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Are climate finance subsidies equitably distributed among farmers? Assessing socio-demographics of solar irrigation in Nepal

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ABSTRACT

Solar-powered irrigation pumps are a vital tool for both climate change adaptation and mitigation. Since most developing countries cannot fully utilize large-scale global funds for climate finance due to limited institutional capacities, small-scale solar irrigation pumps (SIPs) can provide a climate-resilient technological solution. We study the case of a subsidized SIP program in Nepal to understand who likely benefits from a small-scale climate finance program in a developing country setting. We analyze government data on profiles of farmers applying for SIPs and in-depth interviews with different actors along the SIP service chain. We find that vulnerable farmers (women, ethnic minorities, and poor farmers) were less likely than wealthier and non-minority farmers to have access to climate finance subsidies. Even though the government agency gave preference to women and ethnic minority farmers during beneficiary selection, an unrepresentative pool of applicants resulting from social and institutional barriers that prevented them from applying to the program led to an inequitable distribution of subsidized SIPs. The lack of a clear policy framework for allocating climate finance subsidies was a significant constraint. Lack of periodic updating of SIP prices and poor provision of after-sale services were also responsible for the inequitable distribution of subsidized SIPs. We recommend the involvement of local governments in soliciting applications from a wider pool of farmers, periodic revision of SIP prices to reflect market price, replacement of the current fixed subsidy scheme with a variable subsidy scheme, and mandatory provisions of after-sales services.

1. Introduction

Climate change has slowed growth in agricultural productivity in the past fifty years, particularly in low and mid-latitude countries [1–4]. The climate-induced slowdown of agricultural production threatens the food and income security of millions of vulnerable farmers in developing countries because of the primacy of the agricultural sector and a significant contribution of agricultural growth to poverty alleviation in these countries [5,6]. Using agricultural growth to help achieve poverty reduction and sustainable development without additional carbon emissions is a core sustainability challenge for most countries in the Global South.

This challenge is particularly acute in South Asia, which is home to the world's largest number of smallholder farmers, and where productive agriculture relies heavily on fossil fuel-based groundwater irrigation [7–9]. Imported fossil fuel is subsidized, causing a financial burden for the governments, which can reduce public investment in other social sectors like health and education [10,11]. Intensification of groundwater irrigation, particularly in regions where groundwater is abundant, and natural recharge is high, e.g., Nepal's *Tarai* region [12] and parts of eastern Ganga Basin, can improve food security and reduce poverty via higher agricultural productivity [13,14]. In these regions, while intensive use of groundwater irrigation can have a positive externality of increased induced recharge [15],[1] it can also exacerbate the climate

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[1] In alluvial aquifers where water tables are shallow, and there is high recharge due to high rainfall (e.g., aquifers in eastern Gangetic plains, including Nepal Terai), extracting groundwater in the pre-monsoon season results in lowering of groundwater levels, which then creates space for additional recharge of monsoon rainfall, which otherwise would have resulted in “rejected recharge” and floods. This phenomenon is called the “Ganges Water Machine” [16]. Recently, several studies from similar aquifers in the region have established that drawdown of alluvial aquifer in the pre-monsoon season through intensive irrigated cultivation in summer leads to more recharge, and lesser floods in the monsoon and post monsoon seasons [15,17–19].

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crisis by causing additional carbon emissions due to the increased use of conventional fossil fuel pumps for water extraction.

In this context, solar irrigation pumps (SIPs) offer a low carbon, climate-resilient technological solution, especially in groundwater-abundant regions where it can improve access to irrigation. Solar-powered irrigation can help in both climate change mitigation and adaptation efforts. It can increase agricultural production without adding carbon emissions and reduce emissions by replacing existing diesel and fossil fuel-based electric pumps [20–24]. Solar irrigation can also enhance food security and reduce poverty [25–27], primarily by increasing agricultural productivity and reducing the cost of irrigation [21,24,28].

One of the major impediments to adopting SIPs by smallholder farmers is the high upfront cost [21,22] which requires financial support in the form of climate finance. Another critique of climate finance, apart from its general inadequacy, is that it does not often reach those most in need, especially marginal communities like small and marginal farmers [29]. For example, women farmers do not enjoy the same access to irrigation technologies as men [30–32]. Farmers from marginalized social groups face additional barriers from intersections of unequal social identities such as caste, class, or ethnicity [32]. Unequal social and gender norms and rules deeply embedded in formal and informal institutions influence marginal farmers' differential access, adoption, and benefits from technology [33].

In this context, targeted climate finance for SIPs can help reach small and marginal farmers and, in the process, also allow countries better utilize large-scale climate funds [34]. Furthermore, such targeted climate finance for SIPs helps cater to the increasing interest in SIPs among South Asian farmers and policymakers, for whom grants and subsidies remain the most popular tools [35–38]. This study generates much-needed evidence by examining the current policy landscape for climate finance using the case of solar irrigation expansion in Nepal. Specifically, it investigates who benefits from a subsidized solar irrigation program by unpacking barriers and gaps in policies for equitable distribution of subsidized solar pumps to farmers of different gender, caste/ethnicity, and wealth status.

Within the broader context of the policy imperative of decarbonizing irrigation and the government of Nepal's emphasis on promoting SIPs [37], this paper provides much-needed evidence on the determinants of the adoption of a climate finance program and policy gaps for equitable distribution of climate finance subsidy. We analyze the country's SIP expansion program led by a federal government agency - Alternative Energy Promotion Center (AEPC). First, we investigate who benefits from the subsidized solar irrigation program by analyzing administrative data collected by the government from >4500 farmers who applied to the subsidized SIP program. Second, we explore the current policy landscape for solar irrigation development and identify the existing gaps between policies and implementation. This question is answered by studying available policies and programs related to energy and irrigation as well as by conducting expert consultations (key informant interviews – KII) and focus group discussions (FGD) with different actors along the SIP service chain.

