Water - Energy Land - Livelihood (WELL) Nexus

Energy as lever towards a sustainably integrated resource management for Tamil Nadu's agricultural sector

Sustainable Energy Transformation Series

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Sustainable Energy Transformation Series

ACKNOWLEDGMENT

This publication forms part of the Sustainable Energy Transformation, Tamil Nadu (SET-TN) series of documents and activities. SET aims to facilitate higher clean energy deployment in the state by working with all stakeholders in order to find sustainable and equitable solutions. SET is a collaborative initiative by Auroville Consulting (AVC), Citizen consumer and civic Action Group (CAG), the World Resources Institute India (WRI).

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EXECUTIVE SUMMARY

Our world is facing a water crisis. Growing water scarcity and climate change coupled with increasing global energy demand means that the water-energy-food nexus is one of the biggest challenges the world faces today. Correspondingly, it is a priority area of concern for policymakers in India and worldwide.

India has about 4% of world's freshwater resources and accounts for about 18% of the global population. According to a recent report, today, 600 million Indians face high to extreme water stress and about 200,000 people die on an annual basis due to inadequate access to safe water.[1]

India's agricultural sector accounts for about 80% of the total ground water extraction and for 20% of the total electricity consumption.[1] This sector is plagued by socio-economic issues such as the low income of farmer households, high debts and an extremely high suicide rate. Central and state governments have launched a series of schemes to improve water use efficiency, increase farmer income and introduce alternative forms of energy generation to tackle issues faced by the Indian farming community.

In Tamil Nadu, about 40% of the workforce is employed in agriculture and agriculture-related fields; making this a key sector for development programs. Interconnected and interdependent issues of water security, financial burdens on the state and the electricity utility as well as the economic challenges faced by the agricultural community demand an integrated problem-solving approach.

This paper explores leverage points in the water-energy-land -livelihood (WELL) nexus in order to derive a win-win solution for all concerned stakeholders: the farming community, the state and its electricity utility, and the public at large. A possible intervention in the WELL nexus and its associated challenges is a three-pronged approach, which involves introducing (i) grid-interactive solar PV, (ii) energy efficient pumps (EE), and (iii) advanced irrigation technology (AI) at the farm level. Additionally, a financial incentive can be provided to the farmer for reducing energy consumption and primarily consuming electricity from solar energy during daytime hours.

This integrated approach promises to have positive synergies resulting in substantial savings to the state government and the electricity utility, as well as an increase in farmer's income; reduction in water and energy consumption; curbing of CO2 emissions and creation of green jobs.

A scenario analysis of interventions has been undertaken for the entire agricultural sector of Tamil Nadu. The integrated approach of grid-connected solar PV, energy efficient pumps and advanced irrigation technology results in cost savings to the state government of up to 130% over a 20-year time period. This approach has a job creation potential of up to 1.66 crore full-time equivalent (FTE), results in avoided CO2 emissions of 522 million tonnes and reduces water consumption for the agricultural sector by 45%. Further, it will allow the introduction of electricity meters at the farms.

Table 1 Benefits, compared to BAU, by scenario I 20-year time period

Benefit	Units	Grid (BAU)	Solar	Solar & EE	Solar & AI	Solar, EE & AI
NPV of avoided cost of energy supply	INR crore	-	68,370	95,407	1,11,730	1,23,797
NPV of avoided cost (%)	%	-	71.7%	100%	117%	130%
NPV of increase in farmer income	INR crore	-	1,957	9,098	7,01,652	7,05,580
Increase in farmer income (%)	%	-	0.2%	0.9%	69.8%	70.2%
Green job creation	FTE	-	4,85,205	4,98,505	1,66,06,905	1,66,20,205
Avoided C02 emissions	Mt	-	395	457	488	522
Water savings	%	-	0%	0%	45%	45%
Introduction of metering		no	yes	yes	yes	yes

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1. INTRODUCTION

The water, energy, land and livelihood (WELL) sectors are inextricably linked; anthropogenic actions in one sector will have intended or often unintended consequences, or externalities, for one or all the other sectors. A deep understanding of this nexus within their socio-economic, political and ecological systems will be critical to ensure a sustainable resource management for humanity to thrive.

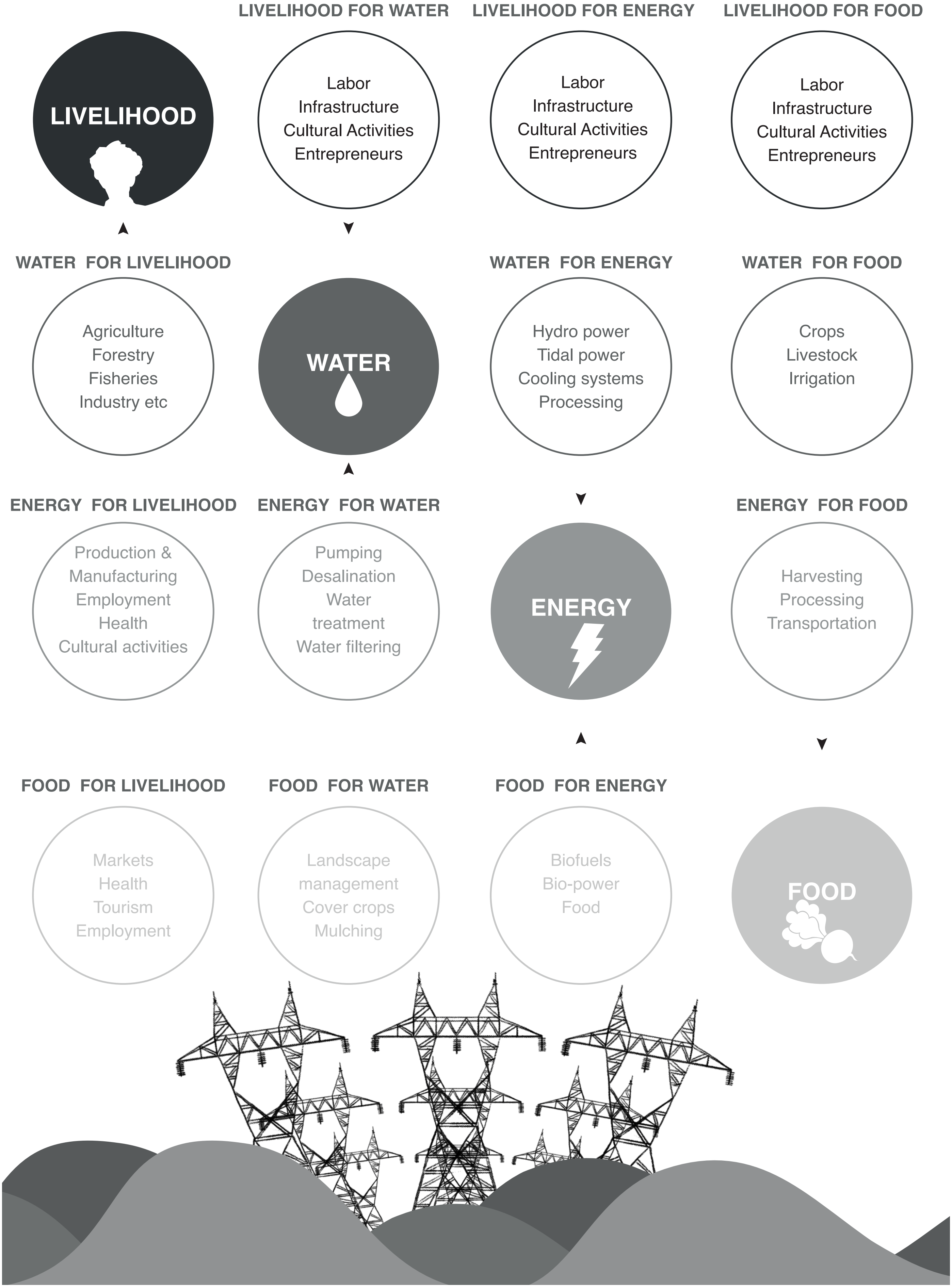
The nexus approach highlights the interdependencies between achieving water, energy and food security for livelihood prosperity and human wellbeing, while ensuring ecologically sustainable use of essential resources. Nexus thinking challenges the solutions to internalize the consequences or external costs of interventions into life-supporting systems or resources through practices and policies that recognize the complex and critical interrelations between systems.

A nexus approach is a paradigm shift, from a sector-by-sector approach to a solution-finding approach that works with an integrated perspective recognizing the interrelatedness of systems. It essentially aims at transforming existing decision-making structures and policy-making frameworks. Under the perspective of the nexus approach, governance of sectors by separate departments and sector-wise policy making invariably leads to partial results, ineffectiveness and an increase in external costs.

WELL sectors depend on the wider ecosystems, socio-political systems and on each other. They are an integral part of the ecosystem and must be used and protected in a balanced manner (refer to *Figure 1*). The nexus may be expanded further to include other sectors such as forests, climate etc. The WELL nexus offers one approach to recognise the interactions between the water, energy, land and livelihoods sectors, while taking into account the synergies and trade-offs that arise from the management of these resources, and potential areas of conflict that may emerge.

This paper explores the interdependencies of the WELL nexus in the context of free electricity supply to the agricultural sector in Tamil Nadu. This paper presents a series of possible technology interventions and their impact on the state's subsidy costs, the farmer income, water and electricity consumption by the agricultural sector, CO_2 emissions, employment generation and food security.

Figure 1 Water-energy-land-livelihood nexus



2. CONTEXT

With the advent of the Green Agricultural Revolution in the 1970s, groundwater irrigation observed a significant increase. This enabled farmers to grow more water intensive crops that could previously not have been cultivated without reliable and affordable access to ground water resources. This also led to a marked increase in groundwater extraction and eventually to a water crisis in Tamil Nadu.

In 2014, agriculture accounted for 80% of water withdrawals in India. Agriculture relies heavily on electric pumps with low efficiency rates of 20-35%.[2]

Subsidised electricity has led to the inefficient use of water and to high government expenditure on subsidies and to financial challenges for the electricity utilities.

Cross country comparisons highlight how big the issue of farm productivity is in India. India uses 2-4 times the volume of water to produce one unit of major food crops compared to other major agricultural countries such as China and Brazil.[3] Improving the efficiency of India's irrigation systems, if done in an integrated way, would help reduce electricity and water consumption while simultaneously contributing to an increase in crop yield and farmer income.

The agriculture sector in Tamil Nadu provides livelihood to nearly 40% of people in the state.[4] The sector is a large consumer of electricity with demand increasing due to monsoon failure and depleting water levels. In 2016, the electricity consumption for the agricultural sector in Tamil Nadu stood at 11,541 MU (approx. 20% of the total electricity consumption in the state). The estimated number of agricultural pumps for the state is 21 lakh. The average pump size is estimated at ~ 5 HP and the total pump capacity in the state stands at 1,19,35,536 HP (or 8900 MW).[5] Compared with the total power generation capacity of 29,859 MW in 2017, the connected load of these agricultural pumps account for 30% of the generation capacity of the state. It may be noted that these figures exclude diesel operated and solar pumps.

