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Short Article

The Role of Women's Participation in a Solar Energy-Agriculture-Gender Equality Nexus towards Mitigating Poverty among Farmers in India

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Abstract

Energy transition should encompass social and economic decision along with achievement of sustainable development goals (SDGs). In developing countries like India, impoverished sectors like agriculture, suffer from economic and gender disparities which make the achievement of climate action a strenuous activity. This paper proposes a solar-agriculture-gender framework nexus that is capable of poverty mitigation (SDG 1), gender inequality mitigation (SDG 5), affordable and clean energy introduction in agriculture (SDG 7), economic and food quality improvement (SDG 9) and climate change mitigation (SDG 13). By introducing solar power into the agricultural mix for irrigation in the fallow lands of poverty-ridden minority communities, a set of life-cycle assessment tools are introduced in this framework package that can guide a sustainable energy transition in the agricultural sector of developing countries.

Keywords: *Sustainable agriculture, Gender equality, Poverty, Farmers empowerment, grivoltaics, Food production*

Introduction

While net-zero targets are the center of energy policy in recent years, transition from fossil fuels (FF) to renewable energy (RE) is a very gradual process, specifically for developing nations. It is estimated that it will take more than 15 years for China to produce 50% of its power from "green" sources, while it is more than 20 years for India . On the other hand, several developed countries and states have already reached more than 50% non-FF electricity generation, such as Norway, France, California, New Zealand, Denmark, etc. In order to accelerate energy transition and meet net-zero targets, participation of all sectors and all demographics is imperative. This is tantamount for a country like India, which despite being a very fast-growing economy, suffers from a large portion of the population being below poverty line (BPL) and a substantial lack of women's participation in the workforce. It is the backward classes of the economic spectrum that are employed in the primary sector of the economy, which happens to be the most emission intensive sectors across all developing countries. In these sectors, decision-making has been homogeneous and hierarchical, specifically in methods of operation (that includes energy-use). Thus, not only does the social aspect of energy transition involve socioeconomics, it also involves equity, justice and inclusion as part of the energy-society nexus [1-11].

India is the fastest-growing emerging economy [5], which is also the third highest global CO_2 emitter [12], owing to heavy dependency on FF (especially coal) in the power and primary sectors. Agriculture accounts for more than 50% of the entire workforce in India, while contributing under 20% of the total gross domestic product (GDP) of India [13]. This is a major issue since agriculture also accounts for 10% of the total CO_2 emissions, while consuming only 7% of the total primary energy supply (TPES). This makes agriculture the second most emission intensive sector of India, behind power generation [8,14]. This is coupled with the fact that only 55% of Indian agricultural energy consumption was electrified in 2019, compared to 38% in 1990 [4], showing the prevalence of FF in the sector. All these data are from 2019, and shown in Figure 1. The second issue of the per capita GDP being tremendously low for agriculture, is that most of the farmers are poverty-ridden. While India's BPL population has reduced from 46% in 1993 to 25% in 2020, more than 80% of the BPL households primarily earn their living from agriculture. Additionally, Figure 2 shows that the slope of increase of the rural population is much higher than that of the number of farms, implying that per

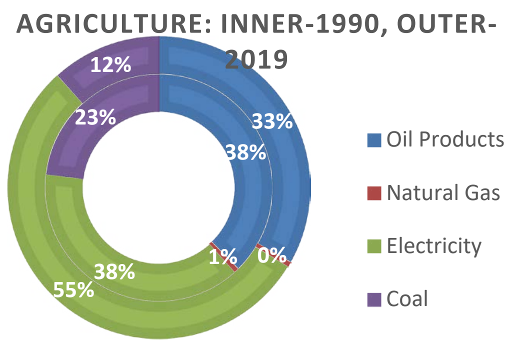

Figure 1: Energy source shares in Agricultural sector in India [14].

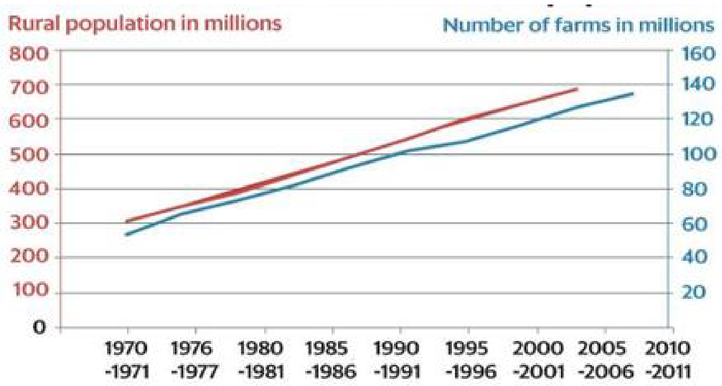

Figure 2: Number of farms vs rural population increase in India.

