

Household Solar Home System Adoption in Rural Ethiopia: Determinants, Service Adequacy and Development Outcomes, with Evidence from Amhara

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Abstract

Off-grid solar has become an important pathway for extending electricity services to rural Ethiopian households, yet adoption remains uneven and the adequacy of installed systems varies substantially. This review synthesizes household-level evidence on the determinants and development implications of solar home system (SHS) adoption in rural Ethiopia, with particular attention to the Amhara Region. A structured critical review was undertaken using peer-reviewed Ethiopian studies published between 2018 and August 2026, complemented by the Ethiopia Socioeconomic Survey documentation and current national energy-policy material. The evidence was organized around economic capacity, education and information, finance, institutional support, spatial and grid conditions, product and service quality, demographic heterogeneity, and post-adoption outcomes. Across studies, household income and wealth are among the most consistent enabling factors, but affordability is better understood as a liquidity and risk problem than as income alone. Education, prior knowledge, media exposure, training and extension contact repeatedly reduce informational barriers. Amhara-specific studies provide especially strong evidence for the importance of credit, knowledge and extension services, while pay-as-you-go models can relax upfront payment constraints and yield welfare gains through lower energy expenditure, longer study time, improved perceived security and changes in time allocation. Evidence from recent Ethiopian studies also shows that market distance, grid access, system cost and system capacity shape adoption in ways that binary adopter/non-adopter measures can obscure. The review concludes that sustainable solar diffusion requires an integrated market ecosystem: affordable finance, credible quality assurance, consumer information, local maintenance, geographically differentiated electrification planning and support for adequate system capacity. Future work should exploit household panel and geospatial data to distinguish initial adoption, sustained use and progression to higher-capacity systems.

Keywords: solar home systems; technology adoption; rural electrification; energy poverty; Amhara; Ethiopia; PAYGO

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1 Introduction

Electricity access is increasingly intertwined with education, communication, health, enterprise activity and the ability of rural households to participate in modern markets. In Ethiopia, however, the economics of extending centralized networks to dispersed settlements have made universal grid connection difficult. Standalone solar technologies therefore occupy a distinctive position: they can be deployed without waiting for conventional distribution infrastructure, but their usefulness depends on what households can afford, what products reach local markets and whether systems remain functional after installation.

The policy relevance of this question has increased. Ethiopia endorsed a National Energy Compact under Mission 300 in September 2025, within a broader effort to expand affordable energy, scale renewable and distributed solutions and strengthen the electricity sector [1]. The World Bank has also emphasized distributed renewable energy, including standalone solar, as a practical route for reaching underserved and remote communities [2]. These policy commitments create a need to understand not only how many systems are distributed, but why households adopt, which households remain excluded and what level of service adopted systems actually provide.

A simple technology-supply explanation is insufficient. Rural Ethiopia has strong solar potential, yet households face heterogeneous budget constraints, market access, information, expectations about future grid connection and

exposure to product failure. A household may understand the benefits of solar lighting and still postpone purchase because the initial payment competes with food, agricultural inputs, school costs or health expenditure. Another household may have adequate purchasing power but lack confidence in product quality or access to repair services. In a remote village, solar may be the only realistic source of modern electricity; near a grid corridor, the same household may wait for a connection instead.

Empirical research has gradually moved beyond describing these barriers. Guta [3] used a logit model in rural communities near Woliso and found that wealth and education increased the likelihood of solar adoption. Zeru and Guta [4] showed that economic status, media access and training shape rural attitudes toward SHSs. Ahmed et al. [5], working with 500 farm households in East and West Belesa in Amhara, identified education, extension services, knowledge and credit utilization among the positive adoption factors. Fentie et al. [7], using Ethiopian household survey data, found that income, education, fuel prices and location influence the transition toward cleaner lighting fuels. More recent work has extended the literature from the decision to adopt toward welfare outcomes and system adequacy [6, 8, 9].