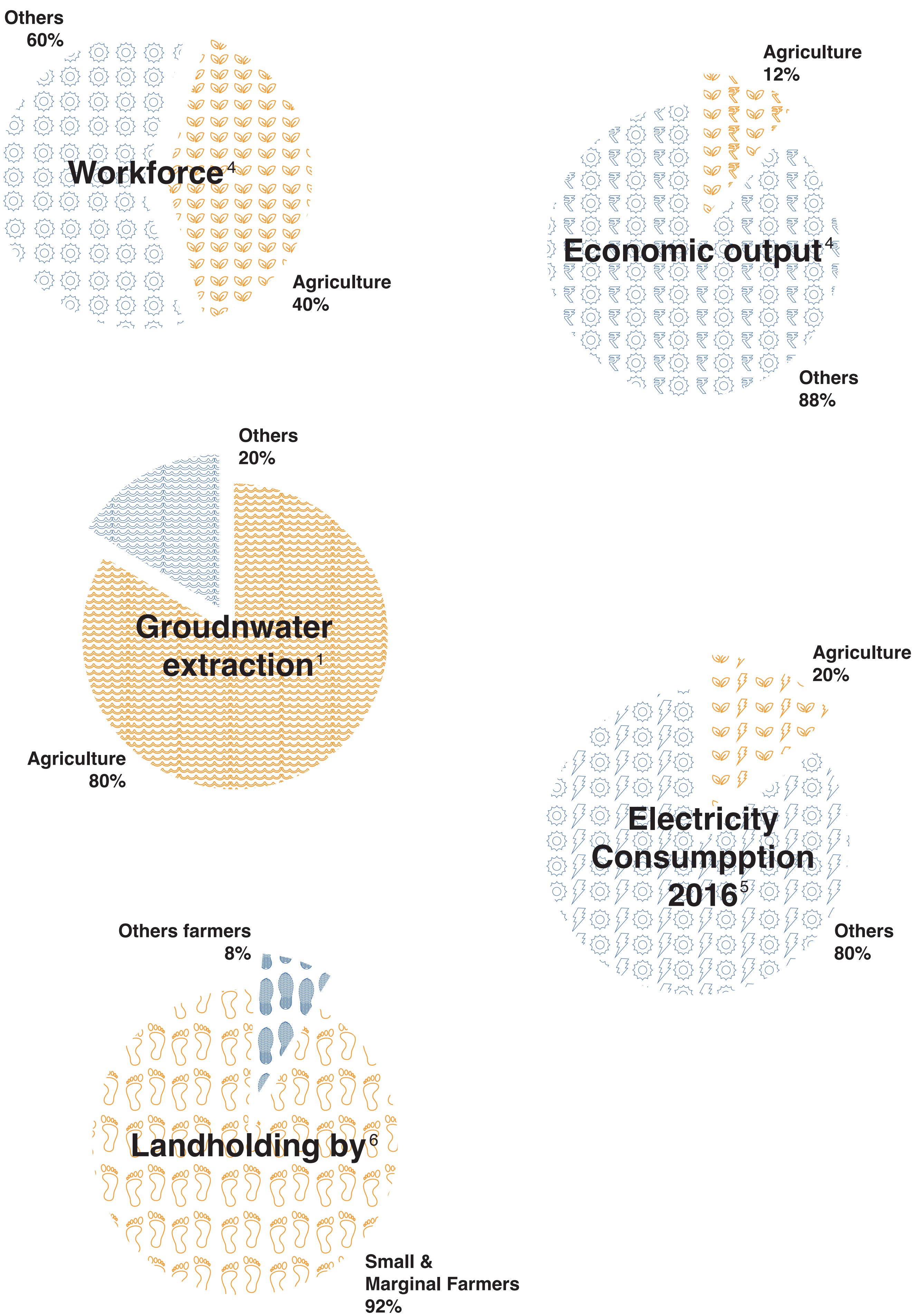
Electricity supply for agriculture in Tamil Nadu is 100% subsidised resulting in financial burden on the state and the electricity utility and has consequently led to poor and unreliable power supply. Irrigation pumps run excessively because farmers are uncertain when 3-phase electricity will be provided. Over extraction of groundwater and the use of inefficient pump sets is evident and this is a recipe for disaster in a water scarce state such as Tamil Nadu.

Electricity meters for the agricultural electricity service connections are not available. Farmers have strongly resisted the installation of the same. This presents additional challenges, besides the heavy subsidy, to the state utility, as actual power consumption for agricultural connections is challenging to estimate.

According to the Agriculture Census 2015-16, the number of operational land holders in the state is 79.38 lakh, operating cultivable land of 59.71 lakh hectares.[6] About 60% of this area is under irrigation.[7] Small and marginal holders account for 92.5% of the total holdings, operating 62.4% of the area occupied. The average size of land holding in the state is 0.75 hectares, which is less than the average size of land holding in the country (1.08 hectares).[6]

The state is the largest producer of bananas in India, its sugarcane yield is the highest per acre in India; and 6% of all Indian vegetables are grown in Tamil Nadu. Paddy (rice) is a staple in the regional diet. These crops – bananas, sugarcane and vegetables – are ideally suited for micro irrigation and precision irrigation technologies. Recent political initiatives to encourage deployment of micro irrigation and solar water pumps indicate a level of technological readiness amongst the Tamil Nadu farmers.

Figure 2 Tamil Nadu agriculture statistics



3. KEY CHALLENGES

3.1 Living income for farmers

Agriculture is the source of livelihood for more than 40% of Tamil Nadu's population.[4] The majority of the farmers are small-holder farmers with an average landholding of 0.75 hectares per farmer. Many are poor and food insecure, and have limited access to markets and services. The average annual household income for a farming family in India stands at approximately INR 1.2 lakh (USD 1,800).[8] In 2014, a report by Ministry of Statistics and Programme Implementation estimated that 82.5% of the farmers are indebted.[9] The number of farmer suicides recorded in Tamil Nadu stood at 382 in 2016.[10] Nonetheless, they produce food for a substantial proportion of the state's population. Reducing farmer incomes and their inability to harness technological innovations is a real cause of concern in Tamil Nadu and globally.

Agriculture is the source of livelihood for more than 40% of Tamil Nadu's population.[3]

3.2 Water scarcity

Water scarcity is one of the top challenges the world and Tamil Nadu face today and water is inextricably linked with energy, land and livelihood issues. In 2017, 1.2 billion people globally were reported to suffer from water scarcity, up from 700 million in 2014. Impacts of climate change, along with wasteful practices; point to a situation where half the world's population will be living in water stressed areas by 2030. Agriculture accounts for about 80% of Tamil Nadu's total ground water extraction. Tamil Nadu has been declared an 'extremely water-stressed' state with ground water levels dwindling at a fast pace.

In 2017, 1.2 billion globaly people were reported to suffer from water scarcity, up from 700 million in 2014.

3.3 Food security

Sustainable agricultural development and food security will be key challenges for Tamil Nadu and for India in this century. The quality of agricultural land and soils is deteriorating due to soil erosion, increasing water scarcity, adverse impacts of climate change and accumulation of toxic elements in soil and water. Land degradation poses a big threat to the sustainable livelihood security of the farming communities across the state. Soil degradation has become a serious problem in both rain-fed and irrigated areas of Tamil Nadu. 2,997 thousand hectares, which is about 23% of the total geographical area of the state, is degraded land. Water erosion, a major causative factor for land degradation, has affected 2,134 thousand hectares (about 16% of the total geographical area).[11] Soil fertility has reduced by half in 30 years. A recent estimate on the annual cost of land degradation places it at INR 820 million for Tamil Nadu.[12] All of these factors combined are contributing to the decline in agricultural productivity and leading to food insecurity.

In 2017, Tamil Nadu's agricultural sector consumed ~12,604 MU of electricity, this equals CO2 emissions of 206 million tonnes and a cost of supply to the state of INR 7,369 crore.[5]

3.4 Energy & climate change

Energy, agriculture and climate change are intricately linked. Energy is required at each step of the food value chain to produce food and to meet the growing demand for food. In Tamil Nadu a major portion of the energy required in agriculture is on account of water pumping in irrigation. Reducing water consumption requirements is directly proportional to reducing energy requirements and saving carbon emissions. In 2017, Tamil Nadu's Agricultural sector consumed ~12,604 MU of electricity, which is equivalent to CO2 emissions of 206 million tonnes and a cost of supply to the state of INR 7,369 crore.[5]

3.5 Political economy

With about 40% of the population in Tamil Nadu working in the agricultural sector[4], farmers present a large proportion of the political votes and any attempt to introduce metering and/or electrical tariff for the agricultural connections in Tamil Nadu has so far proven to be unsuccessful. Considering the financially delicate situation of majority of the farmers, the financial strain of free electricity on the state's electricity utility, the rapidly decreasing ground water resources, food and energy security concerns, and the impacts of climate change globally; different scenarios need to be evaluated to address the complexity and interrelated issues of the WELL nexus to find a win-win solution for all stakeholders involved.

3.6 Employment generation

Unemployment is a major cause of poverty. It leads to loss of income, self-reliance, self-confidence and increased rates of ailment, morbidity and mortality. As per the Government of Tamil Nadu's Department of Employment and Training statistics for August 2018, a total number of 13.6 million citizens were registered as unemployed.[13]

Green Jobs

Implementing large-scale programs that integrate solar pv, energy efficient pumps and advanced irrigation technology will create substantial employment opportunities, both direct employment and indirect. Green jobs contribute to preserve or restore the environment; they are in traditional sectors such as manufacturing and construction, or in new, emerging green sectors including renewable energy and energy efficiency. Direct jobs result from investment in any given economic sector (e.g. jobs created at a recently-built solar energy generation plant). Indirect jobs are created when an investment in a sector leads to an increase in jobs in suppliers and distributors of that sector (e.g. jobs at a solar panel manufacturing plant). The jobs resulting from direct and indirect employees create a number of induced jobs. Growth-related jobs refer to job creation through macro-benefits resulting, for example, from improved infrastructure, such as an increase in water supply that allows for additional production, leading to economic growth, and hence employment.

Figure 3 Green jobs

Green Jobs

Direct jobs — Designing, development, management, construction, installation, maintenance etc.

Indirect jobs — Manufacturing of equipment and material, supply chain, banking, financial sectors etc.

Induced jobs — Created due to spending of earnings by person directly and indirectly employed

Growth-related jobs — Additional crop production, leading to economic growth and hence more employment in agriculture and associated sectors

Green Job Potential in Full Time Equivalent (FTE)

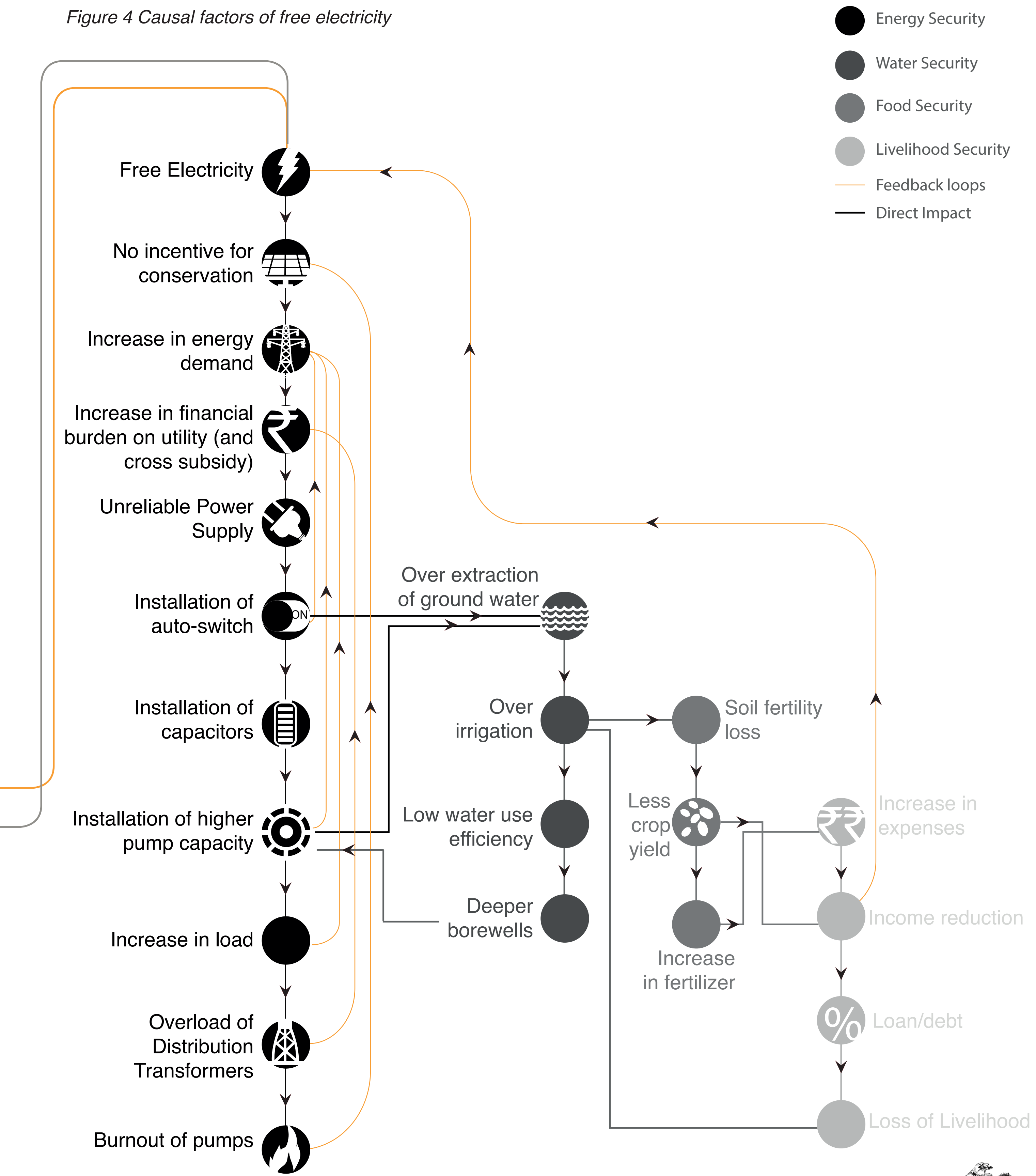
Sector	Direct FTE	Indirect FTE	Total FTE
Solar PV - utility scale (per MW)	3.45	2.60	6.15
Solar PV - consumer scale (per MW)	24.72	2.6	27.32
Energy efficient pumps (per thousand pumps)	5.00	1.33	6.33
Advanced lirigation (per hectare)	3.50	1	4.50

Adapted from:
1. Council of Energy, Environment and Water. 2017. Greening India's Workforce: Gearing up for Expansion of Solar and Wind Power in India
2. Jain Irrigation. Why Drip Irrigation should be considered as Infrastructure Industry?