Results show that a significant portion of subsidized SIPs went to relatively well-off farmers. Results from the administrative data showed that the probability of receiving SIPs increased with land holding size at a decreasing rate. Among the applicants, mid-sized land-holding farmers had a higher chance of receiving the subsidized pumps than small-scale farmers. Likewise, conditional on applying, the probability of receiving SIPs was higher for *Brahmin/Chhetri* than for other minority social groups. The proportion of women farmers who received the pumps was greater than that of women who applied. However, the qualitative survey revealed that despite the federal agency's effort to make the solar program socially inclusive by selecting '*marginal*' farmers from the pool of applicants, the final list of beneficiaries was not representative of true farmer diversity due to a biased pool of applicants. In most cases, smallholders and marginal farmers (women, lower caste/ethnic minorities) were either unaware of the program or excluded from applying, citing small land sizes and poor social connections. Policy gaps and unclear targeting during the application stage, which was outsourced to private firms, resulted in a pool of applicants not representative of the farmer population. We also find that program monitoring, quality checks of SIPs, and provision of after-sale services were weak at best and often non-existing.

The rest of the paper proceeds as follows. Section 2 discusses Nepal's subsidized solar irrigation policies and programs. Section 3 discusses research methods. Data are described in Section 4, along with key summary statistics. Section 5 provides econometric results, followed by qualitative results in Section 6. Section 7 discusses the findings and provides policy recommendations, and Section 8 concludes.

2. Solar irrigation program and policies in Nepal

Nepal is committed to several internationally agreed goals for climate change mitigation and adaptation, such as Nationally Determined Contributions (NDC) of the Paris Agreement, Sustainable Energy for All (SE4All), and Sustainable Development Goals (SDGs). The country aims to generate >4000 MW (MW) of renewable energy (solar energy, bio-energy, wind energy, and mini-hydro) by 2030 [39]. The Government of Nepal (GoN) has been providing financial and policy support to facilitate access to solar energy in rural areas [40]. Solar-powered irrigation has been embedded in the country's alternative energy plans and, as of 2021, the country has installed about 2000 subsidized SIPs. With the Rural Energy Policy of 2006, the government has provided financial and policy support to facilitate the expansion of renewable energy types, including solar-powered pumps, especially in areas with limited grid connectivity. However, the expansion of solar-powered irrigation started after 2016– thanks to two key policies legislated in 2016: Renewable Energy Subsidy Policy and Renewable Energy Subsidy Delivery Mechanism.

The primary goal of Nepal's subsidized SIP program is to raise awareness about solar irrigation and promote SIPs throughout the country in an equitable manner, with a particular focus in the *Tarai* region. The *Tarai* region has traditionally been the country's breadbasket due to its flat and fertile terrain [41,42]. Subsequently, the government allocated 350 million Nepali rupees (~USD 30 million) in 2018 and 960 million Nepali rupees (~USD 90 million) in 2019 for solar irrigation expansion [43]. Policy documents identify lack of credit mobilization as a significant barrier to adopting renewable energy technologies (RETs), including SIPs. Hence, the 2016 policies include a provision of 60 % subsidy to individual SIPs and up to 2000,000 rupees (~USD 20,000) subsidy to a community photo voltaic (PV) solar system [44]. Beneficiary farmers are expected to pay the remaining 40 % of the cost through personal funds or loans. In many cases, local government offices paid most of the remaining 40 % through a grant or interest-free loan. This subsidy policy is subject to review every two years, and AEPC is the sole authority to determine the maximum retail price (MRP) for SIPs to calculate subsidy amounts.

The Renewable Energy Subsidy Delivery Mechanism policy describes the SIP application collection process. Pre-selected private firms are authorized to lead the application collection process with support from local government bodies, including Nepal Electricity Authority (NEA) offices, irrigation department, and agricultural extension offices. Local government bodies are believed to include local government offices (*palikas*) as well, but it is not explicitly mentioned in the policy manuals.

Even though the 2015 Constitution of Nepal has devolved considerable power to the local *palikas* for small-scale RETs, the subsidized SIP program is a federal government's initiative implemented through the federal government agency, AEPC.

Both policies make it mandatory to conduct a feasibility study before installing SIPs, but leave it to the discretion of beneficiary farmers, making them responsible for both arrangements and the cost of the feasibility study. The importance of monitoring and evaluation of the program are identified, and AEPC is required to conduct an on-site monitoring every four months. It is mentioned that regular monitoring can be delegated to local government offices, but a biennial monitoring and impact evaluation of the program must be conducted by an independent third-party organization.

One of the larger stated policy goals is to maximize service delivery and efficiency of RETs in rural areas to improve the livelihoods of disadvantaged households, particularly single women, socio-economically disadvantaged groups, and victims of natural disasters. However, while equality and inclusion considerations seemingly form a core part of the renewable energy policy, it is not well visualized at the level of service delivery and program implementation. Also, there are no specific criteria against which beneficiary selections should be made.

AEPC is the largest provider of SIPs, but it is not the only agency. Some local governments have integrated solar irrigation development into their policies and programs, often independently of the AEPC's subsidized SIP program. In addition, the private sector and Non-Governmental-Organization (NGOs) have invested in solar irrigation. For example, several private firms such as *Sun Farmer* and *Gham Power* have installed a few hundred SIPs in the *Tarai* region. International organizations such as International Center from Mountain Development (ICIMOD), Winrock International, and International Development Enterprise (iDE) have also distributed a few hundred SIPs over the last few years on a pilot basis to test different financial models [45]. In the first five years (2016 to 2021), AEPC distributed >2000 subsidized SIPs nationwide. Official records show a rapidly increasing request for SIPs over time, but AEPC cannot meet the ever-growing requests due to limited budgetary allocations. According to AEPC data, about 300 farmers applied for SIPs in 2017; the number of applications increased to 3500 in 2019 and 4600 in 2020. AEPC has been able to meet only 21 % of the applications so far.

3. Research methods

We used a mixed-method approach to answer the two research questions posed earlier: who received subsidized SIPs and what are the existing gaps between policies and implementation, especially from the perspective of equality and social inclusion in subsidy distribution.

3.1. Quantitative method

Descriptive statistics are used to explore the geographical distribution of subsidized SIPs, the profile of applicants, eligibility criteria set forth by AEPC, irrigation water sources, and types of irrigation management. Finally, the probability of receiving climate finance subsidy, i.e., subsidized SIPs, conditional on applying to the program is estimated with the following probit estimator.