This growing literature is valuable but fragmented. Studies differ in region, sampling frame, unit of analysis, definition of adoption and econometric strategy. Some model a binary adoption decision; others examine attitudes, lighting-fuel transitions, system sustainability, installed capacity or post-adoption outcomes. These outcomes are related but not interchangeable. A household owning a small solar lantern is not equivalent, in energy-service terms, to one operating a 300-W SHS, and neither is equivalent to a grid-connected household using solar as backup.

The present review addresses this fragmentation by synthesizing Ethiopian household-level evidence through an adoption pathway rather than a single binary outcome. It asks what conditions enable initial adoption, what conditions affect the capacity and sustainability of use, and what benefits have been documented after adoption. Amhara is emphasized because it contains both direct determinant evidence from the Belesa districts and an impact evaluation of pay-as-you-go (PAYGO) SHSs, allowing the review to connect adoption mechanisms with observed welfare outcomes.

The review has four objectives: (1) identify the socioeconomic, informational, institutional and spatial determinants that recur across Ethiopian studies; (2) assess which findings are robust and which are context dependent; (3) examine what Amhara-specific evidence adds to the national picture; and (4) derive policy and research implications that distinguish access, sustained use and adequate system capacity.

2 Methods

2.1 Review design and search strategy

This article is a structured critical review and secondary-data synthesis. It is not presented as a systematic review in the PRISMA sense, and no claim is made that every publication on Ethiopian solar energy was captured. The method was designed instead to identify the principal household-level empirical studies that directly inform adoption, attitudes, lighting transition, system sustainability, installed capacity or socioeconomic outcomes.

Searches were conducted up to 17 August 2026 using publisher platforms and scholarly discovery services, including ScienceDirect, SpringerLink, Taylor & Francis Online, the Directory of Open Access Journals, institutional research portals and the World Bank Microdata Library. Search combinations included “Ethiopia solar home system household adoption”, “rural Ethiopia solar energy determinants”, “Amhara solar adoption”, “Amhara PAYGO solar”, “Ethiopia household lighting transition”, “solar home system sustainability Ethiopia”, and “solar home system capacity Ethiopia”. Citation details and study findings were checked against publisher or institutional records where available.

Peer-reviewed studies were included when they (a) focused on Ethiopia; (b) used households or household energy choices as a central unit of analysis; (c) reported evidence directly relevant to solar adoption, attitudes, capacity, sustainability or impacts; and (d) provided sufficient methodological information to interpret the result. Authoritative public survey documentation and current policy sources were included to contextualize the household evidence. Purely engineering studies of photovoltaic performance, studies without an Ethiopian empirical component and unverifiable secondary claims were excluded from the core synthesis.

The principal empirical evidence base spans 2018-2026. This period captures the development of a household-adoption literature from early cross-sectional logit studies through recent research on PAYGO impacts, capacity choice and mixed-method impact evaluation. Because the number of directly relevant Ethiopian household studies remains modest and study designs are heterogeneous, a statistical meta-analysis was not appropriate.

2.2 Evidence extraction and synthesis

For each study, the review extracted the geographical setting, sample or data source, outcome studied, analytical method and principal findings. Findings were then coded into seven conceptual domains: household economic resources; education and information; credit and payment mechanisms; institutional and extension support; grid, market and spatial context; product quality and after-sales service; and demographic heterogeneity. Post-adoption outcomes were considered separately so that determinants of adoption were not conflated with consequences of adoption.

The synthesis emphasizes consistency rather than vote-counting. A variable was treated as comparatively robust when conceptually similar relationships appeared across different datasets or regions. Contradictory or weak findings were retained rather than averaged away. The review also distinguishes the extensive margin of adoption (whether a household adopts) from the intensive margin (the capacity or level of energy service obtained after adoption).

The Ethiopia Socioeconomic Survey (ESS) 2018/19 was used only as documented secondary context. The public catalogue records the survey design and household energy variables, but this review did not download unit-record data or estimate new weighted regressions. No coefficient, prevalence rate or Amhara-specific estimate in this article is presented as newly generated from ESS microdata.