Table 1: Decile-wise Income-Expenditure reporting for farmers owning less than 1 hectare of land [9].

Decile Class	Total Income (Rs.) Monthly	Total Exp. (Rs.) Monthly	Income - Exp	MPCE (Rs.)		
				Family 4	Family 5	Family 6
1	3870	3537	333	884.25	707.4	589.5
2	4263	4337	-74	1084.25	867.4	722.8333
3	4697	4708	-11	1177	941.6	784.6667
4	4739	4933	-194	1233.25	986.6	822.1667
5	5471	5358	113	1339.5	1071.6	893
6	5830	5515	315	1378.75	1103	919.1667
7	5703	5896	-193	1474	1179.2	982.6667
8	6122	6385	-263	1596.25	1277	1064.167
9	7430	7169	261	1792.25	1433.8	1194.833
10	12458	11107	1351	2776.75	2221.4	1851.167

capita productivity has also reduced over the years [9,13,15,16]. Table 1 shows the calculation for monthly income and expenditure by decile for the rural agricultural population of India, where it can be seen that several households up to the 8th decile are all in negative income zones. The third issue has been highlighted by multiple previous studies, which is a direct consequence of the persisting poverty in Indian agriculture. Mechanization of agriculture has been quite under-developed in India, due to the purchasing power of farmers being sub par, and even insufficient funds to buy fuel for tractors, pumps, etc. [17-19]. Moreover, rural-farm electrification is below 60%, specifically poverty-ridden areas facing issues with access to electricity [20]. As a result, policy mechanisms, such as subsidy on agricultural fuel exist in many states of India, such as Haryana and Maharashtra [13,18], which indirectly drives the cost of fuel higher in the transportation and service sectors. This also decreases the public enterprises' earning from fuel taxes, affecting the value of oil trade. The resultant decreased trade creates a 'death spiral' that increases the inflation in agriculture and transport sectors, which decreases real-GDP compared to inflated GDP [21,22].

In addition to the economic concerns, a critical social issue prevents the escape from poverty in Indian agriculture, which is the disparity in gender participation in the sector [11]. Notwithstanding that women in rural societies are more inclined towards family-roles, such as child-rearing, the issue is pronounced when women decide to participate in the agricultural process. The author of, highlighted that wages are consistently low for female farmers occupied in growing rice, the staple food crop for a majority of India, and especially pronounced when there is a shortfall in rainfall and irrigation water supply. Studies have also analyzed that the labor market is immature, which leads to further reduction of female labor's wages much more than male labor wages [8,23]. This is coupled by the fact that landowners are completely dependent on productivity, which is erratic due to a lower penetration of electricity for farming. The disparity in access to clean and modern energy by farmers extends to the gender disparity issue as well, as the authors of pointed out that access to clean cooking fuel is more diminished for poverty-ridden women-run households than that of men-run households in rural India. Finally, the access to education in farming communities in rural India is also negatively skewed for women, as pointed out by multiple reports [9,11,16]. It is therefore, imperative to analyze these economic and socioeconomic issues from the lens of renewable energy and agricultural productivity in rural India.

The central idea of this study is to build a framework that throws light on a new energy-society nexus in India, namely, solar-agriculture-gender (SAG) nexus. The objective of this paper is to build a policy regime that utilizes the integration of solar energy into the agricultural energy mix of rural India, targeted at emission intensity reduction of farming processes and mitigation of poverty and disparity against women involved in the sector. While several previous studies have highlighted how RE integration can improve not only the energy profile of farming processes, it can also boost agricultural productivity [24]. On the other hand, RE and the involvement of women have been an active area of energy policy research and socioeconomic development [25-28]. However, most existing studies isolate the issue of gender equality in energy transition and focus centrally on the involvement of women in decision-making in the energy sectors. Moreover, most of these studies are directed at the sectors which are demographically urban and mainly limited to the power sectors. The novelty of the framework presented in this paper is that it targets at a specific sector (Indian agriculture), which is gender-inequal as a result of poverty and inaccessibility to education. This paper opens up the possibility to utilize RE integration as a tool for poverty eradication and gender disparity mitigation in poverty-ridden sectors [25-27].