Let S_i be a binary indicator for receipt of solar irrigation pump by household i, L_i be the size of agricultural land (bigha) owned by household i, and X be the vector of eligibility criteria which include the gender of the applicant, submission of citizenship card, submission of a land ownership certificate or land lease agreement, and submission of a recommendation from *palikas*. Let W_i be types of water resource available (groundwater or surface water), M_i be the type of irrigation management (individual pumps or community managed pumps), and ε_i be an idiosyncratic error term. Eq. (1) models the probability of receiving SIP given land holding size and other eligibility criteria.

$$Pr(S_i|L_i, X) = E\left(\alpha_0 + \alpha_1 L_i + \alpha_2 L_i^2 + \Theta X_i + \beta W_i + \delta M_i + \varepsilon_i\right) \quad (1)$$

Estimating Eq. (1) with a probit estimator gives the estimated probability of receiving solar irrigation pumps conditional on meeting eligibility criteria set forth by AEPC. The effect of land holding size on the probability of receiving solar irrigation pumps is calculated by using the coefficient estimates of α_1 and α_2. Elements of the coefficient estimates matrix Θ provide the effect of each eligibility criterion on the probability of receiving solar irrigation pumps. Coefficient estimates β and δ provide the effects of water resources and irrigation management on the probability of receiving solar irrigation pumps.

3.2. Qualitative methods

Table 1 describes the research tools used along with the dates of interviews, mode of interviews, and the information extracted from each tool. We also conducted a desk review of policies on renewable energy development and subsidy delivery mechanism. We reviewed the two key policies – Renewable Energy Subsidy Policy (2016) and Renewable Energy Subsidy Delivery Mechanism (2016) – taking into account gender, equality, and social inclusion considerations.

A total of 14 focused group discussions (FGDs) were conducted to explore and better understand the gender and social inclusiveness of the SIP program, its impacts on households and communities, and the overall performance of the SIPs. Particular attention was paid to ensuring each FGD included a good mix of farmers in terms of gender, caste/ethnicity, and socio-economic status as well as representatives from local government offices (*palikas*). These FGDs were conducted in person in Eastern *Tarai*– Bara, Parsa, Rautahat, Sarlahi, and Udayapur districts. We interviewed 70 individuals, of which 12 were women and 58 were men.

We also conducted key informant interviews (KIIs) to gather information about the evolution of SIPs policies and implementation in the country, barriers to adoption, implementation challenges, potential solutions to removing the barriers, and the scope of solar irrigation. Due to the prevailing COVID-19 situation, KIIs were conducted virtually and over the phone. We conducted 41 KIIs, including eight female and 33 male SIP stakeholders. Stakeholders to be interviewed were carefully chosen to represent a wide variety of perspectives from actors along the SIP service chain – farmers, local government officials, the private sector, and NGOs. Information collected via KIIs and FGDs is transcribed by the interviewers and studied by each member of the research team separately. Each research team member synthesized the transcripts and drafted a brief summary of key findings, which are then tallied against each other to arrive at a common finding presented in this paper.

4. Data and descriptive statistics

4.1. Administrative data for the SIP program

AEPC provided basic demographic data on all farmers who had applied for SIPs and on farmers selected for subsidized SIPs. The database included information on land holding size (converted to bigha, one bigha = 0.25 hectare),[2] possession of land title or lease agreement, source of water available for irrigation (e.g., groundwater, surface water), submission of citizenship card, a recommendation from the local

[2] Land size data consisted some outliers in both sides of the tail. Two different approaches were used to deal with the outliers. First, land size values that were greater (or smaller) than the sum of two standard deviations and three means in either tail of the distribution were replaced by local median for each province. The resulting data still consisted some outliers in all provinces, which were replaced by winsorized values at the first and 99th percentiles (which helps limit extreme values in the data by replacing them with data values at the selected percentiles).

Table 1
Data sources and methods for qualitative analysis.

Activity	Description	Data/information extracted	Date	Mode of collection
Policy review	Review of AEPC's renewable energy subsidy policy (2016) and subsidy delivery mechanism (2016) from a gender, equality, and social inclusion (GESI) lens.	Policy provisions for equitable distribution of subsidized solar irrigation pumps.	April 2020, January 2021	Desk reviews
Focused group discussions	Semi-structured discussions with farmers and representatives from local governments (*palikas*) in five districts - *Bara, Parsa, Rautahat, Sarlahi, Udayapur*. A total of 14 different group discussions with 70 individuals (12 females and 58 males) from nine different *palikas*.	Insights on access to SIPs, their impacts, inclusiveness, and overall performance of installed SIPs	March 2020	Field visits
Key informant interviews	Semi-structured phone interviews with 41 key informants (eight females and 33 males) along the solar irrigation service chain. Key informants included farmers, local *palika* representatives, private firms that installed solar irrigation pumps, technical service providers, social mobilizers, financial institutions, and government officials.	Evolution of solar irrigation pumps in Nepal, barriers to adoption, implementation challenges, potential solutions, and future of solar irrigation in the country.	April 2020	Phone interviews

Source: Authors' illustrations.

government office, and finally, the type of irrigation management proposed by the applicant. The types of irrigation management included individually managed pumps (SIP is individually managed by a single user), community managed pumps, or privately managed by a group of multiple users or a company. For farmers who received SIPs, the size and cost of solar pumps were also available.

Applicants' gender and social identity (caste/ethnicity etc.) were not available, but they were constructed based on their first names (for gender) and surnames (caste and ethnicity). This approach to constructing gender and social identity variables has limitations, but it was the best we could do given the circumstances.

Many names could be unisex, sometimes surnames cannot be attributed to a single caste group, and the listed name on the database may have been that of an agent who applied on behalf of the farmers. Based on our calculations, the potential gender and caste/ethnicity misclassification errors are low. We drew a random sample of 1 % of the analysis sample. We calculated the potential gender misclassification error by counting first names that could be unisex instead of a specific gender. Potential caste/ethnicity misclassification error is calculated by counting surnames that were not explicitly associated with a particular caste or ethnicity. Both misclassification errors were reasonably low, with a 9 % chance of gender misclassification and an 11 % chance of caste misclassification.