3 Evidence base and Ethiopian context

Table 1 summarizes the core household-level studies used in the synthesis. The studies collectively cover central Ethiopia, Amhara, Tigray and southern Ethiopia, as well as nationally oriented household survey evidence. Their diversity is useful because it exposes both recurring determinants and regional heterogeneity, but it also limits direct numerical comparison: definitions of solar adoption, sampling frames and model specifications differ substantially.

Table 1. Core Ethiopian household-level evidence included in the review. NRM = natural resource management; KII = key-informant interview; FGD = focus-group discussion; PSM = propensity-score matching.

Study	Setting	Data/sample	Method/outcome	Main contribution
Guta [3]	Two rural kebeles near Woliso, Oromia	Cross-sectional household survey	Logit; binary solar adoption	Wealth and education increase adoption; gender effect differs from common assumptions.
Zeru & Guta (2021)	Baso Liben, northern Ethiopia / Amhara	371 households: 228 adopters, 143 non-adopters	Ordered logit; attitude toward SHS	Economic status, media access and training are associated with more favorable attitudes.
Ahmed et al. [5]	East and West Belesa, Amhara	500 farm households; multistage sampling plus qualitative evidence	Binary logit; solar adoption	Education, family size, NRM participation, extension, knowledge, credit use and climate perception positively predict adoption.
Fentie et al. [7]	Ethiopia	World Bank socioeconomic survey panel plus cross-sectional evidence	Panel multinomial logit; lighting-fuel transition	Income, education, fuel prices and location shape transition toward cleaner lighting.
Beyene et al. [6]	Rural Amhara	PAYGO SHS adopters and comparison households	Descriptive analysis and propensity-score matching; welfare impacts	Lower energy expenditure and gains in study time, perceived security, health and time allocation; no discernible income effect.
Gebre et al. [8]	Rural Tigray	161 female-headed SHS-adopting households	OLS; installed SHS capacity (80-700 W)	Higher cost reduces and higher income increases installed capacity; age is negative, demonstrating an intensive-margin constraint.
Gebretsadik et al. [9]	Southern Ethiopia	154 households: 82 adopters, 72 non-adopters; KIIs and FGDs	Binary logit with robust SEs and PSM; adoption and impacts	Education, income, credit, awareness and cooperative participation positive; market distance and grid access negative; welfare/environmental gains reported.
Gebreslassie [10]	Rural Ethiopia	398 SHS households from a wider user population	Questionnaire; sustainability of SHS use	Initial cost, awareness, failures, maintenance capacity, installation costs and spare-parts availability affect sustained use and market confidence.

3.1 Secondary-data context

The World Bank Microdata Library documents the 2018/19 Ethiopia Socioeconomic Survey as a nationally implemented household survey with regional and rural/urban coverage and a detailed housing module that includes household lighting sources and solar devices [11]. This matters methodologically because national

household survey data make it possible to study energy choices with survey weights and, where panel structure is available, to examine transitions over time. Fentie et al. [7] demonstrate the value of this approach by modeling household lighting-fuel transitions rather than relying only on cross-sectional ownership.

Current policy developments also reinforce the relevance of distributed energy. Ethiopia's National Energy Compact was endorsed in September 2025 as part of Mission 300 [1]. Rather than treating grid and off-grid electrification as competing ideologies, the policy direction emphasizes multiple delivery channels. For household adoption research, this means grid proximity, expected connection timing and service reliability should be modeled jointly with solar-market factors.

4 Synthesis of determinants

4.1 Economic capacity, affordability and liquidity

Economic capacity is the most consistent theme across the evidence. Guta [3] found that wealthier households were more likely to adopt solar technology, while Fentie et al. [7] found that higher income facilitates transition toward cleaner lighting fuels. Recent work reaches a similar conclusion from a different outcome: among female-headed SHS users in Tigray, higher income is associated with higher installed system capacity, while system cost constrains capacity choice [8]. Gebretsadik et al. [9] also report a positive association between income and adoption in southern Ethiopia.