4. CAUSAL FACTORS OF FREE ELECTRICITY

Free electricity supply in Tamil Nadu has resulted in a conundrum of interconnected issues such as heavy subsidy burden on the state government and the state electricity utility, unreliable power supply to the farmers, increase in installed pump capacity, over extraction of groundwater, over irrigation and soil fertility issues, reduced crop yield, increase in farmer's expenditure on fertilizers, pump repair and drilling of deeper borewells. Farmers in Tamil Nadu have little or no direct incentives to reduce water and energy consumption. The state's WELL nexus is caught up in a self-perpetuating feedback loop with high environmental, economic and social costs *(*refer to *Figure 4)*.

Figure 4 Causal factors of free electricity



5. AN INTEGRATED APPROACH

Addressing the challenges related to WELL for Tamil Nadu's agricultural sector calls for an integrated approach that develops a win-win solution for all key stakeholders, including the required inter-departmental co-ordination. The proposed approach in this paper is to use the energy and water sector as a lever to bring about a transformation in the nexus. The following approach is being presented:

- Introduction of grid-interactive solar PV plants
- Deployment of energy efficient pumps sets
- Deployment of advanced irrigation technologies (mirco and precision irrigation)

Additionalities listed in *Figure 5* are not being detailed in this paper. These however are considered as interventions that can play a critical role in on overall strategy in the WELL nexus.

Figure 5 Integrated approach

Technology
5-star rated pumps

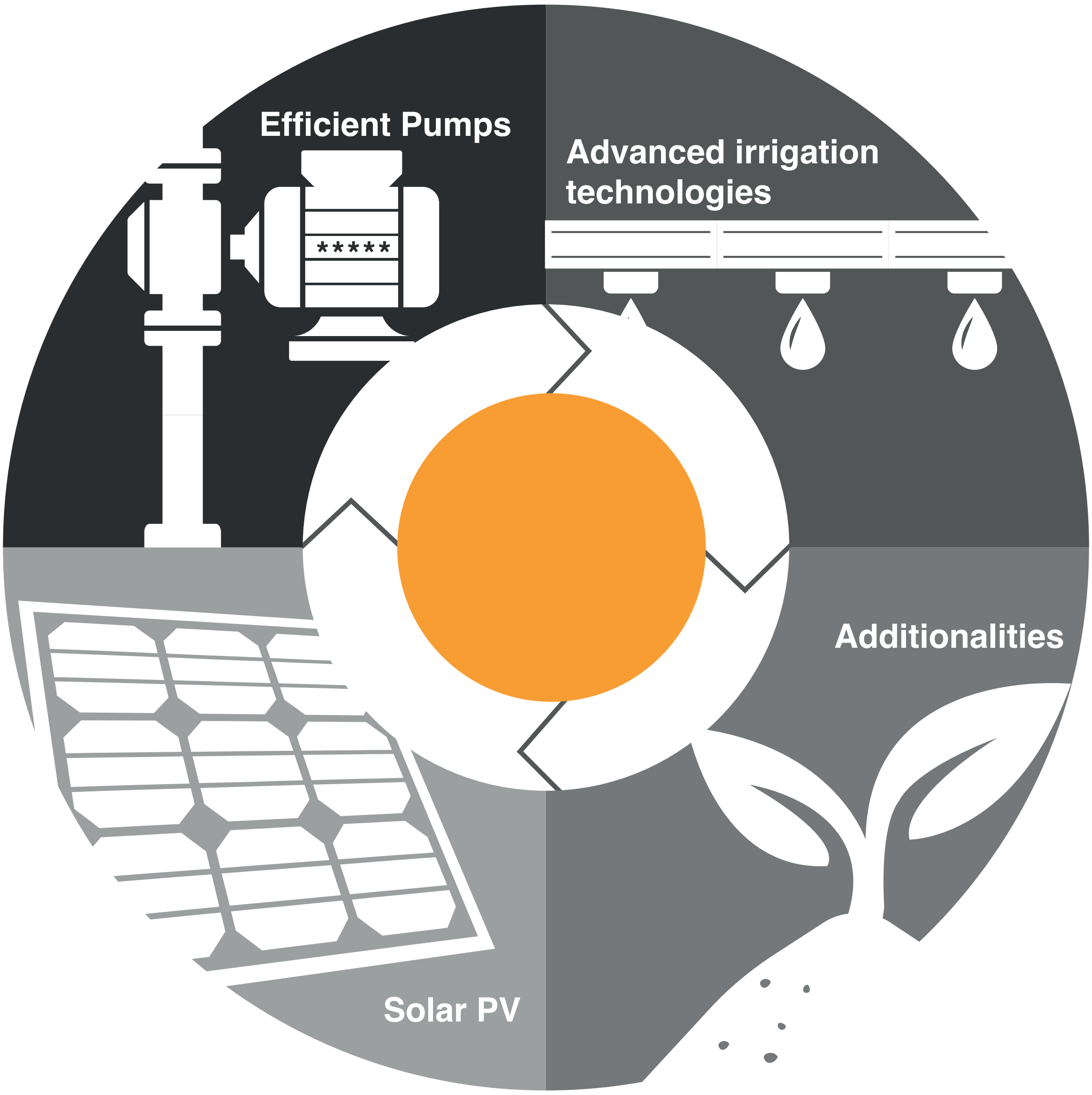
Government Schemes

Potential Savings
Energy: 30%

Technology
Micro irrigartion
Precision irrigation

Government Schemes
PMKSY

Potential Savings
Energy: 45%
Water: 45%



Technology
Grid-connected solar
Metering facilities

Government schemes
KUSUM
MNRE subsidy
RPO obligations

Potential Savings
Energy: From self consumption

Technology
Storm water management
Erosion control
Direct route to market
Appropriate crop selection
Minimum support prices

The following benefits are expected for major stakeholders if an integrated approach to the WELL nexus is taken in the context of free electricity supply to Tamil Nadu's agricultural sector.

Figure 6 Stakeholder benefits of an integrated approach

Utility

Reliable data to estimate distribution losses

Reliable data to claim subsidy from State Government

Helps in addressing commercial losses (power theft etc.) and brings in additional revenue, improvement of collection efficiency

Load reduction during day time (day-time peak load shaving)

Supports fulfillment of renewable energy purchase obligations (RPOs)

Improvement of power quality (voltage, harmonics) as power is fed from the tail end of the grid

State Government

Reduction in subsidy on electricity and fertilizer

Employment generation/green jobs

Reduction in water consumption, leading to less burden on existing infrastructure of water supply and wastewater treatment systems.

Contribution towards renewable energy targets and CO2 emission reduction targets

Farmer

Increase in income and diversification of income stream

Uninterrupted quality power supply

Increase in crop yield through advanced irrigation technology, reduction in fertilizer input, reduction of labor time through automated irrigation

Industry

Boost for solar energy, efficient pump and irrigation supply sector - leads to cost reduction

Green job creation

Citizens/Public

Reduction in CO2 and air pollution

Green jobs and employment generation

Water, energy and food security

6. VIRTUAL CASE STUDY

The following section compares the expected impact of the following scenarios:

- Grid-connected pump (Business as Usual)
- Grid-connected solar PV
- Solar PV with energy efficient pumps (EE)
- Solar PV with advanced irrigation (AI)
- Integrated approach (solar PV, EE & AI)

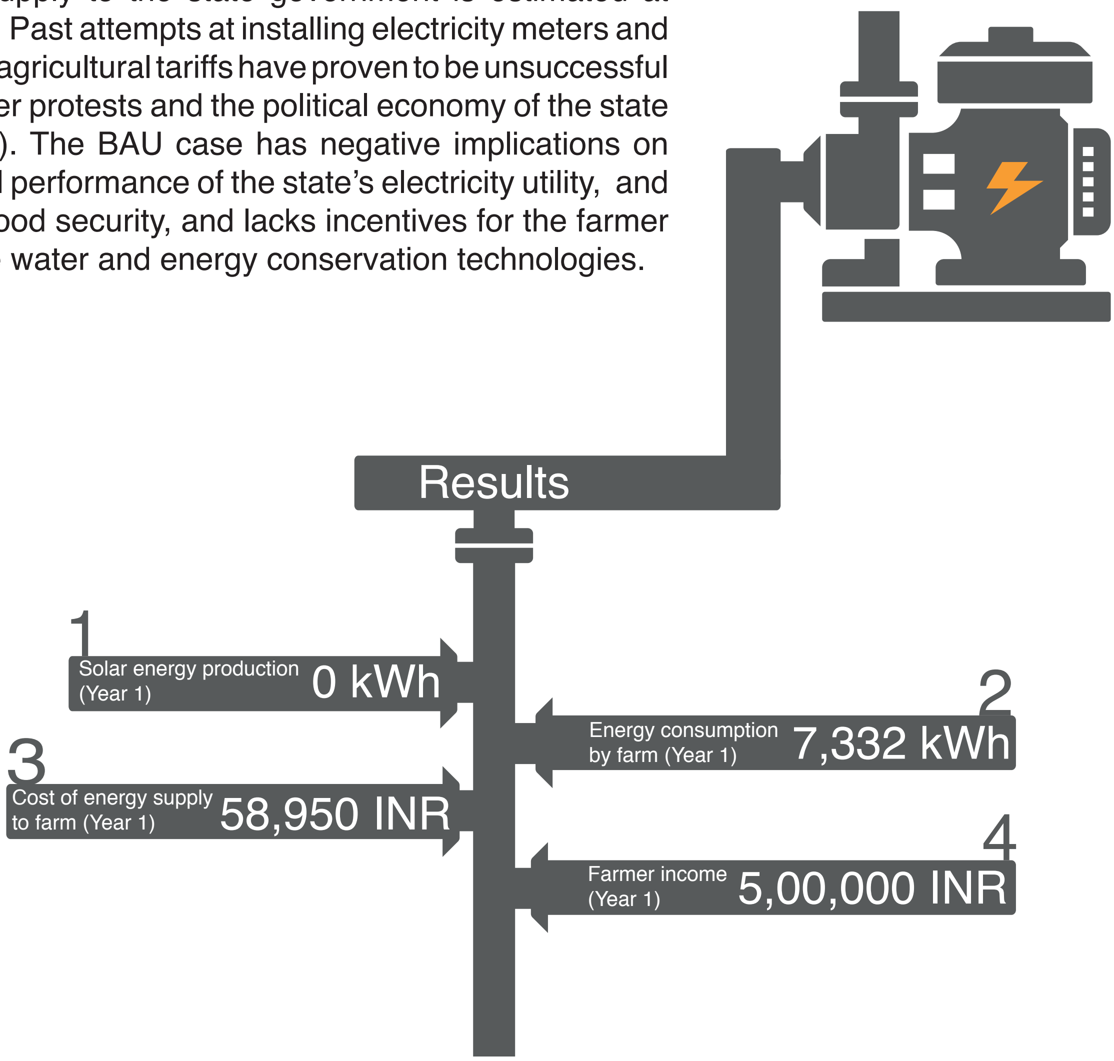
The assumptions used for impact evaluation of the scenarios have been listed in the Annexure.

A virtual case of a 5-acre farm has been taken as a baseline for estimation of impacts. The crop chosen for cultivation is banana, one of the major crops cultivated in Tamil Nadu.