4.2. *Descriptive statistics*

Fig. 1 presents the number of SIP applications received and the approval rate over time. In the first five years between 2016 and 2021, a total of 9100 farmers had applied for solar irrigation, of which 21 % were granted SIPs. Most farmers were not given SIPs due to limited budget allocation, but the number of SIPs granted increased over time, from 75 in 2017 to 1056 in 2019. The number of SIPs granted dropped in 2020 to 552 due to COVID-19 restrictions and the ensuing economic crisis. Except for 2020, when only 12 % of SIP application was approved, SIP approval rates increased over time, from 25 % in 2017 to 36 % in 2018 and 30 % in 2019. Table A1 in the appendix provides SIP applications and approval rates by provinces. SIP approval rates were higher for farmers in the three *Tarai* provinces – Province 1, Madhesh, and Lumbini.

The rest of the quantitative analysis is based on the data for the first four years of the SIP program, between 2016 and 2019. The 2020/21 data could not be used for the analysis because disaggregated details are not available yet.

Fig. 2 presents the country's map showing the geographic distribution of SIPs. Most pumps are concentrated in a few *Tarai* districts. Specifically, about 86 % of applications came from *Tarai* districts, and roughly 85 % of the pumps were given to these districts. Both SIP applications and distribution were higher for eastern *Tarai* than western *Tarai*.[3]

Table 2 presents summary statistics for program eligibility criteria and characteristics of farmers who applied for solar irrigation pumps. The first panel in Table 2 presents land area and binary indicators for land certificate, lease agreement, applicant's gender, and possession of citizenship card. On average, farmers who applied for SIPs owned 3.5 bighas (~1 ha) of land. However, those who received the pump owned less land (2.3 bighas) than those who did not receive the pump (3.8 bighas), and the difference was statistically significant at the 1 % level of significance. Overall, 82 % of applicants had submitted land-holding certificates; only 69 % of solar pump recipients had submitted the same as opposed to 88 % of non-recipients.

The share of female farmers who applied for solar pumps was 19 %, but it was higher for SIP recipients (22 %) than non-recipients (18 %). Similarly, the share of farmers who submitted citizenship cards was lower among SIP recipients (68 %) than non-recipients (83 %). We also examined the social identity of farmers; >37 % of farmers belonged to the *Brahmin/Chhetri* caste, followed by *Madhesi* (25 %), *Janajati* (17 %), *Muslim* (4.3 %), *Dalits* (4 %), and *Newar* (2.6 %). The social identity of the remaining 10 % of farmers was difficult to determine.

The rest of Table 2 presents statistics for the submission of *palika*'s recommendation, the source of water for solar irrigation, and the type of irrigation management. Overall, 79 % of farmers had submitted *palika*'s recommendations; even though it was not mandated in the policy, submission of *palika's* recommendation was made mandatory in practice. Submission of *palika's* recommendation was higher among non-SIP farmers (85 %) than SIP farmers (64 %). Most farmers applied for SIP for individual use (79 %), but some farmers applied for community use or as a private farming group.[4] Groundwater was the primary source of water for irrigation. Among SIP applicants, 64 % were using groundwater, with 14 % using surface water (river, lake, pond), and 5 % using rainwater harvesting.

[3] Eastern Tarai received more SIPs than other regions because a vast majority of applications came from the region. The region is rich in groundwater reserve and the highly fertile alluvial plain has made agriculture an attractive venture to many farmers. In addition, Eastern Terai is much better connected to markets and roads than other parts of the country. These factors contribute to higher request of SIPs from this region, which leads to higher allocation of SIPs.

[4] Private management was different from individual management in that the former involved multiple individuals as owner/end-users but the latter was managed and owned by a single user. Community managed pumps also involved multiple end-users but these were owned by a community.

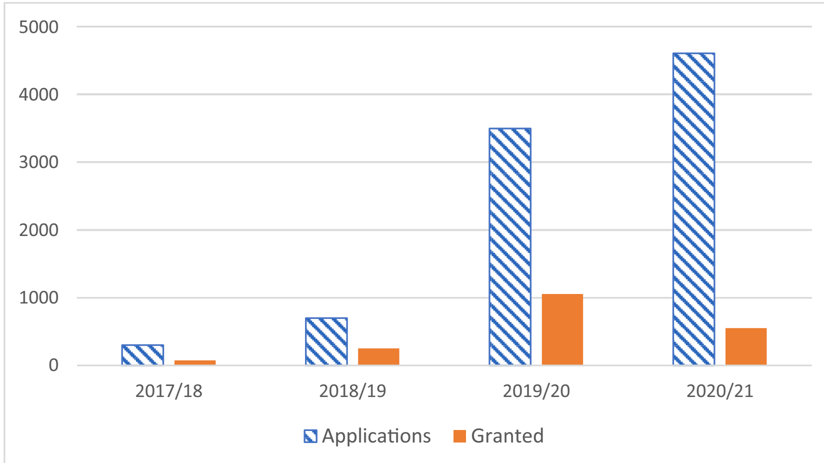

Fig. 1. Number of applications and granted solar irrigation pumps.

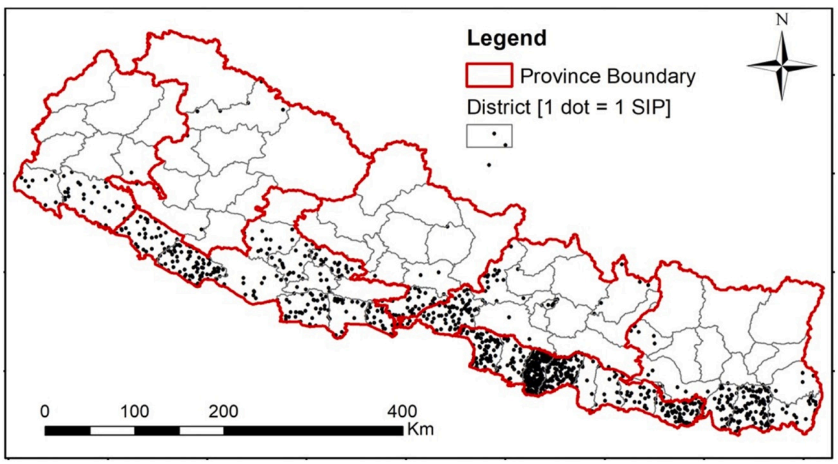

Fig. 2. Distribution of solar irrigation pumps (SIP) in Nepal.