The important analytical point is that income should not be interpreted merely as preference for modern energy. SHSs involve a capital or contractual commitment. Even when the lifetime cost of solar is favorable relative to kerosene, dry-cell batteries or repeated phone-charging payments, the household must finance the acquisition at a specific moment. Seasonal agricultural income, uncertain harvests and competing expenditure obligations can make a technically cost-effective system financially inaccessible.

This distinction between economic value and liquidity explains why credit emerges as a separate determinant. In the Belesa districts, credit utilization was a positive predictor of adoption [5]. In southern Ethiopia, access to credit was also positively associated with solar adoption [9]. The convergence of these findings across regions suggests that rural solar policy should examine cash-flow constraints directly rather than assuming that declining equipment prices will automatically produce equitable uptake.

Affordability also operates on the intensive margin. A household may cross the threshold into solar ownership but remain restricted to a small system that provides lighting and phone charging only. Gebre et al. [8] demonstrate that system cost and income affect the capacity chosen among existing users. This is important for SDG 7 because meaningful energy access depends on adequacy, reliability and service capability, not ownership alone.

4.2 Education, knowledge, media and training

Education and information recur almost as consistently as economic resources. Guta [3] reports a positive association between education and adoption. In Belesa, education and knowledge about solar technology were positive determinants [5]. Zeru and Guta [4] identify media access and training as important for favorable attitudes toward SHSs, and Gebretsadik et al. [9] report positive roles for education and awareness.

These variables likely capture several mechanisms. Education can improve the ability to compare future operating costs, understand warranties and evaluate claims about system capacity. Media and extension contact can reduce uncertainty about where to buy equipment and how it performs. Training can also improve correct use, which matters because poor operating practices may shorten component life and generate negative word-of-mouth effects.

The evidence therefore favors practical consumer information over generic promotion. Rural households need to know which appliances a system can support, how battery life depends on use, what payment obligations continue under a PAYGO contract, who provides maintenance and whether spare parts are locally available. Information is most valuable when it reduces a concrete decision risk.

4.3 Extension, cooperative participation and institutional contact

Institutional contact has an independent role in several studies. Ahmed et al. [5] identify extension services and participation in natural resource management activities as positive predictors of adoption in Belesa. Gebretsadik

et al. [9] find that cooperative participation is positively associated with adoption in southern Ethiopia. These findings suggest that organizations already embedded in rural communities can act as information and trust channels.

The mechanism is plausible but should be interpreted cautiously. Participation in extension or cooperatives may proxy for social connectedness, access to projects or unobserved household initiative. Cross-sectional logit models cannot fully separate these pathways. Even so, institutional channels are operationally important because they can reduce transaction costs for suppliers and consumers, particularly where private retail networks are thin.

4.4 Grid access, remoteness and market distance

Spatial context affects both the value of solar and access to the solar market. Where grid electricity is available or expected soon, households may postpone a standalone investment. Gebretsadik et al. [9] report a negative relationship between grid access and solar adoption. Fentie et al. [7] also show that location affects household lighting-fuel choices. These results are consistent with substitution between energy options, although reliability and connection cost can make solar complementary to the grid in some settings.

Remoteness creates a more complex relationship. Distance from the grid can increase the value of standalone solar, while distance from markets can reduce adoption by raising equipment, transport and service costs. Gebretsadik et al. [9] report a negative association between market distance and adoption. The implication is that the households for whom solar is most technically appropriate may simultaneously face the weakest commercial service environment.

This spatial tension supports geographically differentiated electrification planning. A credible program should combine information about expected grid arrival with road access, settlement density, supplier presence and repair networks. Without that coordination, households may be encouraged to buy systems shortly before grid connection, or remote communities may be nominally targeted for off-grid electrification without a viable after-sales chain.

4.5 Product quality, maintenance and after-sales service

Adoption is not complete at the point of purchase. Gebresslassie [10], based on a survey of 398 SHS-using households, identifies high initial investment cost, incomplete awareness of system operation, frequent failures, limited maintenance expertise, high installation and maintenance costs and shortage of spare parts as sustainability challenges. These factors affect both continued use by adopters and confidence among prospective adopters.