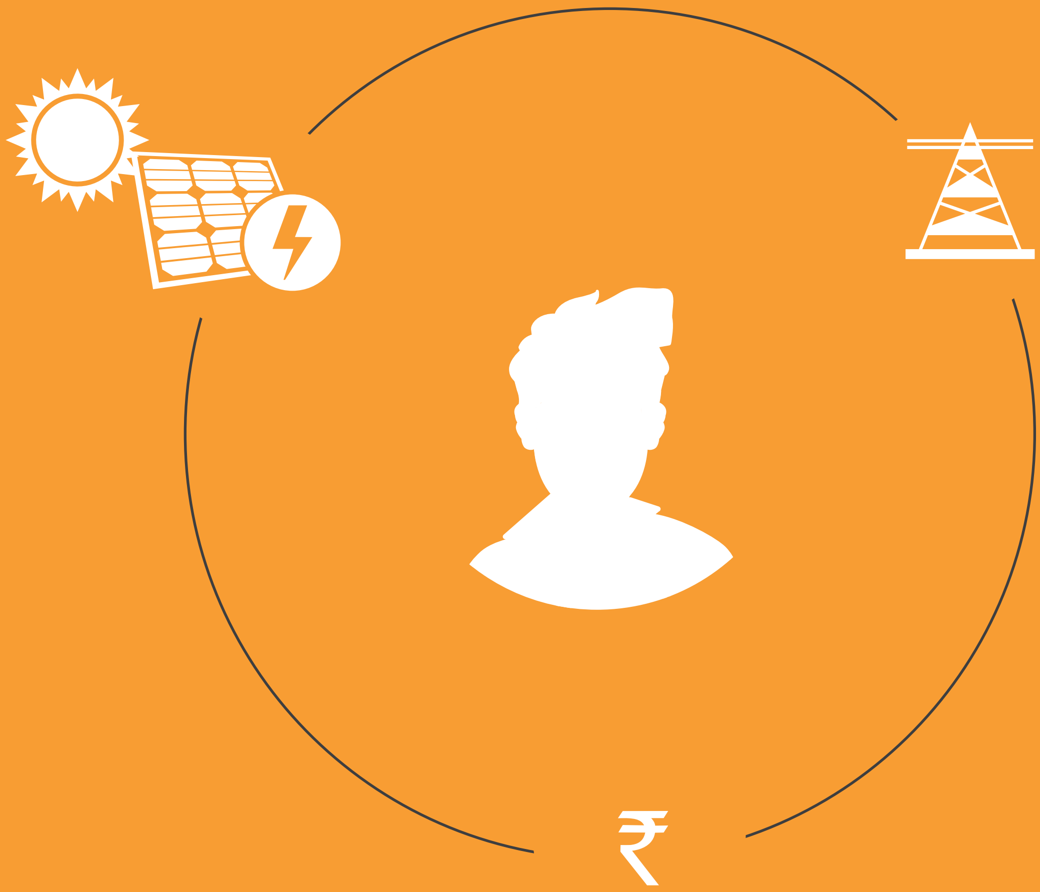
Area under cultivation	**5 acres**
Crop	**Banana**
Production cost per acre	**INR 20,000 (fertilizer, labor etc.)**
Income per acre	**INR 1,20,000**
Net profit per acre	**INR 1,00,000**
Pump load factor	**15%**
Pump size	**7.5 HP**
Annual electricity consumption	**7,332 kWh**
Cost of electricity supply	**INR 58,950 (Year 1)**
Irrigation technology	**Flood irrigation**

6.1 Grid-connected pumps (Business as Usual)

Under the Business as Usual (BAU) case of free electricity supply to agricultural connections, the total annual cost of electricity supply to the state government is estimated at INR 58,950. Past attempts at installing electricity meters and introducing agricultural tariffs have proven to be unsuccessful due to farmer protests and the political economy of the state (voter bank). The BAU case has negative implications on the financial performance of the state's electricity utility, and water and food security, and lacks incentives for the farmer to introduce water and energy conservation technologies.



Prosumption means "production by consumers".
The term prosumption involves the complex relationship between production and consumption. In the inter-related process that involves simultaneous production and consumption, individuals become prosumers, in that they consume and produce a product. In the case of electricity, this means that the prosumer (the farmer) is producing a portion of their energy to be sold back to the utility via the grid and simultaneously reducing their share of the cost for maintaining that very grid.

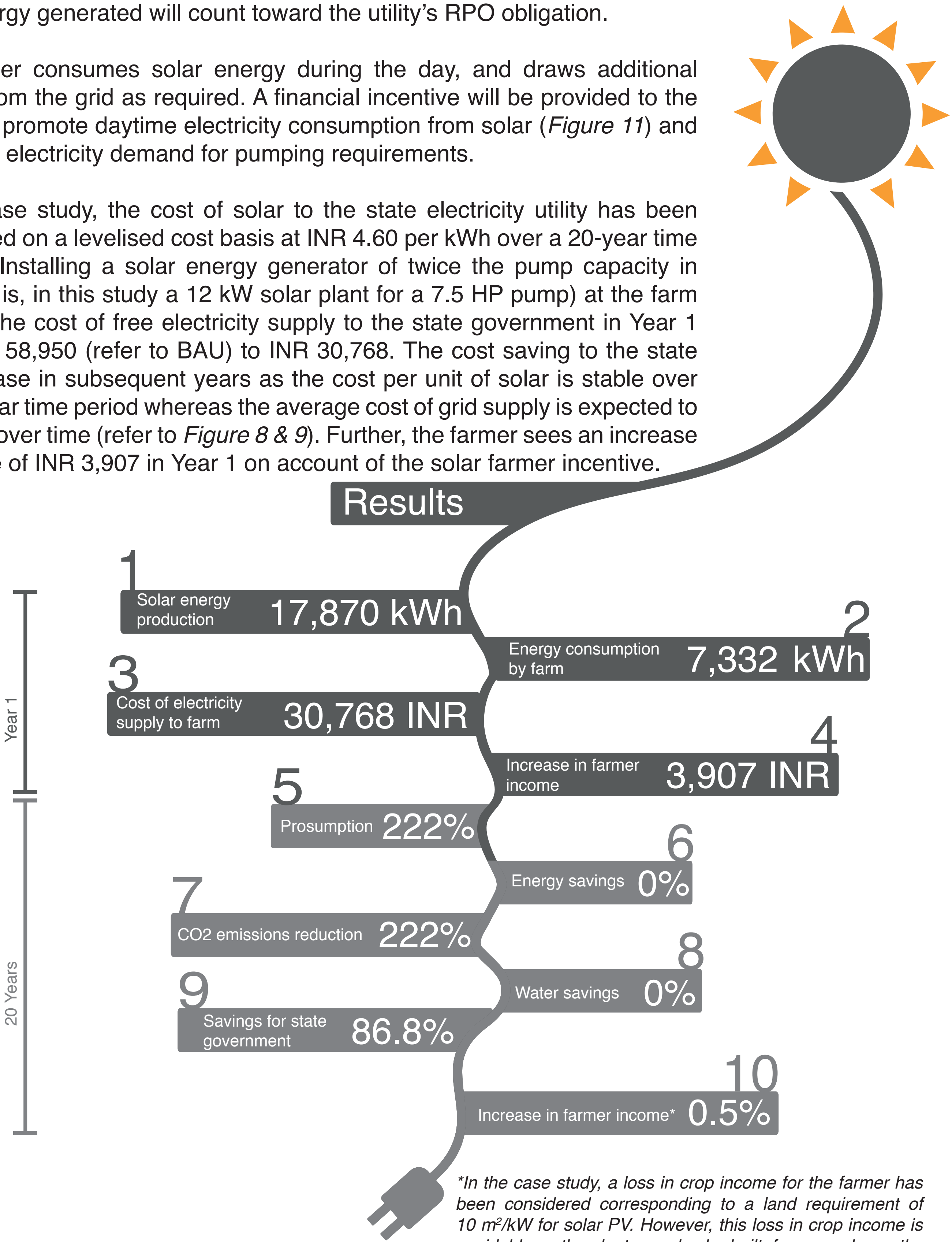


6.2 Grid-connected solar PV for farms

Farms in Tamil Nadu can be transitioned to grid-connected solar power plants to partly meet their energy demand for irrigation. The state electricity utility or a Renewable Energy Service Company (RESCO) may install, operate and own the plants. Bi-directional electricity meters will be installed to account for energy exported to and imported from the grid (refer to *Figure 10*). The gross solar energy generated will count toward the utility's RPO obligation.

The farmer consumes solar energy during the day, and draws additional energy from the grid as required. A financial incentive will be provided to the farmer to promote daytime electricity consumption from solar (*Figure 11*) and to reduce electricity demand for pumping requirements.

In this case study, the cost of solar to the state electricity utility has been considered on a levelised cost basis at INR 4.60 per kWh over a 20-year time period.[14] Installing a solar energy generator of twice the pump capacity in kW, (that is, in this study a 12 kW solar plant for a 7.5 HP pump) at the farm reduces the cost of free electricity supply to the state government in Year 1 from INR 58,950 (refer to BAU) to INR 30,768. The cost saving to the state will increase in subsequent years as the cost per unit of solar is stable over the 20-year time period whereas the average cost of grid supply is expected to increase over time (refer to *Figure 8 & 9*). Further, the farmer sees an increase in income of INR 3,907 in Year 1 on account of the solar farmer incentive.



**In the case study, a loss in crop income for the farmer has been considered corresponding to a land requirement of 10 m²/kW for solar PV. However, this loss in crop income is avoidable as the plant can also be built, for example, on the roof of the pump house. In this case, the increase in farmer income is 1.1%.*

Refer to Annexure for assumptions

Advantages of installing grid-connected solar PV at farms

- Reduces the financial burden of free/subsidised electricity for the state and the utility, as the levelised cost of solar is less than the average power purchase cost of energy for the utility.

- Reduces distribution losses on both self-consumption of solar energy by the farmer and export of solar energy to the local distribution network.

- Contributes to voltage improvement of the local distribution network as the grid is being fed from its tail end.

- Justifies an uninterrupted day-time power supply for agricultural connections and empowers the farmer to have control over pump operation timings and irrigation scheduling and may make auto switches for pumps redundant.

- Incentivises the farmer for day-time pump operation to make maximum use of on-site solar energy generation (refer to *Figure 11).*

- Incentivises the farmer towards water and energy conservation since the farmer is being financially rewarded for every unit of solar energy fed into the grid. The farmer will be able to diversify his income with a solar crop. This will also contribute to government target of doubling the average farmers' incomes by the end of financial year 2021-22.

- Requires the introduction of metering, which will help the utility to get a clearer understanding of the agricultural electricity consumption.

- Contributes to the state's renewable energy targets and renewable energy purchase obligations.

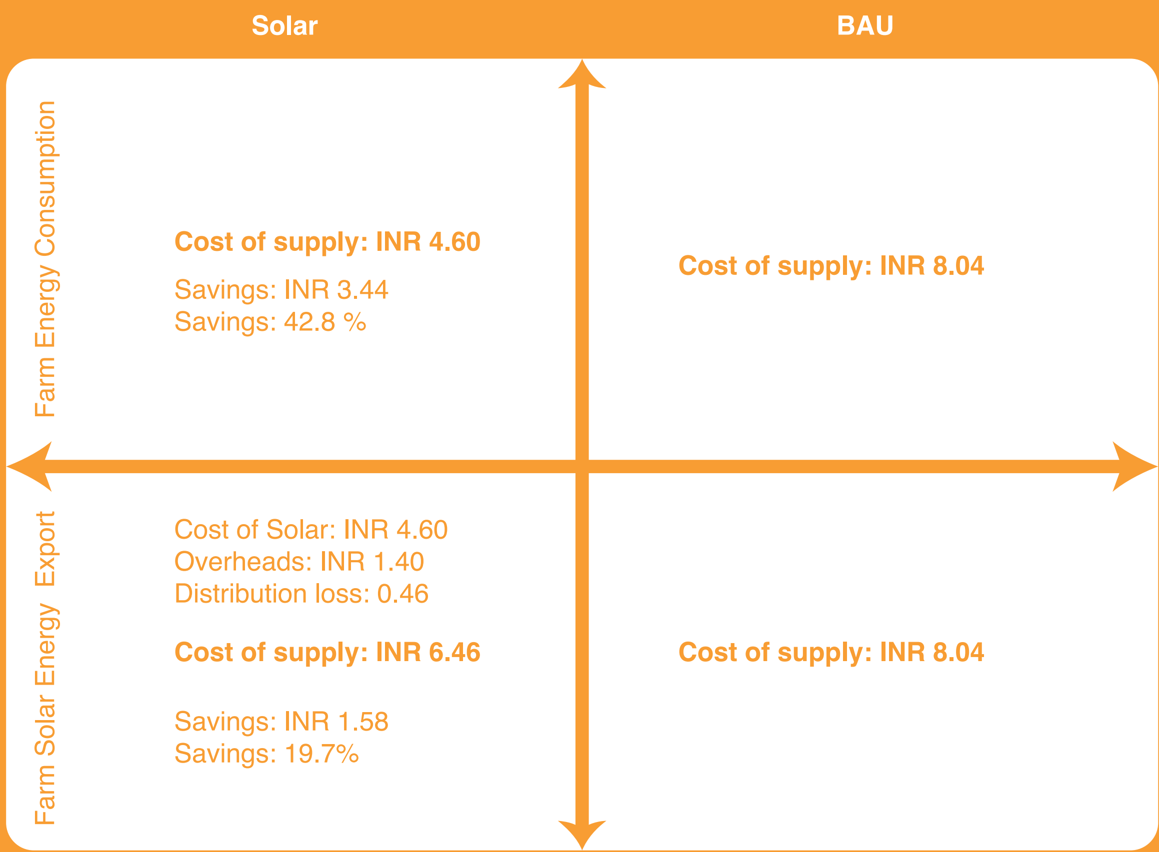
- Boosts the solar energy sector and creates new jobs, especially in the engineering, procurement and construction (EPC) sector.