5. Econometric results

Table 3 presents the marginal effects on the estimated probability of receiving solar irrigation pumps conditional on satisfying various eligibility criteria set forth by AEPC. We estimate two different models, both with a probit estimator. The base model (model 1) assumes a linear relationship between land area and SIP approval. In addition, it does not control for regions, *palika*'s recommendation, source of water,[5] and irrigation management type. The second model (model 2) assumes a non-linear relationship between land area and SIP approval and controls for all eligibility criteria and regional differences. Our preferred model is the second model, but results from the first model are included for completeness.

Results in Table 3 show that the probability of receiving SIPs increases with the land area but at a decreasing rate. Fig. 3 presents the predicted probability of receiving solar pumps against the size of land owned, holding everything else constant. The probability of receiving solar pumps first increases with land size and reaches the plateau around the land size of three bighas. After that, the probability of receiving solar pumps starts declining for farmers owning more than three bighas of land, showing positive discrimination towards farmers with smaller land holding during the selection process. However, this may not mean that marginal farmers were more likely to receive SIP subsidies because this finding is representative of the farmers who were able to apply to the program.[6] We have documented in the qualitative analysis that marginal farmers (smallholders, women farmers, and ethnic minority farmers) could not apply to the program. Existing evidence from Nepal shows that subsidies for shallow tube well programs throughout the 1980s and 1990s had disproportionately benefited larger farmers, prompting the government to withdraw direct subsidy schemes in the early 2000s and replace them with indirect support through agricultural inputs program [46]. In the case of SIP, it is premature to conclude which direction the subsidy program will take. Given the growing importance of low-emissions agriculture, it is likely that SIPs will continue to remain significant.

The rest of Table 3 presents the marginal effects of other eligibility criteria for SIP. The probability of receiving a solar pump was higher for female farmers than males, and it was also higher for those who submitted citizenship cards than those who did not submit. However,

[5] Groundwater is the primary source of irrigation in all but *Karnali* province, where >68 % farmers reported surface water as the primary source.

[6] Even though AEPC prioritized underrepresented groups during the final selection stage, the pool of applicants that reached to AEPC was not representative of the actual farmer diversity. Farmers who were connected with the service providers, local government officials, or local leaders were more likely to apply. Marginal farmers (small-holders, female farmers, and caste/ethnic minority farmers) were less likely to have their applications forwarded to AEPC. Therefore, the distribution of subsidized SIPs favored relatively better off and socially connected farmers.

Table 2
Profile of solar irrigation pumps (SIP) applicants.

	All applicants	Received SIP	Did not receive SIP	Difference
	(1)	(2)	(3)	(4)
Land area (bigha)†	3.47	2.30	3.81	−1.51***
	(0.411)	(0.191)	(0.506)	
Land holding certificate	0.82	0.69	0.88	−0.19***
	(0.021)	(0.034)	(0.022)	
Land lease agreement	0.037	0.027	0.042	−0.015
	(0.008)	(0.011)	(0.009)	
Applicant is female	0.19	0.22	0.18	0.041**
	(0.009)	(0.017)	(0.009)	
Citizenship card	0.79	0.68	0.83	−0.15***
	(0.026)	(0.035)	(0.029)	
Social identity (1 = yes, 0 = no)				
Brahmin/Chhetri	0.37	0.37	0.37	−0.005
	(0.032)	(0.037)	(0.034)	
Madhesi	0.25	0.23	0.26	−0.033
	(0.033)	(0.028)	(0.039)	
Dalit	0.039	0.031	0.042	−0.011
	(0.006)	(0.006)	(0.008)	
Newar	0.026	0.011	0.032	−0.021*
	(0.009)	(0.004)	(0.012)	
Janajati	0.17	0.18	0.17	0.006
	(0.014)	(0.024)	(0.016)	
Muslim	0.043	0.037	0.046	−0.01
	(0.010)	(0.007)	(0.013)	
Regions				
Hills	0.14	0.067	0.17	−0.10***
	(0.037)	(0.023)	(0.045)	
Eastern Tarai	0.60	0.71	0.55	0.16***
	(0.068)	(0.065)	(0.075)	
Western Tarai	0.26	0.22	0.28	−0.059
	(0.063)	(0.063)	(0.071)	
Palika's recommendation				
No	0.11	0.28	0.039	0.24***
	(0.016)	(0.033)	(0.014)	
Yes	0.79	0.64	0.85	−0.21***
	(0.029)	(0.047)	(0.028)	
Not applicable	0.10	0.074	0.11	−0.037
	(0.020)	(0.026)	(0.022)	
Management type				
Individually managed	0.79	0.68	0.84	−0.16***
	(0.032)	(0.037)	(0.040)	
Community managed	0.066	0.036	0.078	−0.042
	(0.029)	(0.015)	(0.037)	
Privately managed	0.063	0.021	0.080	−0.06***
	(0.015)	(0.006)	(0.021)	
Source of water				
Groundwater	0.64	0.53	0.69	−0.16***
	(0.040)	(0.049)	(0.044)	
Surface water	0.14	0.09	0.17	−0.078***
	(0.030)	(0.022)	(0.036)	
Rainwater	0.054	0.057	0.053	0.004
	(0.023)	(0.027)	(0.023)	
Unspecified sources	0.14	0.31	0.075	0.24***
	(0.017)	(0.034)	(0.013)	
Observations	4530	1384	3146	

Notes: Standard errors are in parentheses. Level of significance * $p < .1$, ** $p < .05$, *** $p < .01$.
† Land area is available for 3093 households only, among them 691 households received SIP and 2402 households did not receive SIP.

neither of these relationships is statistically significant at the 10 % significance level. Likewise, the probability of receiving subsidized solar pumps was higher for those who submitted land holding certificates or lease agreements than those who did not submit. Submission of a land holding certificate or land lease agreement was also a program requirement.