Quality and service produce neighborhood externalities. A reliable installation can function as a demonstration of value, while visible failures can discourage multiple potential customers. The relevant policy unit is therefore not only the device but the service chain: importer or manufacturer, distributor, installer, financing provider, technician, warranty process and spare-parts channel.

This perspective also changes how adoption should be measured. A one-time household survey that records ownership can overstate effective access if the system is broken, under-sized or no longer used. Future surveys should record functionality, system wattage, battery condition, repair history, warranty experience and duration of use.

4.6 Demographic heterogeneity and gender

Demographic effects are less stable than economic and informational effects. Guta [3] found male-headed households less likely to adopt than female-headed households in the study setting, and Zeru and Guta [4] report more favorable SHS attitudes among female-headed households. In contrast, later studies show that age and gender effects vary by model and location. These results should not be generalized into a universal claim that one sex is inherently more likely to adopt solar.

Gender may operate through decision-making authority, exposure to household energy burdens, control over cash, access to credit and responsibility for children's study conditions. Recent Tigray evidence is instructive because it focuses exclusively on female-headed adopter households and asks a different question: what determines the capacity of the system chosen? In that setting, income and cost dominate, while several household characteristics have limited effects [8]. The result suggests that gender-responsive policy must address economic constraints, not simply target women with information campaigns.

Age effects also require careful interpretation. Older household heads may have different technology preferences, planning horizons and income sources, but age can proxy for lifecycle wealth or social position. A negative age coefficient in one cross-section is therefore not sufficient evidence of a general behavioral mechanism.

5 Amhara Region: what the regional evidence adds

Amhara provides an unusually useful combination of determinant and impact evidence. Ahmed et al. [5] examined 500 farm households in East and West Belesa using a multistage sample and binary logit model. Seven variables were reported as positive adoption determinants: education, family size, participation in natural resource management activities, extension services, knowledge about solar technology, credit utilization and perception of climatic change. The study is especially relevant because credit, extension and knowledge are variables that policy can influence more directly than demographic characteristics.

The Belesa findings should nevertheless be interpreted in light of the sample context. The districts and sampled kebeles were connected to project intervention areas, and the reported adoption share in the sample was very high. This raises the possibility that intervention exposure and purposive site selection affect generalizability. The findings are therefore strong evidence about mechanisms within the study context, but not an estimate of Amhara-wide adoption prevalence.

Beyene et al. [6] provide a complementary perspective by evaluating PAYGO SHSs marketed in rural Amhara. Using descriptive analysis and propensity-score matching, they found no discernible effect on household income but did find lower monthly energy expenditure and improvements in children's evening study time, self-reported health, women's allocation of time and perceived safety and security. This matters because it separates the value of solar electricity from an assumption of immediate income growth.

Taken together, the two Amhara studies suggest a coherent pathway. Credit and institutional information can facilitate entry into adoption; PAYGO can reshape the timing of payment; and adoption can generate welfare benefits even where measured income does not rise. Yet an unresolved question remains: which Amhara households are excluded from both conventional purchase and PAYGO, and what determines whether adopters progress from basic lighting systems to capacity adequate for productive uses? Existing regional studies do not fully answer that question.

A future Amhara research design should therefore distinguish at least four states: non-electrified households, basic solar users, higher-capacity SHS users and grid-connected households that use or do not use solar. It should combine household socioeconomic variables with distance to markets and grid infrastructure, supplier presence, credit terms and system functionality. Such a design would move beyond a binary adoption variable toward a more policy-relevant model of energy-service progression.

6 Post-adoption welfare and environmental outcomes

The adoption literature often implies that access to electricity should increase household income, but the Ethiopian evidence calls for a more differentiated expectation. Beyene et al. [6] did not identify a discernible household-income effect from PAYGO SHS use in Amhara, while observing several non-income benefits. This is plausible because a system designed mainly for lighting and charging can reduce recurring energy costs and extend usable evening hours without supplying enough power for irrigation, refrigeration or mechanized production.