Solar-Agriculture-Gender (SAG) Nexus Framework

SAG framework will be defined in this section, with its components as a policy package for the Indian agriculture sector. The most appealing characteristic of this framework is from the perspective of sustainable development goals (SDGs), as it forms a feedback loop between SDG 1 (no poverty), SDG 5 (promoting gender equality), SDG 7 (clean and affordable energy), SDG 8 (decent work and economic growth) and SDG 13 (mitigating climate change). Figure 3 shows the schematic flow of the SDG policy implementation under the SAG nexus.

The first action of introducing solar plants (solar photovoltaic technology- SPV) into the agricultural mix is in line with SDG 7, which is targeted at meeting the Paris Agreement targets of India, and also towards net-zero targets (SDG 13). In addition, the policy framework can be mutated to be completely owned by the farmers, instead of centralized SPV plants. While decentralization will require a lot of awareness programs to be launched and is time-consuming from a policy implementation standpoint, it will directly be affecting SDG 1. Poverty eradication is completely looked at from increasing the earning of a farmer through two channels: (a) increasing the productivity of existing crops by providing a stable supply of groundwater irrigation, and (b) enabling the farmers to sell off the excess electricity to distributor companies (DISCOM). When agricultural productivity increases due to stable irrigation, it creates a higher economic growth for the farmers' communities and also increases the value of the food being produced (SDG 8). SDG 8 is also achieved when participation of women increases due to the opportunity of maintaining SPV plants creates additional jobs. In fact, women-owned farms can benefit largely from this, since excess electricity sold will be determined by feed-in-tariff (FiT) mechanisms, bypassing existing problems of produce-related income shortage. This creates a feedback loop towards gender-equal labour-force participation and equal wages for women in poverty-ridden societies (SDG 5) with SDG 1 and SDG 7 achievements. Figure 4 shows the policy framework that will enable the SDG achievements of Figure 3 [29,30].

Economic Planning Subsection

Within this part of the framework, the ramifications of the microeconomics are considered for integrating SPV power within the agricultural mix. Firstly, a community of minority-dominated farmers have to be selected in India, who mainly are concentrated in the states of Bihar and Chhattisgarh. For the test case, the community size should be between 100 and 200 persons in a rural setting. With the absence of disposable income for such farmers, it will be impossible for them to procure the SPV equipment and necessary grid interconnections. This is where subsidy-shifting mechanisms should be employed by local village governments, as they remove the subsidy on oil and equivalently apply it to the interest rates of loans on SPV-related expenditure. Several policy mechanisms like 'PM Surya Ghar Muft Bijli Yojana' are in action for rooftop solar schemes, which offer subsidized rooftop SPV equipment. If solar pumps can be subsidized similarly, it will incur no additional cost for the government due to removal of subsidy on oil. Feed-in-Tariffs can be fixed by banks to recover the principal and subsidized investment on SPV, which can be funded by the farmer community's excess electricity production earning [31,32].

Figure 3: SDG interactions resulting from the proposed SAG framework.