The second panel in Table 3 presents the relationship between social identities and the probability of receiving SIPs. Compared to *Brahmin/Chhetri*, all other social groups were less likely to receive SIPs. Specifically, *Madhesis*, *Dalits*, and *Muslims* were about 9 % less likely, and *Newars* were 13 % less likely to receive SIPs compared to *Brahmin/Chhetri*, even after controlling for all other eligibility criteria and regional differences.

Table 3
Probability of receiving solar irrigation pumps (SIP) – marginal effects.

All variables are binary (1 = Yes, 0 = No), unless otherwise indicated.	Dep. variable: Received solar irrigation pump	
	Model 1	Model 2
Log (land area, bigha)	−0.024**	0.11***
	(0.011)	(0.038)
Log (land area)^2	–	−0.045***
		(0.013)
Applicant is female	0.016	0.0079
	(0.019)	(0.019)
Citizenship card	0.11***	0.037
	(0.033)	(0.036)
Land-holding certificate	0.036	0.048
	(0.036)	(0.036)
Land lease agreement	0.0091	0.065*
	(0.036)	(0.039)
Social identity (default: Brahmin/Chhetri)		
Madhesi	−0.037*	−0.087***
	(0.019)	(0.019)
Dalit	−0.080**	−0.084**
	(0.035)	(0.037)
Newar	−0.14***	−0.13***
	(0.032)	(0.040)
Janajati	−0.012	−0.028
	(0.021)	(0.022)
Muslim	−0.054	−0.081**
	(0.037)	(0.036)
Palika's recommendation *(default: not applicable)*		
Yes		−0.054
		(0.048)
No		−0.012
		(0.051)
Source of water *(default: groundwater)*		
Surface water		0.0098
		(0.022)
Other sources		0.010
		(0.032)
Management type *(default: community managed)*		
Individually managed		0.097***
		(0.023)
Privately managed		−0.021
		(0.036)
Regions *(default: hills)*		
Eastern Tarai		0.15***
		(0.022)
Western Tarai		0.10***
		(0.022)
Observations	3086	3086

Notes: Standard errors in parentheses. Level of significance * $p < .1$, ** $p < .05$, *** $p < .01$.

Among other eligibility criteria, submission of *palika*'s recommendation did not affect the probability of receiving solar pumps, but the source of irrigation water did. Farmers whose primary source of irrigation was groundwater had higher chances of receiving solar pumps than those with surface water as the primary source. Similarly, the probability of receiving SIP was higher for individual applicants than community applicants or private groups/companies. Farmers in Eastern *Tarai* had the highest chance of receiving SIPs, followed by Western *Tarai* and hills.

We find that among the application pool, AEPC prioritizes smaller farmers, women farmers, and farmers who may not have the needed political clout to receive recommendations from local governments. We also find that majority of the applications come from the *Tarai* region, especially eastern *Tarai*, which is considered a breadbasket of the country for its abundance of groundwater reserve as well as fertile alluvial soil [41,42].

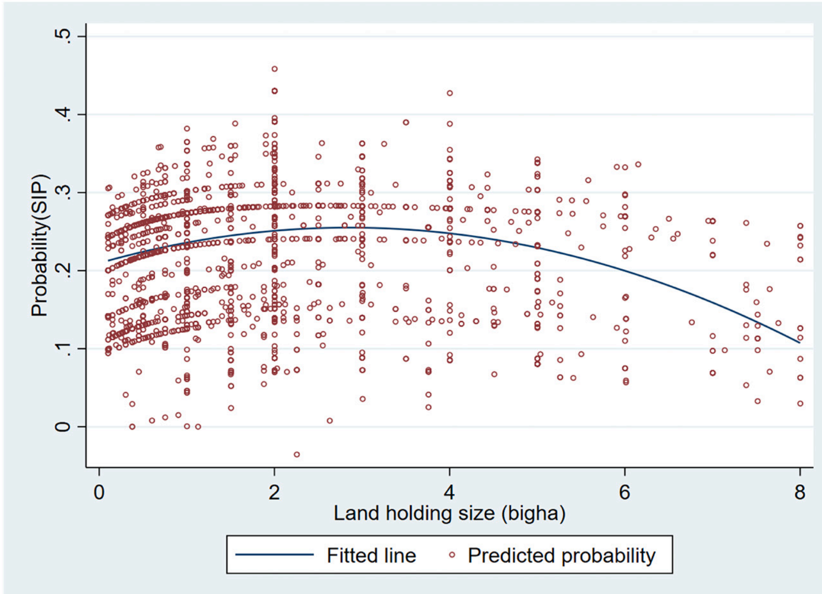

Fig. 3. Predicted probability of receiving solar irrigation pumps (SIP) against land holding size.

The quantitative analysis did not allow us to answer additional research questions. Specifically, we could not answer the following two questions using the government data: 1) “does the current application process make it difficult for small-scale, marginal, and women farmers to apply for subsidized SIPs?”, 2) “what are the barriers to adopting subsidized SIPs?” Therefore, we used a qualitative study to fill the gaps in the data. Next, we discuss findings from the qualitative fieldwork that provided insights into these questions.

6. Findings from the qualitative study

6.1. The current SIP application collection process favors relatively well-off farmers

Call for application for subsidized SIPs are published in two different ways – radio announcements and printed notifications in national newspapers. Service-provider companies, pre-selected by APEC through a competitive process, are informed about the call subsequently and authorized to collect applications. The service providers then reach out to farmers through *palika* offices, social mobilizers, or local agents. We found that the service providers reached out to selected farmers only, especially those who were better connected socially and relatively well-off economically. An estimated 80 % of SIP applications are collected in this way.

Another 20 % of the applications come directly from farmers themselves or through *palika* offices. Some farmers we spoke with learned about the program through their peers or independently through radio or newspapers. These farmers prepared their applications either by themselves or with help from social mobilizers or local *palika* offices. As service providers and social mobilizers are predominantly males and from upper social class, females and minority farmers are often left out in this process. Applications collected in this way were centralized in the *palika* office, where *palika* representatives made the final decision on which applications to send to AEPC for consideration for selection. At this stage, applications from farmers who owned <0.5 ha of land were not forwarded to AEPC, even though AEPC had not specified any land size limitations for application.