Recent southern Ethiopian evidence reports broader livelihood and environmental effects, including reductions in fuelwood use and biomass-collection time and increases in children's study time among adopters [9]. Because that study combines cross-sectional matching with qualitative evidence, causal interpretation should still be cautious; unobserved differences between adopters and non-adopters may remain after matching. Nevertheless, the direction of these results is consistent with the household service changes expected when electric lighting substitutes for traditional fuels.

For policy evaluation, this means outcome metrics should be matched to system capability. Small SHSs should be evaluated on lighting quality, communication, expenditure savings, safety, study time and time use. Productive-use systems should additionally be evaluated on enterprise revenue, agricultural output, refrigeration,

irrigation or processing. Conflating these categories can produce unrealistic expectations and unfair assessments of otherwise valuable household systems.

7 Cross-study interpretation

Table 2 summarizes the direction and consistency of major determinants across the reviewed Ethiopian evidence. The strongest convergence concerns economic capacity, education/information and access to finance. Grid and market variables are important but context-specific because they affect both the relative value of solar and the feasibility of obtaining service. Demographic coefficients are the least portable across settings.

Table 2. Cross-study synthesis of determinants. “Consistency” refers to recurrence across the reviewed Ethiopian evidence, not a formal meta-analytic effect size.

Determinant/domain	Typical direction	Consistency	Interpretation
Income/wealth	Positive	High	Raises ability to pay upfront or sustain installments; also affects capacity choice.
Credit/PAYGO access	Positive enabling effect	High-to-moderate	Relaxes liquidity constraints; contract terms and repayment risk still matter.
Education	Generally positive	High	Improves information processing and is associated with cleaner-fuel transition and adoption.
Knowledge/awareness	Positive	High-to-moderate	Reduces uncertainty about benefits, operation and product choice.
Training/media/extension	Positive	Moderate	Provides information and institutional trust; may also proxy for project exposure.
Market distance	Negative where measured	Moderate	Raises transaction and service costs; especially important for remote households.
Grid access	Often negative for standalone adoption	Context dependent	Grid can substitute for standalone solar, but unreliable grids may create complementary demand.
System cost	Negative	High	Constrains both initial adoption and higher-capacity choice.
Maintenance/quality	Positive when service is reliable	Moderate	Affects sustained use, reputation and willingness of other households to adopt.
Gender/age/family structure	Mixed	Low	Effects vary by region, sample and outcome; should not be treated as universal determinants.

7.1 From binary adoption to an adoption pathway

The literature increasingly reveals a limitation of the standard binary adoption model. A household can move through several stages: awareness, intention, acquisition, continued use, replacement or upgrading, and productive use. Different constraints dominate at different stages. Information may be decisive before first purchase; maintenance becomes decisive after installation; income and credit affect both initial purchase and upgrading; and grid arrival can change the value of keeping a standalone system.

The distinction between extensive and intensive margins is particularly important. Binary models answer who crosses the threshold into ownership. Capacity-choice models ask whether the acquired service is adequate. Gebre et al. [8] show that income and cost continue to constrain households even after adoption. This implies that an electrification program can achieve high ownership while leaving energy poverty partially unresolved if most systems remain too small for household aspirations or productive applications.

A pathway framework also clarifies why inconsistent coefficients need not be contradictions. For example, education may matter strongly for initial adoption but less for capacity once all sampled households are experienced users. Grid access may reduce standalone adoption in one region but stimulate backup-solar demand in another. The outcome being modeled must therefore be specified precisely.

8 Policy implications

8.1 Treat affordability as cash-flow design

Evidence across Ethiopia supports financing interventions, but financing should be designed around rural cash flow rather than simply converting a purchase price into installments. Seasonal repayment schedules, transparent total costs, consumer protection and mechanisms for temporary income shocks can matter as much as the headline monthly payment. PAYGO can broaden access, but it does not eliminate affordability constraints for the poorest households.