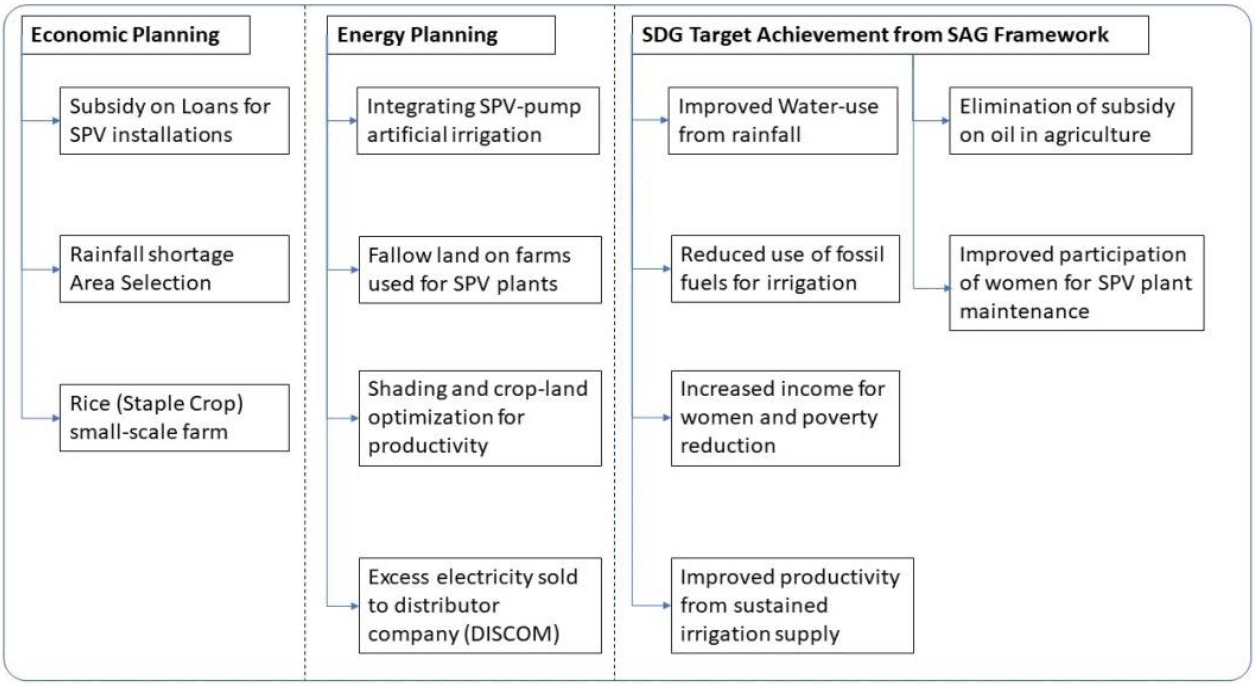

Figure 4: The Solar-Agriculture-Gender (SAG) policy framework for sustainable and gender-equal agriculture in India.

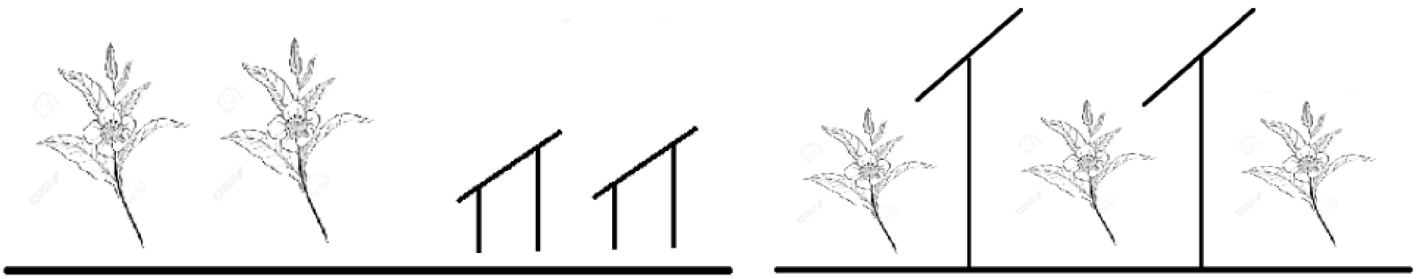

Figure 5: Co-locating SPV and crops on the same owned land in two configurations: (left) separate land with standard-mounted SPV, (right) high-mounted SPV in-between crops.

Secondly, it might be thought that rainfed areas are better for SAG framework installation, due to higher incidence of natural irrigation. However, the cloud cover will make SPV power production unpredictable, leading to very low FiTs for the farmers, which will defeat the purpose of the SAG nexus. Thus, rain-shadow areas are paradoxically more suitable for SPV integration into agriculture, because of two reasons: to get a higher FiT on the installed solar and SPV integration would streamline the availability of water in drought-prone areas [33,34].

Thirdly, any regional or specific crop cannot be selected for the framework. Cash crops and specific regional food crops depend not only on the soil quality, but also on the type of soil. Such soils are mostly unsuitable for any shared purpose of land, wherein previous studies have shown that integration of solar into agriculture would actually decrease the productivity of such special crops. Rice and wheat are the two staple crops of India, but wheat requires a much drier climate than rice, making wheat limited to the northern and north-western part of India. Rice is grown in more than 70% of India's agricultural land, making it the ideal candidate for solar and agriculture integration. Moreover, due to the abundant supply of rice, it is often the minority group population that grow rice are the poorest among all farmers of India [35,36].

Agriculture and SPV (Adapted Agrivoltaics)

Agrivoltaic systems have been analyzed in a plethora of existing studies, where co-location of agricultural activity and power production benefits both the systems explored how land-use can be optimized by usage of different densities of photo-voltaic panels on farms primarily considering shading effect on the crops as well. The study specifically analyzes a full density installation and a half-density installation of solar panels in a field, and by virtue of a factor called Land-Equivalent-Ratio, wherein the productivity of land was greater in both configurations. This can be attributed to the fact that irrigation becomes streamlined by the integration of SPV. Figure 5 shows the configurations of SPV and agriculture co-location arrangements [37].