Savings on account of solar PV

(i) Cosumption at the point of production: With a levelized cost of solar energy (LCOE) estimated at INR 4.60 per kWh at the point of consumption and an average cost of supply (COS) of grid electricity at INR 8.04 per kWh (as of 2019); the utility will be able to reap a saving in the first year of INR 3.44 per kWh solar energy consumed at the the farm.

(ii) Export and selling of solar energy to other consumer categories: Surplus solar energy exported from the farm to the electricity grid comes at a cost of INR 6.46 per kWh, including utility overheads and distribution loses. Compared to the COS of INR 8.04, the utility will have a financial saving of INR 1.58 on every unit of solar energy exported from the farm and resold to other consumers. These savings are expected to increase over time as the cost of solar energy will be stable over a 20 to 25 year time horizon whereas the COS is expected to increase at least with the inflation rate (refer to *Figure 8*).

Figure 7 Savings from solar to state government on cost of electricity supply



As the cost of solar energy is linear over a 20-25 year time period and the COS is assumed to increase at least with the inflation rate (assumed at 5%), installing solar energy generators at farms will yield substantial financial savings to the state government over a 20-25 year time window. Permitting export of surplus solar energy to the grid allows the utility to resell the solar energy, this contributes significantly to the achievable savings *(*refer to *Figure 9).*

The financial incentive being provided to the farmer will provide them an additional source of income, through a 'solar crop'. Having reliable power supply and an incentive to reduce energy and water consumption, as every kWh of solar energy avoided can be exported to the grid, it is expected that annual electricity and water consumption will reduce. Introduction of electric meters will be an added benefit to the electricity utility.

Figure 8 Cost trajectory: solar PV vs gird supply

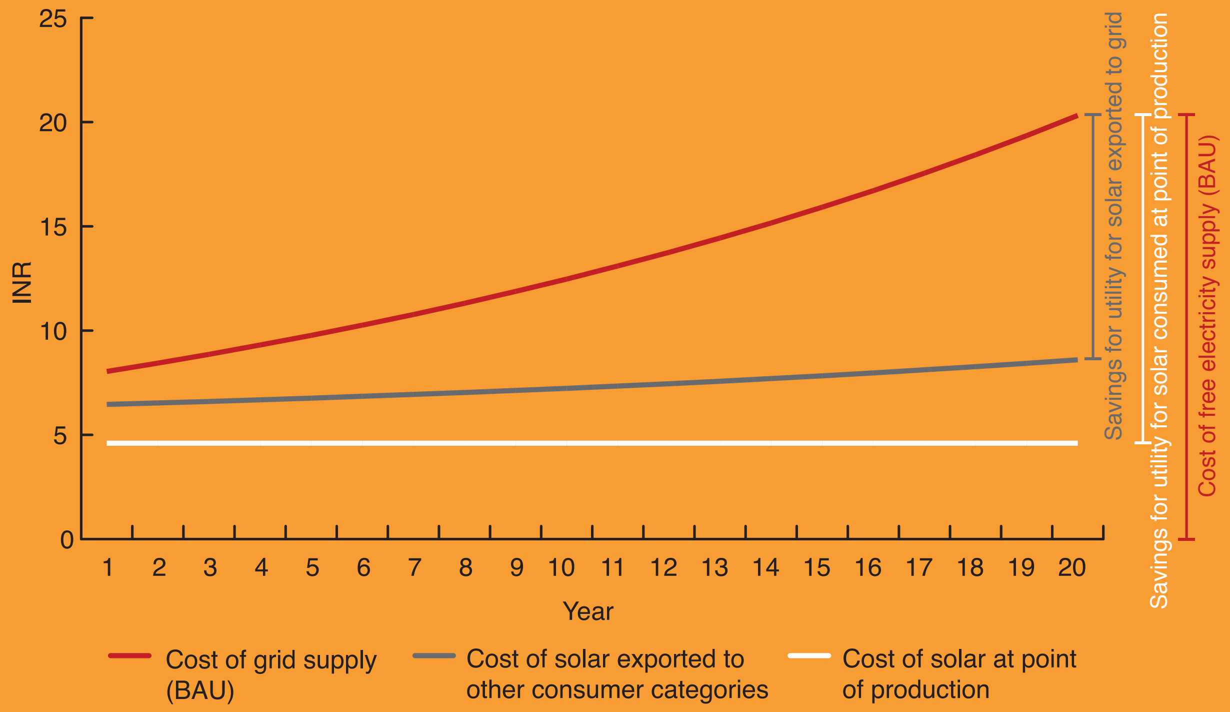


Figure 9 Cost to the state government of energy supply | Comparison

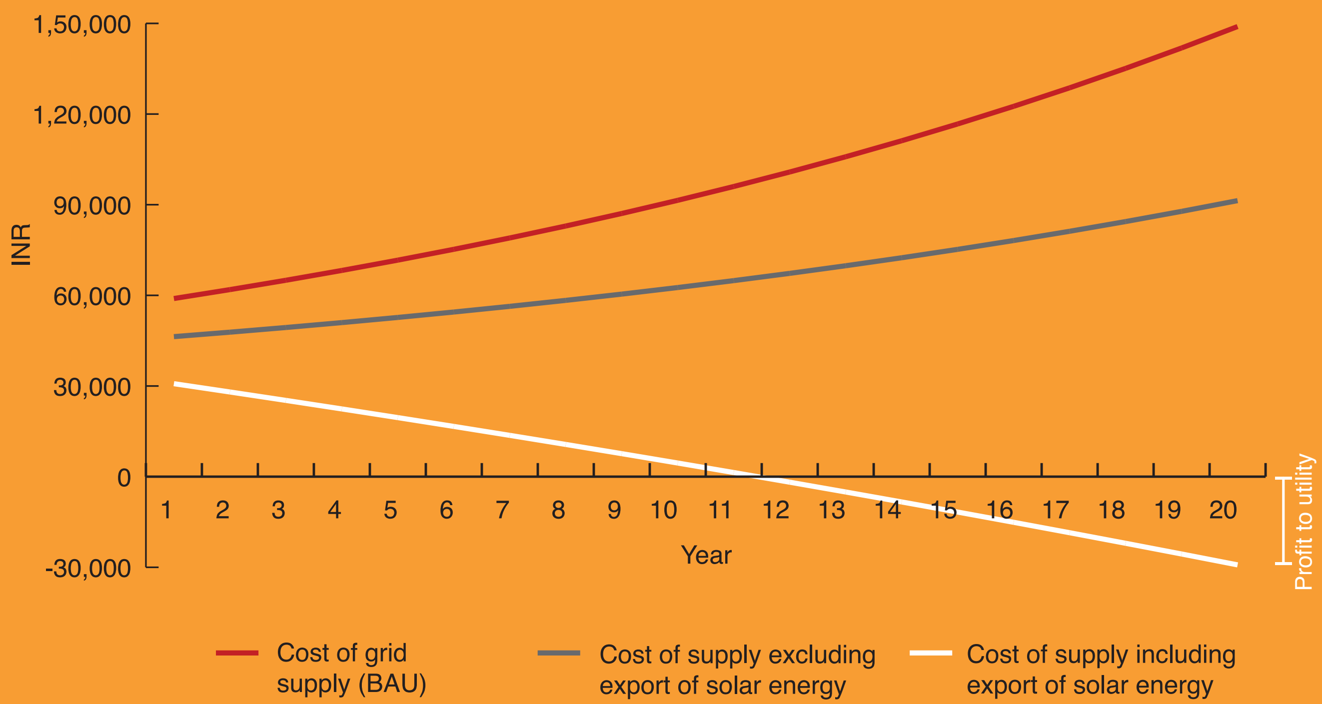
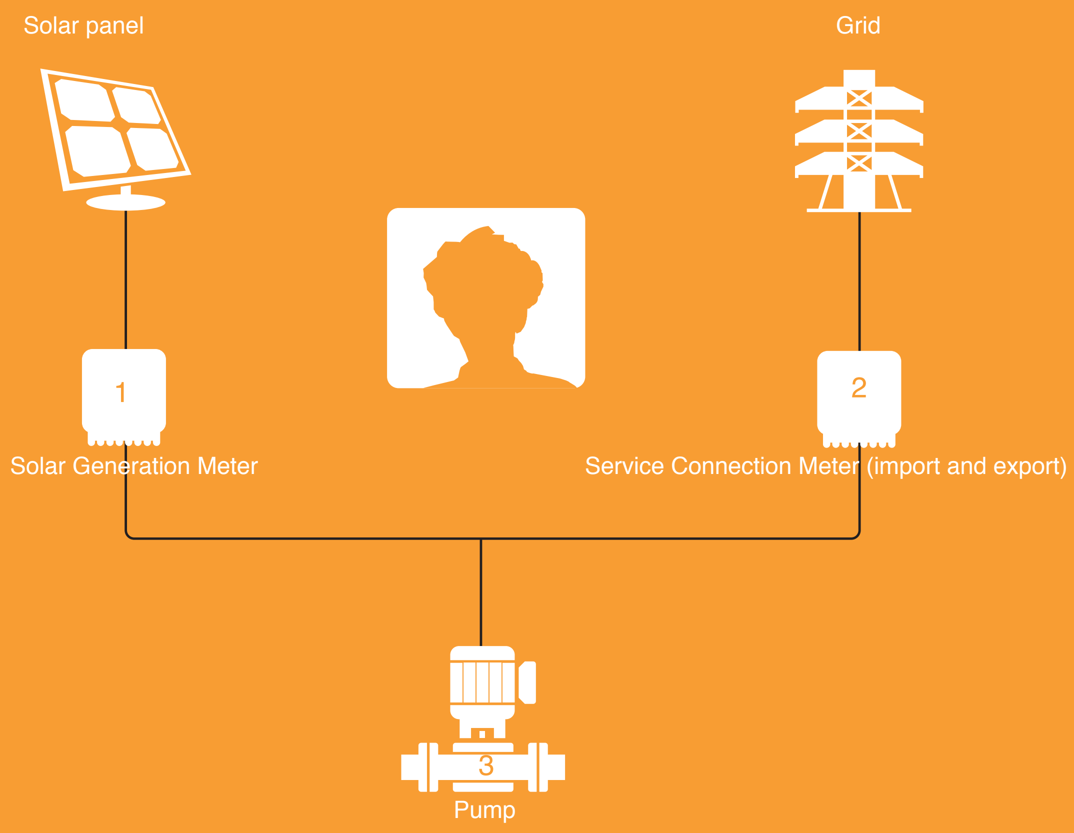