8.2 Combine finance with trustworthy information

Credit without credible information can finance the wrong product. Programs should disclose rated capacity, expected battery life, warranty terms, replacement costs, permitted appliance loads and total repayment obligations. Extension agents, cooperatives and community demonstrations can help, but information should remain product-neutral where possible to avoid turning trusted institutions into sales channels for low-quality devices.

8.3 Build maintenance into electrification programs

The sustainability evidence indicates that spare parts, technicians and installation quality are part of electricity access, not post-project extras. Public support or results-based finance for system distribution should therefore incorporate after-sales performance indicators such as warranty resolution, repair turnaround time and system functionality after one or two years.

8.4 Plan grid and off-grid expansion jointly

Spatial targeting should integrate expected grid-extension timing with market access and settlement patterns. Households in locations unlikely to receive the grid in the medium term have a stronger case for standalone systems, while areas close to planned network expansion may require modular or interoperable technologies. Information about credible grid plans can also reduce uncertainty for households deciding whether to invest.

8.5 Support progression to adequate capacity and productive use

Policy should distinguish first access from adequate access. Financing products for higher-capacity systems, efficient appliances and productive equipment may be needed after households gain experience with basic solar. For agriculture and rural enterprise, the relevant intervention may be a package combining energy, equipment, finance and market linkage rather than a household SHS alone.

9 Research gaps and priorities

First, Ethiopia needs more regionally representative evidence. Many existing studies use purposively selected districts or project areas. These studies identify mechanisms but cannot estimate regional prevalence or fully separate program exposure from household characteristics. Weighted survey data combined with geospatial grid and market information would improve external validity.

Second, longitudinal analysis is needed. Cross-sectional adoption models cannot determine whether income causes adoption, whether adoption changes income, or whether both reflect unobserved household capability. Panel data can model transitions into adoption, system failure, replacement and upgrading.

Third, research should record system capacity and functionality. The binary variable “owns solar” collapses substantial variation in wattage, battery storage, service hours and appliance capability. Energy-access research should distinguish pico-solar, basic SHS, higher-capacity SHS and productive-use systems.

Fourth, financing needs household-level evaluation. Studies should compare outright purchase, microcredit, PAYGO and subsidized models using repayment performance, default, disconnection, total lifetime cost and welfare outcomes. The poorest households may remain excluded even when PAYGO expands the addressable market.

Fifth, the relationship between solar and the grid requires more precise treatment. Grid access should be separated into distance to infrastructure, actual household connection, reliability, tariff and expected connection timing. Each can influence solar adoption differently.

Finally, conflict and institutional disruption deserve attention in northern Ethiopia. Market networks, household assets and public infrastructure can change rapidly after shocks, altering both demand for decentralized systems and the feasibility of repair and financing. Research in Amhara and Tigray should therefore be explicit about survey timing and local operating conditions rather than assuming institutional stability.

10 Limitations

This review has four main limitations. First, it is a structured critical review rather than a preregistered systematic review, so publication selection may not be exhaustive. Second, the empirical studies are heterogeneous in outcome definition, geography and sampling design, which prevents formal pooling of coefficients. Third, most determinant studies are observational and cross-sectional, so associations should not

automatically be interpreted as causal effects. Fourth, current national policy is evolving quickly; policy context described here reflects information available through 17 August 2026.

The review also deliberately avoids generating new household statistics from the ESS catalogue. Public documentation confirms that relevant energy variables and regional survey structure exist, but unit-record analysis with survey weights would be required for valid new population estimates. This restraint is important because raw catalogue frequencies should not be treated as weighted Ethiopian or Amhara prevalence estimates.

11 Conclusion

The Ethiopian evidence no longer supports a simple explanation of rural solar adoption as a function of sunshine availability or household income alone. Adoption is a staged decision made under financial, informational, institutional and spatial constraints. Income and wealth are consistently important, but credit evidence from Amhara and southern Ethiopia shows why liquidity and payment structure must be treated separately. Education, awareness, training, media and extension services reduce uncertainty; market distance and grid conditions alter the relative value and accessibility of standalone systems; and system quality and maintenance determine whether ownership becomes sustained energy access.

