*** (0.048) | |
| Sell/buy any firm products online | 0.745*** (0.042) | | 0.767*** (0.043) | |
| Receive payment for online sales through mobile banking account | 0.508*** (0.049) | | 0.579*** (0.050) | |
| Receive payment for online sales through E-wallets | 0.534*** (0.057) | | 0.511*** (0.066) | |
| Other means of receiving payment for online sales | 0.424*** | | 0.413*** | |

| | | | | | | |
|--|---------|-------|----------|---------|----------|----------|
| | (0.056) | | | (0.062) | | |
| Awareness - clean energy | | | | | 0.907*** | |
| | | | | | (0.012) | |
| Awareness- renewable energy | | | | | 0.905*** | |
| | | | | | (0.013) | |
| Willingness to pay | | | 0.790*** | | | 0.907*** |
| | | | (0.041) | | | (0.012) |
| Clean energy use intention | | | 0.716*** | | | 0.905*** |
| | | | (0.047) | | | (0.013) |
| Observations | 979 | 979 | 979 | 979 | 979 | 979 |
| Cronbach's Alpha (construct validity test) | 0.637 | 0.878 | 0.243 | 0.637 | 0.782 | 0.243 |
| Composite Reliability test | 0.762 | 0.895 | 0.725 | 0.758 | 0.902 | 0.706 |
| rho_A | 0.656 | 0.899 | 0.245 | 0.682 | 0.782 | 0.304 |

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A6: Discriminant validity using Fornell-Larcker criterion

| | Behavioural intention | | | Awareness | | |
|------------------------------------|-----------------------|-----------------------|-------------------|---------------------|------------------------------------|-------------------|
| | Financial inclusion | Behavioural intention | Energy transition | Financial inclusion | Clean & renewable energy awareness | Energy transition |
| Financial inclusion | 1.000 | 0.039 | 0.064 | 1.000 | 0.024 | 0.063 |
| Behavioural intention | 0.039 | 1.000 | 0.098 | | | |
| Clean & renewable energy awareness | | | | 0.024 | 1.000 | 0.088 |
| Energy transition | 0.064 | 0.098 | 1.000 | 0.063 | 0.088 | 1.000 |
| Average variance extracted (AVE) | 0.322 | 0.422 | 0.569 | 0.323 | 0.821 | 0.559 |