Figure 10 Metering arrangement for grid-connected solar in agriculture



1 Metering of gross solar energy production for settlement with develpoer

2 Metering of import from grid and export from solar

3 Pump energy consumption: solar energy generation - solar energy export + energy imported from grid

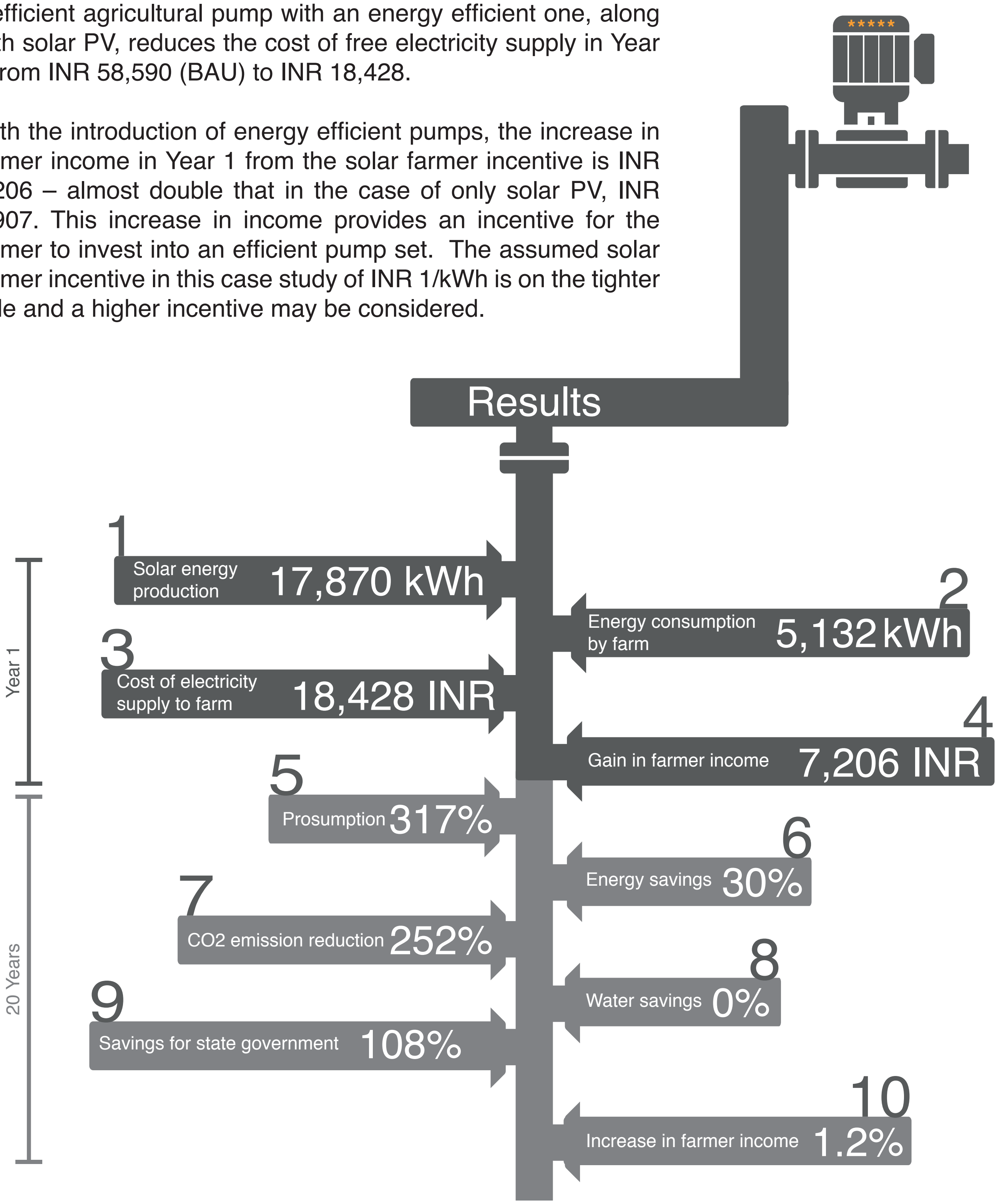
Figure 11 Farmer incentive design I Year 1

Solar energy production (gross)	17,870 kWh
minus	
Pump energy consumption	7,332 kWh
minus	
Energy import from grid to farm	3,666 kWh
equals	6,872 kWh
Multiplied by farmers incentive	INR 1.00
equals	INR 6,872

6.3 Solar PV with energy efficient pumps

The low efficiency rates of 20-35% of many of the existing agricultural pumps can be significantly improved with the widespread adoption of energy efficient pump sets.[2,15] An average energy saving potential of 30% can be expected.[16] Energy efficient pumps will also significantly reduce the pump load on the grid and can defer investment for upgrading the distribution infrastructure. In the virtual case study done, replacing the inefficient agricultural pump with an energy efficient one, along with solar PV, reduces the cost of free electricity supply in Year 1 from INR 58,590 (BAU) to INR 18,428.

With the introduction of energy efficient pumps, the increase in farmer income in Year 1 from the solar farmer incentive is INR 7,206 – almost double that in the case of only solar PV, INR 3,907. This increase in income provides an incentive for the farmer to invest into an efficient pump set. The assumed solar farmer incentive in this case study of INR 1/kWh is on the tighter side and a higher incentive may be considered.



Refer to Annexure for assumptions

6.4 Solar PV with advanced irrigation technology

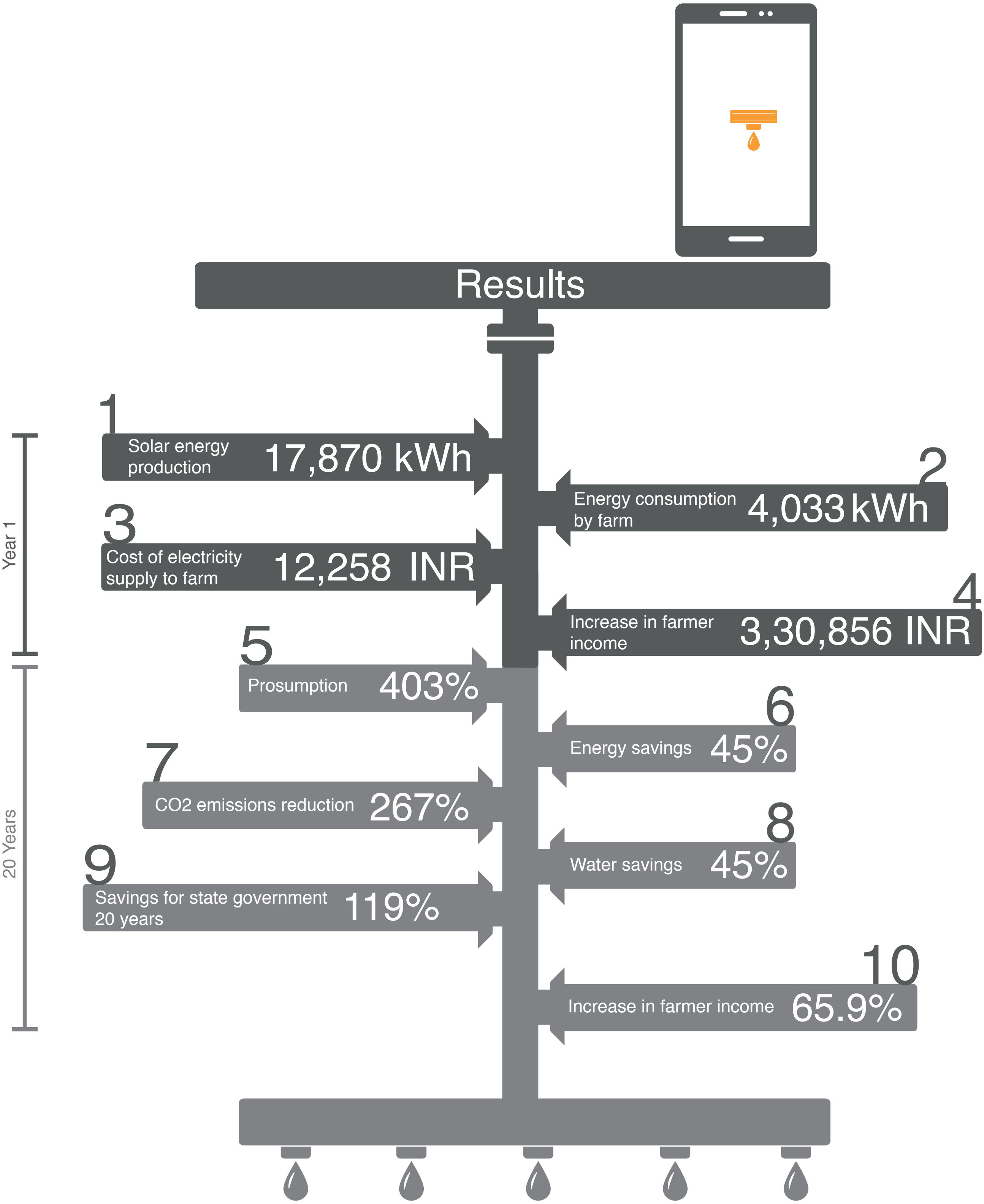
Precision irrigation paired with micro irrigation technology is expected to yield substantial water and energy savings while simultaneously increasing crop yield, reducing fertilizer input and contributing to improved soil fertility. Precision irrigation is defined as ITC-enabled irrigation control that delivers the right amount of water at the right time for a specific crop, soil and climate context. It reduces farm labour input, as the control of irrigation is automated. A further advantage of deploying precision irrigation technology is that the system can be programmed to avoid operation of agricultural pumps during grid peak demand hours, and hence contributes to the utility's demand side management.

The range of water savings that can be achieved by micro irrigation (without precision irrigation technology) varies and depends on multiple parameters, some of which are crop, soil type and farmer behaviour. Drip irrigation shows water savings in the range of 20% to 60%.[17] For crops such as rice, micro irrigation technologies have not yet advanced sufficiently for commercial application, but can be expected to in the near future.

Large-scale deployment of the above technologies will result in job creation for the manufacturing, installation and maintenance sectors.

For the purpose of this paper, a 52% yield increase[18] and a 10% reduction in input cost[19] from introducing advanced irrigation have been assumed. Average achievable water saving of micro and precision irrigation combined is assumed at a conservative 45%. A 45% water savings will translate to a 45% reduction in electricity demand.

In the virtual case study, introducing advanced irrigation technology along with solar PV reduces the annual cost of free electricity supply from INR 58,950 (BAU) to INR 12,258. Additionally, there is a big increase in farmer income by INR 3.30 lakh in Year 1. This increase is on account of the 52% crop yield increase and a higher solar farmer incentive. The expected increase in income provides a strong incentive for the farmer to invest into advanced irrigation technology.



Refer to Annexure for assumptions

Water use efficiency of irrigation technologies

With usage of micro irrigation systems, conveyance loss is minimal. Evaporation, runoff and deep percolation are also reduced by using micro irrigation methods. Another water saving advantage is that water source with limited flow rates such as small water wells can be used. Micro irrigation provides significantly higher water usage efficiency due to proximity and focused application (*Figure 12*).

Micro irrigation systems simultaneously reduce the water demand while increasing the crop yield. *Figure 13* indicates average water saving and yield increase potential by different types of crops.

Figure 12 Water usage efficiency[20, 21]