Amhara-specific evidence is particularly instructive. In East and West Belesa, education, extension, knowledge and credit are among the positive adoption determinants. PAYGO evidence from rural Amhara shows that solar can lower energy expenditure and improve study time, perceived security, health and time allocation even without a discernible household-income effect. The combined message is that the value of solar should be assessed in terms of service and welfare, not only income or ownership.

The next generation of Ethiopian solar research should therefore move from a binary adoption question to an adoption pathway: who learns about solar, who can finance it, who receives a functioning system, who maintains it, who upgrades to adequate capacity and who converts electricity into productive use. Policy can then be designed around the actual point at which households are constrained. For rural Ethiopia, sustainable solar diffusion is best understood not as device distribution but as the construction of a reliable energy-service ecosystem.

Abbreviations

ESS	Ethiopia Socioeconomic Survey
FGD	Focus-group discussion
KII	Key-informant interview
NRM	Natural resource management
PAYGO	Pay-as-you-go
PSM	Propensity-score matching
SHS	Solar home system

References

- [1] World Bank. (2025). National Energy Compacts in Africa: Ethiopia National Energy Compact (September 2025). Mission 300. <https://www.worldbank.org/ext/en/energizingafrica/national-energy-compacts>
- [2] World Bank. (2025). Mission 300: Unlocking capital for off-grid solutions in Africa. <https://blogs.worldbank.org/en/energy/mission-300--unlocking-capital-for-off-grid-solutions-in-africa>
- [3] Guta, D. D. (2018). Determinants of household adoption of solar energy technology in rural Ethiopia. *Journal of Cleaner Production*, 204, 193-204. <https://doi.org/10.1016/j.jclepro.2018.09.016>
- [4] Zeru, A. M., & Guta, D. D. (2021). Factors influencing rural household attitude towards solar home system in Ethiopia. *Renewable Energy and Environmental Sustainability*, 6, 42. <https://doi.org/10.1051/rees/2021048>
- [5] Ahmed, Y., Ebrahim, S., & Ahmed, M. (2022). Determinants of solar technology adoption in rural households: The case of Belesa districts, Amhara region of Ethiopia. *Cogent Economics & Finance*, 10(1), 2087644. <https://doi.org/10.1080/23322039.2022.2087644>
- [6] Beyene, A. D., Mekonnen, A., Jeuland, M., & Czakon, S. (2024). Socioeconomic impacts of solar home systems in rural Ethiopia. *Renewable and Sustainable Energy Reviews*, 192, 114197. <https://doi.org/10.1016/j.rser.2023.114197>
- [7] Fentie, A., Hassen, S., & Sebsibie, S. (2023). Climbing up the ladder: Households' fuel choice transition for lighting in Ethiopia. *Energy Economics*, 128, 107162. <https://doi.org/10.1016/j.eneco.2023.107162>

- [8] Gebre, T., Hailu, L., Abera, B., & Gebreegziabher, F. (2026). Determinants of solar home system capacity choice (80-700 W) among female-headed households in rural Tigray, Ethiopia. *Discover Sustainability*, 7, 826. <https://doi.org/10.1007/s43621-026-03244-3>
- [9] Gebretsadik, T., Zavale, H., & Manuel, L. (2026). Determinants and impacts of solar energy on rural livelihoods and environmental sustainability outcomes in southern Ethiopia. *Discover Sustainability*. <https://doi.org/10.1007/s43621-026-03853-y>
- [10] Gebreslassie, M. G. (2020). Solar home systems in Ethiopia: Sustainability challenges and policy directions. *Sustainable Energy Technologies and Assessments*, 42, 100880. <https://doi.org/10.1016/j.seta.2020.100880>
- [11] World Bank. (2020). Ethiopia Socioeconomic Survey 2018-2019 (ESS4), Version 04 [Data documentation]. Microdata Library. <https://doi.org/10.48529/3gma-7g23>