6.2. Lack of periodic review of SIP prices

The policy manuals consider a 60 % subsidy as a starting point and identify the need to update the subsidy scheme yearly to make it a need-based subsidy program. However, no such revisions have been made, even though retail prices of SIPs have decreased significantly in the last few years. The lack of price updates has created a situation where private vendors can artificially jack up their prices to claim higher subsidies from the government. Some vendors, however, have offered higher discounts to farmers based on actual market prices. Had the government agency revised the SIP prices to reflect the actual market prices, it could have saved some subsidy burden or allocated the same subsidy to a larger number of grantees.

According to government data, the average cost of a solar pump was 8500 USD (Appendix Table A2). Even with a 60 % subsidy, farmers' contribution to a 1 HP pump was 1600 USD. It was 2630 USD for a 2 HP pump, 4000 USD for a 3 HP pump, and 6000 USD for a 5 HP pump. This price is significantly greater than the current market prices. In 2015–16, ICIMOD procured 1 HP solar pump for 3500 USD (including the cost of three years of maintenance) through a competitive bidding process [45]. Since then, SIP prices have come down significantly. According to a local solar firm in Nepal, the maximum retail price for a 1 HP SIP was 2500 USD in 2020.

6.3. The role of local government is unclear in the current renewable energy policy, and it has evolved in practice

One of the significant gaps identified through a review of policy documents and discussions with stakeholders is the role of local governments. Neither of the two renewable energy policies envisions the active role of local *palikas* in program implementation. In practice, however, *palikas* have played a critical role in the application collection and selection stage. For example, even though AEPC does not require applicants to submit local government's approval, *palikas* have made it mandatory to be eligible for applying to the program. Some *palikas* have offered a top-up grant to SIP farmers to help them pay a part of the up-front 40 % of the cost. We found that local governments have become a central de-facto player in the SIP subsidy program, despite the lack of clarity on the local government's roles in the SIP program.

6.4. Poor monitoring and after-sale services

While there are provisions for periodic monitoring and third-party evaluation, no such monitoring and evaluation seem to have taken place. Contractually, service providers are committed to a 2-year complimentary after-sales service package, but whether farmers receive these services regularly is not monitored actively. Many farmers reported having had to wait for months to get their SIPs repaired. In most cases, the lack of after-sale services boiled down to a lack of local capacity. As service providers are based in Kathmandu or some other regional city, it is challenging for farmers to get hold of them in case of SIP breakdowns. The SIP program itself did not include any local capacity development activities; service providers were encouraged but not required to offer such activities. As a result, the capacity building of local technicians remains a large gap.

6.5. Policy gaps for equitable distribution of climate finance

The two renewable energy policies recognize the importance of the equitable distribution of climate finance subsidies in renewable energy development. However, they envision a blanket subsidy approach with no recognition of different barriers faced by different sub-groups (e.g., men and women farmers, farmers from lower caste/ethnic minorities, as well as marginal and well-off farmers) to accessing and adopting SIPs or any other renewable energy technologies. For example, unlike solar-powered drinking water pumps, the SIP program has no provision for additional subsidies to female-headed households with dependent children, earthquake victims, and endangered indigenous communities.

The policies characterize SIP access as a predominantly financial problem, assuming that if there are subsidies and credit access, the poor can adopt SIPs successfully. This linear view of technology adoption ignores other significant social and institutional barriers to adopting SIP [47]. For example, the requirement of land ownership/land tenancy proof to be eligible for SIP may implicitly exclude marginal, tenant, and landless farmers from the ambit of the subsidy. Even though AEPC did not exclude farmers from receiving SIPs just because they could not submit land certificates, the requirement excluded many farmers from applying.

Subsequently, we found that AEPC prioritized women farmers, farmers from ethnic minority groups and lower castes, and small-scale farmers in the final selection stage. However, the final pool of applicants that made to the agency was not representative of true farmer diversity.[7] Despite the government agency's effort to distribute the climate finance subsidy equitably, the lack of specific selection criteria has left much to the discretion of service providers and implementers, providing room for inconsistent policy application.

7. Summary and recommendations

This analysis investigated who likely benefits from a climate finance program in a developing country setting. In addition, it explored potential barriers to adopting a climate-smart technology – a solar irrigation pump (SIP). We use administrative data from a subsidized SIP program and a qualitative survey of different actors along the SIP service chain in Nepal. We showed that farmers who received subsidized SIPs are relatively well-off economically, better connected socially, and are from higher social groups. Even though the federal government agency prioritized smallholders, female farmers, and ethnic minorities over large holders, male farmers, and higher caste for the distribution of subsidized pumps, an unrepresentative pool of applicants resulted in an inequitable distribution of climate finance subsidy. We found that the application solicitation process, which was outsourced to private service providers, was restricted to farmers with strong social networks and better socio-economic status.

Focused interviews with different actors along the SIP service chain revealed that the application collection process was inaccessible to disadvantaged groups due to significant asymmetry in information dissemination. For example, non-Nepali speakers (e.g., *Maithili* speakers), mainly from female-headed smallholder households with low or no literacy skills and poor social networks, are de-facto excluded from the program. The call for applications appeared in the Nepali language only, and information dissemination occurred primarily within selective networks.

In addition to the application collection process, other barriers to adopting SIP included a lack of clear selection criteria, lack of after-sale services, lack of periodic revision of market prices and subsidy scheme, and lack of clarity on the local government's roles. Unclear selection criteria for application collection left it to the discretion of the private service providers and representatives of local governments on who gets to apply and who does not. For example, among those who could apply for subsidized SIPs, submission of a citizenship card or land holding certificate increased the probability of receiving a pump. While applicants who could not submit these documents with their application were not always denied solar pumps, the requirement of these documents prevented many farmers from applying to the program. Likewise, lack of clarity on local *palika*'s role in program implementation resulted in a situation where *palikas* mandated their recommendations for SIP application, even though the federal government agency, AEPC, had no such requirements.