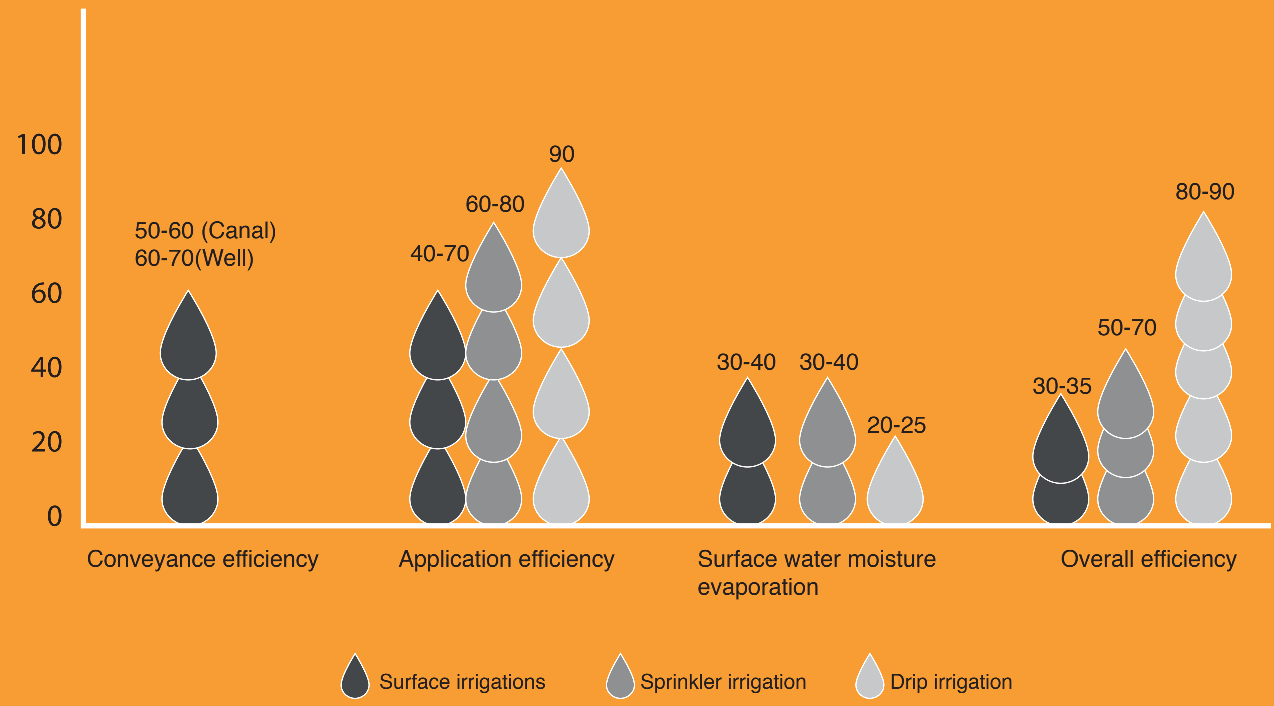
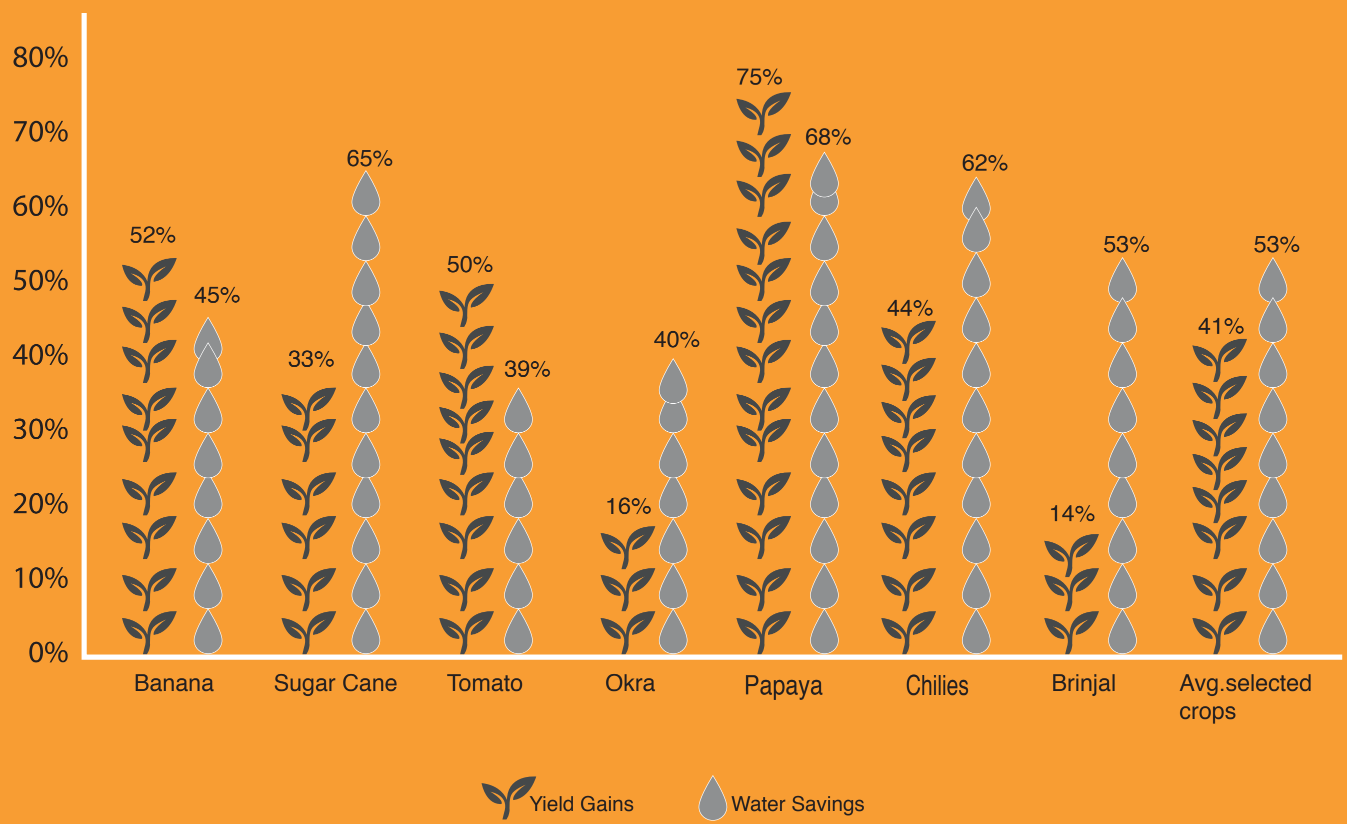
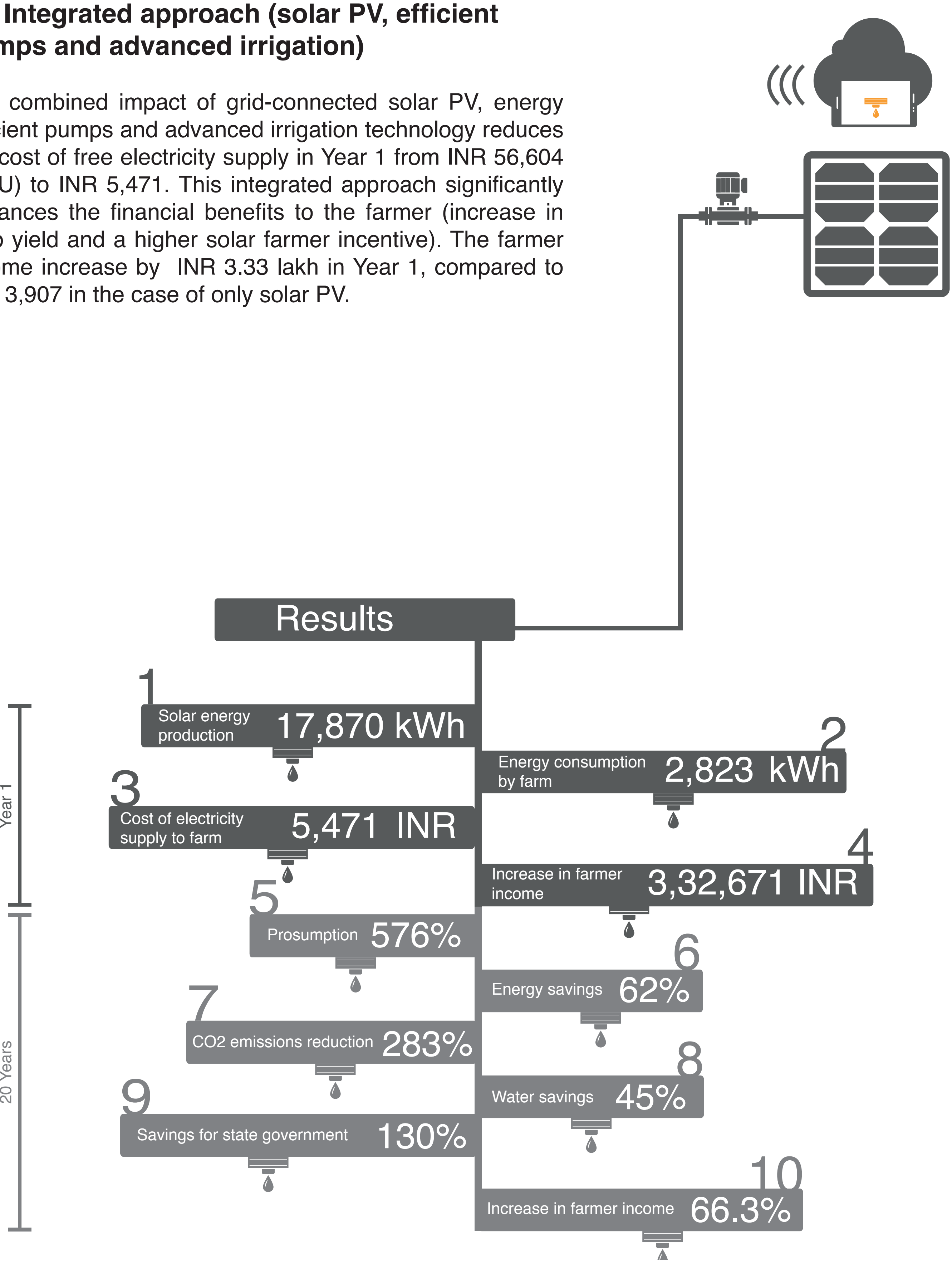


Figure 13 Water saving and crop increase in % on account of micro irrigation[18]



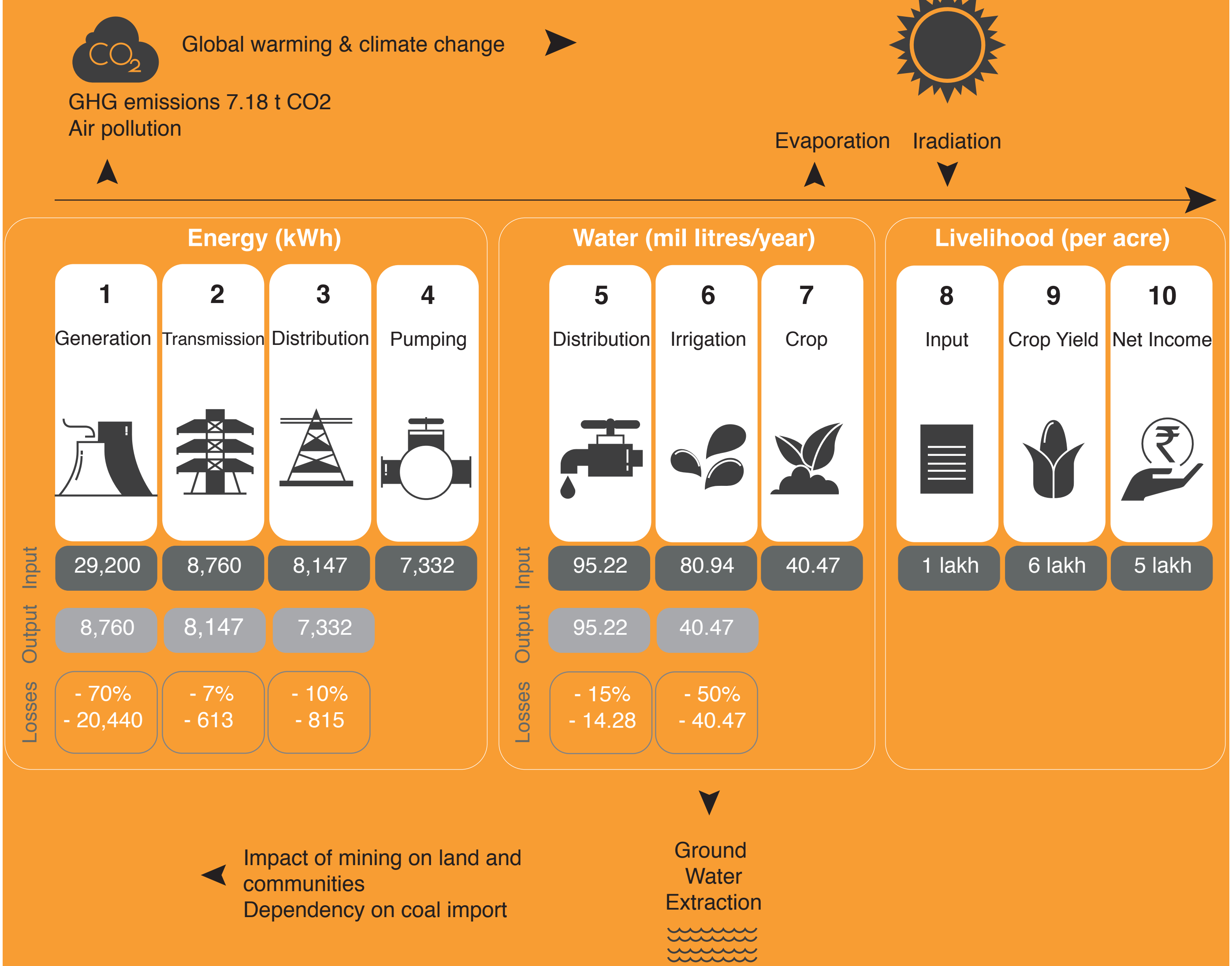
6.5 Integrated approach (solar PV, efficient pumps and advanced irrigation)

The combined impact of grid-connected solar PV, energy efficient pumps and advanced irrigation technology reduces the cost of free electricity supply in Year 1 from INR 56,604 (BAU) to INR 5,471. This integrated approach significantly enhances the financial benefits to the farmer (increase in crop yield and a higher solar farmer incentive). The farmer income increase by INR 3.33 lakh in Year 1, compared to INR 3,907 in the case of only solar PV.