In the high-mounted SPV shading effect of the solar panels are optimized against the growth of the plants. This configuration not only requires a higher knowledge of crops' growth trajectories, but involves a higher SPV system cost due to expensive mounting structures and more expensive maintenance cost [37,38]. Due to the target demographic being poverty-ridden and not sufficiently aware of SPV maintenance, separate-land, standard-mounted SPV and crops co-location is recommended. This is also coupled with the fact that minority-owned agricultural land has quite a lot of fallow land [13]. Thus, the SPV system could utilize the fallow land, where no crops are grown in any case. In such a case, the fallow land-based solar powered irrigation can provide a much higher economic performance per unit area of land, compared to diesel pumps utilizing the existing land area of crops [39]. This could create opportunities for increasing the productivity of the owned land, thereby increasing the value of land in women-owned communities.

Water and Food Nexus

The first achievement of this framework is from the perspective of food security and water conservation nexus. Existing studies have already proven that Agrivoltaic systems can not only increase the efficiency of land-use, but also the utilization of water [40] showed how specifically water-use can be made efficient by usage of solar panels and planting a low-water-consuming crop like Aloe Vera together in drylands. While rice is a water-intensive crop, separated land can easily be optimized by land-use engineering, where fallow land-based SPV panels can be located at a higher elevation. The run-off water from washing of the panels can trickle down to the rice fields, making dual use of the water, increasing efficiency. This was proven by the researchers of, who showed that the food-water-energy nexus is benefitted in arid areas by agrivoltaics [40,41].

An entirely new methodology for assessment of Agrivoltaic technology was investigated by Leon and Ishihara [42]. In their paper, they assessed the life-cycle CO_2 emissions of a greenhouse, used for tomato cultivation, padded with solar cells at optimum angles. They created new functional units called modified-area based and monetary-based units to assess the emissions from a collocated system. To gauge the potential of increased water and food security of the SAG framework, newer functional units are proposed that would ensure an empirical outlook of the nexus achievements. Table 2 shows the functional units for gauging the viability of the framework to deliver policy outcomes. All such functional units will be based on the life-cycle assessment of the proposed system.

Poverty Mitigation and Gender-Equality Achievement

The central focus of the SAG framework implementation is improving the condition of poverty-ridden farmers and eliminating economic disparity against women in such poverty-ridden communities. Assuming that the SPV integration in the community of the farmers do not involve any exogenous addition of labour, more workers will be required for maintenance of SPV-powered irrigation pumps compared to diesel pumps. Moreover, with increased productivity due to timely availability of irrigation water from the SPV-powered pumps, the surplus crops will also need additional labour to manage. This is exactly where women can be involved in the process. For communities that are preexisting dominated by women farmers, extra unemployed workers from the same community should be assumed to be involved.

While there have been literature that have addressed inclusion of women in academic and technical planning for energy transition, and from the perspective of leadership, specifically in the roles of energy justice and democracy [25,27], there are very few studies that have analyzed how discrimination of poverty-ridden women can be eliminated by their inclusion in energy transition programs. Several key bibliometric reviews point out the leadership-building initiatives for inclusion of women in rural India's energy transition spectrum, all concluding that class and caste discrimination are considerable hurdles that need to be overcome for removing gender disparities [26,43]. Ethnographic methods in literature have also explored how women's and men's participation at household levels can be streamlined [44]. However, while addressing the justice issue, no existing literature has provided a framework that can uplift caste and gender issues by the specific integration of RE towards a sustainable energy transition. This is where the SAG framework addresses these deficiencies by quantifying how gender disparities can be removed while simultaneously improving the economic situation by SPV integration.

From Table 2, the poverty and gender indices are measures to assess how much income increases within the entire SAG nexus per capita. The increased income results not only from the selling of excess electricity from the grid-connected SPV, but also from the

Table 2: Functional units for LCA analysis of the SAG framework for empirical representation of SDG achievements.