Based on these findings, we recommend improving program targeting at the application stage by allowing all types of farmers to apply to the program with no strings attached, such as removing the requirement of a citizenship card, land holding certificate, etc. These documents can be checked at a later stage for due diligence. We suggest that local *palikas* be made entirely responsible for application collection. The federal government agency can train representatives from local *palikas* on the process of SIP promotion and application screening, with independent monitoring of the process to ensure transparency and accountability. Additionally, local *palikas* could help translate the calls into local languages (e.g. *Maithili*) to increase information dissemination. As different government agencies have resources for similar types of programs, workable coordination among the different agencies, such as between AEPC and local *palikas*, is critical to fulfilling increasing farmer requests for SIPs.

To address the lack of periodic revision to the current fixed subsidy scheme, we recommend replacing the current 60 % subsidy with a variable subsidy scheme that provides a higher subsidy rate for smaller-sized pumps and a lower rate for larger pumps. A subsidy rate variable on pump size will help target small and marginal farmers and women farmers who often use smaller-sized pumps for their vegetable gardens.

Likewise, to resolve the discrepancy between the market prices of SIP and the price tagged by AEPC, we recommend that the agency carries

[7] In 2018, AEPC drafted a new gender, equality, and social inclusion (GESI) policy to address some of these concerns, but the policy is yet to be adopted formally in their SIP program.

out an annual SIP market price discovery exercise and revise the MRP of SIP accordingly. This will not only avoid the accrual of extra-normal profits by private vendors but also can save dollars that can be used to scale the climate finance program.

We also note the urgent need to include an after-sale service package, which can consist of regular monitoring from third parties, repair and maintenance services, marketing support, agricultural advisory services, etc. In this context, it is necessary to provide capacity-building training to local technicians, so they can provide repair and maintenance services as and when needed. Theft and vandalism of PV panels were commonly reported issues. This can be minimized by mounting the panels on a high stand, locking them with anti-theft bolts, installing an alarm system, or engraving the owner's name on the panels, making it difficult to resale in the market [21].

8. Conclusion

In conclusion, Nepal's subsidized solar irrigation program, a typical example of climate finance in a developing country, has created awareness for climate-friendly energy sources of irrigation, especially in the agricultural heartland of *Tarai*. Even though the federal agency coordinating the overall program prioritized smallholders, female farmers, and ethnic minorities during the final selection stage, the application collection process failed to reach out to more marginalized sections of the population due to the lack of specific selection criteria, lack of clarity in institutional roles, and limited resources. That, together with the lack of periodic adjustment of the maximum retail price of SIPs based on market rates and poor provision of after-sale services, remain a few critical bottlenecks of an otherwise well-implemented and ambitious climate finance program.

One could question our findings and argue that SIPs are not yet financially or technologically viable for all groups of farmers because of their high fixed cost and the unwillingness of financial institutions to work with resource-poor farmers. However, several pilot studies in Nepal have shown that it is possible to distribute SIPs equitably through targeted interventions if appropriate incentives and institutional support are provided to smallholders, marginal farmers, and women farmers. For example, ICIMOD's pilot in the Saptari district showed that women farmers are more likely to apply for SIPs when social mobilizers were specifically incentivized to reach out to women farmers [45]. Similarly, many marginal farmers and even landless farmers adopted SIPs when specific institutional arrangements, like cooperative ownership and land-lease arrangements, were put in place [48].

This analysis opens up several important questions for future research. First, it highlights the importance of estimating the impacts of climate finance subsidy on climate mitigation as well as livelihood enhancement (for example, amount of diesel saved/replaced, increase in farm revenue, reduction in costs of irrigation, etc.). Second, it lays out a strong case for evaluating the mitigation potential of SIPs compared to other mitigation measures in the agricultural sector. Finally, the analysis demands a rigorous analysis of equity and social inclusion in climate finance programs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

Table A1
Number of solar irrigation pumps (SIP) applications and approval rate by province.

Province	SIP applications (number, share)		Approval rate (%)	
	2016–2019	*2020–2021*	*2016–2019*	*2020–2021*
Province 1	645 (14.2)	863 (18.7)	28.2	
Madhesh	1635 (36.1)	2357 (51.2)	42.7	
Bagmati	731 (16.1)	344 (7.5)	18.9	
Gandaki	61 (1.4)	66 (1.4)	23.0	
Lumbini	1076 (23.8)	736 (15.9)	28.2	
Karnali	65 (1.4)	12 (0.3)	12.3	
Sudurpaschim	317 (7.0)	226 (4.9)	12.9	552 SIPs were distributed. Breakdown by province is not available.
Sub-total	*4530*	*4611*	*30.6*	*11.9*
Total	9111		21.2	

Notes: Numbers are based on the data provided by AEPC; data are up to date until May 2021. For 2020/2021, the SIP approval rate by province was not available. *Province 1* has not been named yet.

Table A2
The average cost of SIP by pump capacity.

Pump capacity (hp)	Number of pumps	Total cost (USD)	Farmer contribution (USD)
<1 hp	4	3275.0	1310.0
1 hp	653	4007.4	1602.9
2 hp	388	6577.2	2630.9
3 hp	71	9939.2	3975.7
5 hp	114	15,016.6	6006.6
>5 hp	15	12,447.8	4979.1
Total	1245	8543.9	3417.5

Notes: Cost and pump size data are based on the AEPC database of SIP recipients between the years 2016 and 2019.

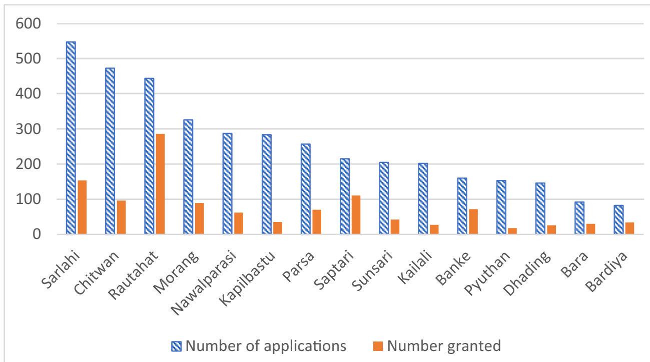

Fig. A1. Distribution of solar irrigation pumps by districts until 2019.

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