SDG Targets	LCA Nomenclature	Functional Unit Definition
SDG 8	Land area productivity	Total revenue per unit area of land
	Water productivity	Total revenue per litre water-use
	Monetary efficiency	Total revenue per unit cost input
SDG 13	Food production emission intensity	Total CO_2 emission per kg of crops produced
	Income emission intensity	Total CO_2 emission per unit revenue
	Energy emission intensity	Total CO_2 emission per unit energy consumed and sold
SDG 1 and SDG 5	Poverty index	Total income increased per capita of poverty-ridden population
	Gender index	Total women's income increased per capita of female population
	Poverty emission index	Total CO_2 emission per capita of poverty-ridden population
	Gender emission index	Total CO_2 emission per capita of female population

Note: All of these LCA assessments are to be done in two scenarios: Business-as-usual without integrating SPV and SPV-integrated SAG nexus.

saving on oil expenditure by the farmers' community despite the oil being subsidized. Moreover, increased productivity is estimated to also add to the income, thereby providing a comprehensive nexus performance. These indicators empirically address one of the key questions by the International Renewable Energy Agency (IRENA) on the gender perspective of renewable energy. The other two indices, poverty emission and gender emission, gives the outcome as to how sustainably the income increase happens in the SAG framework as compared to business-as-usual agricultural approach, which answers the sustainability challenge of the Asian Development Bank for gender equality achievement [45,46].

Fossil Fuel Reduction and Climate Action

The SAG nexus is designed to be an effective and inclusive policy framework that enables the achievement of net-zero targets at the lower end of the social strata. Existing agrivoltaic research has already indicated that from the perspective of an individual agricultural holding, solar-powered pumping has a much higher social and economic performance than fossil fuel-powered pumps [39]. There have been other researchers who have focused on concentrated solar power, where it was found that it had higher energy efficiency, lower heat loss and a markedly high economic viability than a traditional system employing electricity, kerosene and diesel. Along with climate benefits, the payback time for concentrated solar and SPV is quite less compared to a diesel pump, while the operational cost is much lesser for the solar plants [47,48].

From Table 2, three separate climate action benefits can be empirically determined by the SAG framework. Firstly, the food production emission intensity is vastly reduced by solar integration because of the irrigation being completely power by a non-emitting source. Apart from irrigation systems, there are multiple other farm applications of solar electricity such as, solar cooling and heating in greenhouses. Alleviation of poverty and increased income has always been associated with a higher emission intensity of increased wages. Traditional economic models have always indicated that wages are increased at the cost of the environment. The second indicator under SDG 13 in Table 2, has the potential to prove this theory wrong, and show that RE integration into poverty-ridden and minority-dominated communities has the potential to mitigate poverty and promote gender equality sustainably [49,50].

Finally, while many sectors of India have entered a decoupling phase of energy-use and production, agriculture has always suffered from not achieving decoupling at the energy source . As a result, the third indicator in Table 2 under SDG 13, will show that reduced FF-use in agricultural processes can effectively push Indian agriculture towards decoupling [2].

Conclusion

This paper proposes a framework called the Solar-Agriculture-Gender (SAG) framework that has the potential to solve three key issues in the Indian agricultural sector: poverty and gender inequality among farmers, stable food production and high emission intensity of food production. This is achieved by integrating solar power into the agricultural mix for the primary purpose of irrigation and replacing existing diesel-powered pumps. Such agrivoltaic systems will be implemented in communities of poverty-ridden and minority farmers and specifically gauge the acceptance of new and renewable energy in such communities. Through a series of life-cycle assessment indicators, the framework is expected to reveal the socio-economic and environmental achievements of this framework, to ensure that it can be readily accepted as a policy direction by existing governments or as a project by large corporations.

At the heart the central policy that the SAG framework targets is the subsidy on agricultural oil-use given by governments, which is essentially a death spiral economic policy, that not only makes agricultural markets non-competitive, but also leads to a stagnation in the awareness and wages of farmers. The incentive is expected to be firstly created with the government, wherein the subsidized oil can be given to other sectors for a higher price. At this moment, the list of indicators of this SAG framework will be the incentive for financial institutions or corporations to loan the capital for a reduced interest rate to the poverty-ridden community of farmers. Only upon the installation of solar power, and that results in higher gains, can farmers and specifically women farmers realize that higher production of food and excess electricity sold adds to their income. Thus, the incentive does not come from the farmer because of their lack of awareness of solar systems and their economic potential. This reverse incentive idea is where the SAG framework provides an effective tool for the implementation of this nexus that can result in the simultaneous achievement of 5 SDGs.

A lot of future research needs to be conducted based on the premise of this paper. The first recommendation is to conduct a ground-level data collection and selection of impoverished communities, based on which actual empirical data can be simulated. The second direction is to simulate such data at a market-level to uncover the macroeconomic potential of this type of framework, such that it can be readily adopted by policy makers.

Competing Interest

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