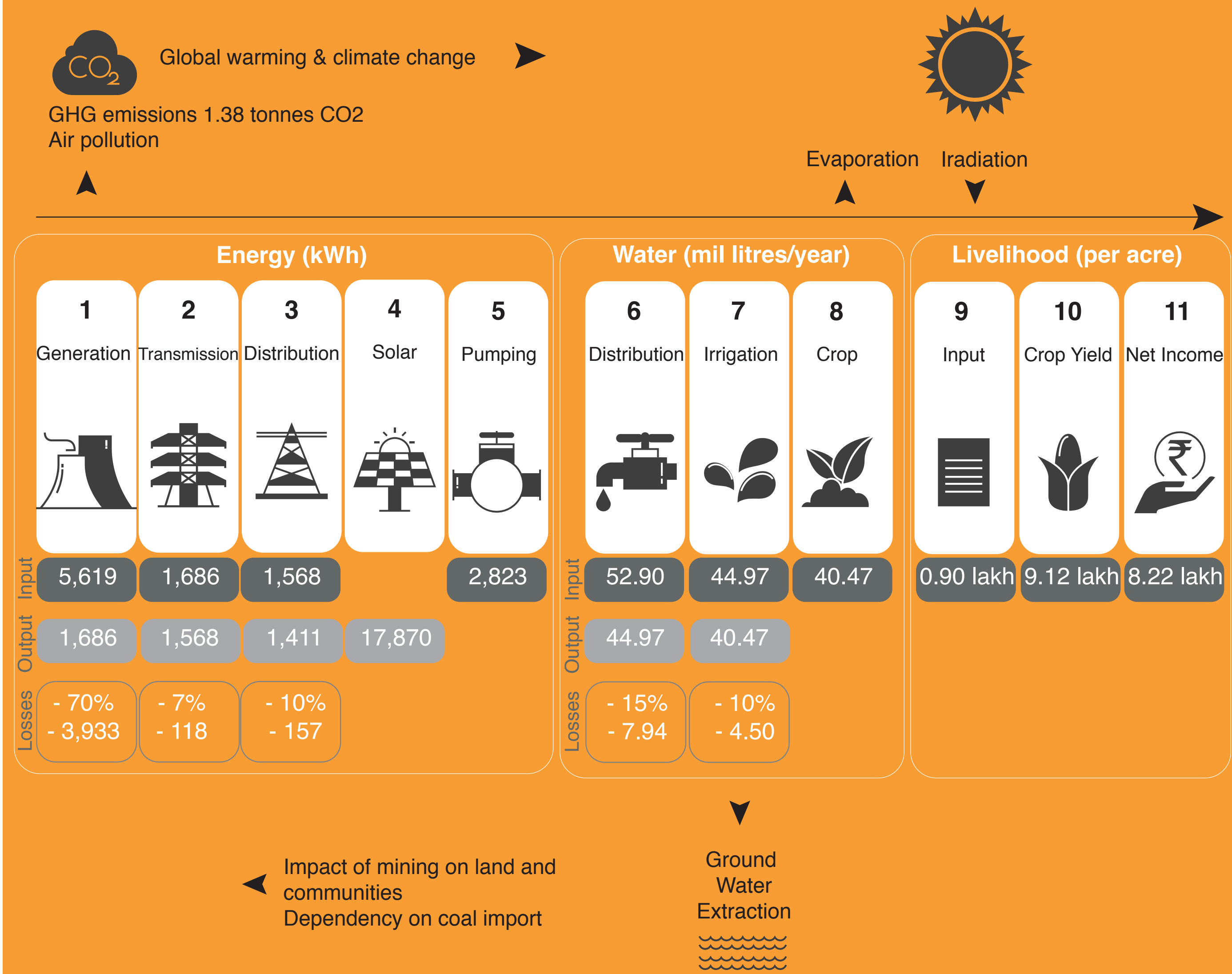
Refer to Annexure for assumptions

Resource utilization process for BAU Case



The info-graphic above illustrates the resource utilization process for the BAU case (an example 5 acre farm with banana cultivation). 40.47 mil litres of water per annum is required to be delivered to cultivate banana crop (step 7 in the chain). This results in an annual gross revenue of INR 6 lakh. The cultivation process requires input costs for labor and fertilizer of INR 1 lakh (electricity is free of cost in this example). Annual net income to the farm is INR 5 lakh. In order to deliver the energy service required for pumping the water, an initial energy input of 29,193 energy units is required. Here 70% (20,440 units) of the energy gets wasted as heat output due to generation inefficiency (step 1). From the thermal power plant, 8,760 electricity is exported to the electricity transmission network, with estimated transmission losses at 7% (613 units), and 7,970 units of electricity is delivered to the local distribution network (step 2). 10% (815 units) of electricity will be lost in the distribution grid and 7,332 units will be finally delivered (step 4) to operate the water pump in order the draw the required water of 95.22 mil litres/year. The average pump efficiency is estimated to be 25%, hence 75% (5,499 units) of the energy delivered for pumping services is being lost. Accounting for 15% water losses (14.28 mil litres/year) in the water distribution network on the farm, 80.94 mil litres/year of water is finally delivered via conventional flood irrigation (step 6). 50% of the water delivered is lost on account of evaporation and does not benefit the crop. Amount of water finally utilised by the banana crop is a 40.47 mil litres/year.

Resource utilization process for the integrated approach



The energy chain in the integrated case only considers supply of electricity to the farm. Hence, 1,411 units are supplied by the grid to the farm (Step 3). However, in reality, the distribution system not only supplies grid electricity to the farm, but will also be fed electricity from the solar plant in the farm.

The integrated approach introduces 3 strategically-placed interventions in the resource conversion chain.

(i) a grid-connected solar energy generator at the point of consumption,

(ii) an efficient water pump and

(iii) advanced irrigation technology (drip irrigation and precision irrigation control).

The advanced irrigation technology impacts the resource chain in both directions (step 7 in the chain). It increases the yield and thus the income of the farmer, while at the same time reduces the water demand and consequently the energy demand for pumping (by an estimated 45%). This results into an increase in solar energy exported to the grid, which in turn increases the income to the farmer (refer to *Figure 11)*. Introducing energy efficient pumps reduces the energy demand for pumping further (step 5) and in turn increases the income to the farmer on account of additional net-export of solar energy to the grid.

This three-pronged approach of solar energy, energy efficiency and advanced irrigation technology has a synergistic effect, in which the combined sum of the three interventions is greater than the sum of the efforts of each individual intervention. The three interventions combined result in significantly lower losses in transmission and at the thermal power plant, leading to reduced carbon emissions from electricity generation. Additionally, there are no distribution losses for the solar energy consumed at the point of generation (there will be still be distribution losses for the surplus solar energy exported to the grid and re-sold to other consumers).

Overall less water is pumped and distributed. Irrigation requirement is reduced on account of the advanced irrigation technology. In the case study, the total yield (crop yield and 'solar yield' corresponding to additional income from farmer incentive) increases by 54.3% and there is a reduction in input costs by 10%, resulting in an increase of net income of 66.3% from INR 5 lakh to INR 8.32 lakh in Year 1.

6.6 Comparison of the interventions

This section presents the impact of each of the presented interventions with respect to the virtual 5-acre banana farm. The impact of the different scenarios considered on the state government, the state electricity utility, the farmer and the environment are summarised in *Table 2* and *Table 3*.

The combination of all the interventions, as presented, results in an impressive savings of INR 9,66,858 or 130% (on NPV) to the state government over a 20-year time period; and an increase in the farmer income by 66.3%. It reduces the grid energy demand of the farm by 1,18,414 kWh or 61.5% over a 20-year period. Further water savings of 45%, and reduction in CO2 emissions of 283% (including solar energy export) are achieved.

The integrated approach as presented will result in an impressive 130% savings over a 20-year time period to the state government.

Only solar PV (a 12 kW plant in this case study) results in 86.8% (on NPV) savings to the state government on cost of free electricity supply. On the other hand, energy efficiency alone results in 30% savings to the state government corresponding to the 30% energy savings. Further, only advanced irrigiation results in 45% savings to the state government corresponding to the 45% decrease in energy demand.

Amongst the different interventions, advanced irrigation techonology has by far the largest impact on the farmer income due to crop yield increase and redution in input costs. It alone (without any solar farmer incentive) is expected to contribute to an increase of 64.4% in farmer income. Energy efficiency on its own doesn't lead to a financial benefit to the farmer, unless it is combined with the solar farmer incentive.

Table 2 Impact by scenario in percenatge I 20-year time period

Impact	Units	Grid (BAU)	Solar	Solar & EE	Solar & AI	Solar, EE & AI
Prosumption*	%	0.00%	222%	312%	403%	576%
Farm energy savings	%	0.00%	0.0%	30.0%	45.0%	61.5%
Co2 emission reduction	%	0.00%	222%	252%	267%	283%
Water savings	%	0.00%	0.0%	0.0%	45.0%	45.0%
Savings for state government	%	0.0%	86.8%	108%	119%	130%
Increase in Farmer income	%	0.0%	0.5%	1.2%	65.9%	66.3%

** Prosumption: Ratio of solar energy generation over electricity consumption*

Figure 14 Financial impact on state government by scenario I 20-year time period

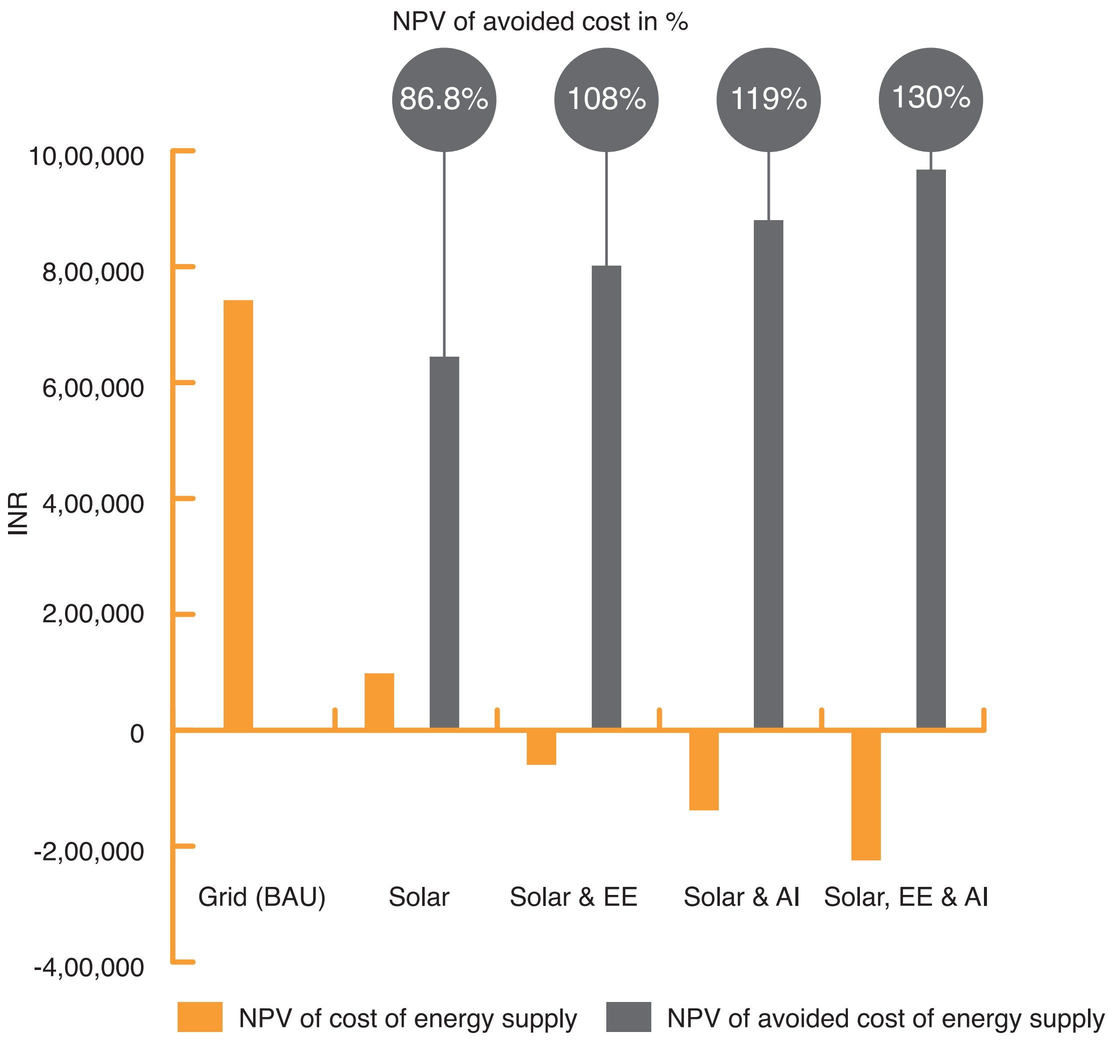


Table 3 Impact by scenario I 20-year time period

Impact	Units	Grid (BAU)	Solar	Solar & EE	Solar & AI	Solar, EE & AI
Solar energy production	kWh	-	3,25,408	3,25,408	3,25,408	3,25,408
Energy consumption by farm	kWh	1,46,642	1,46,642	1,02,650	80,653	56,457
Solar energy surplus exported	kWh	-	2,52,086	2,74,083	2,85,081	2,97,179
Avoided farm grid energy consumption	kWh	-	73,321	95,318	1,06,316	1,18,414
NPV of cost of electricity supply	INR	7,42,201	97,776	-59,508	-1,38,151	-2,24,657
NPV of avoided cost of electricity supply	INR	-	6,44,425	8,01,710	8,80,352	9,66,858
Capital Investment required	INR	-	4,80,000	5,32,500	7,80,000	8,32,500
Introduction of metering		no	yes	yes	yes	yes

Figure 15 Impact on electricity demand-supply I 20-year time period

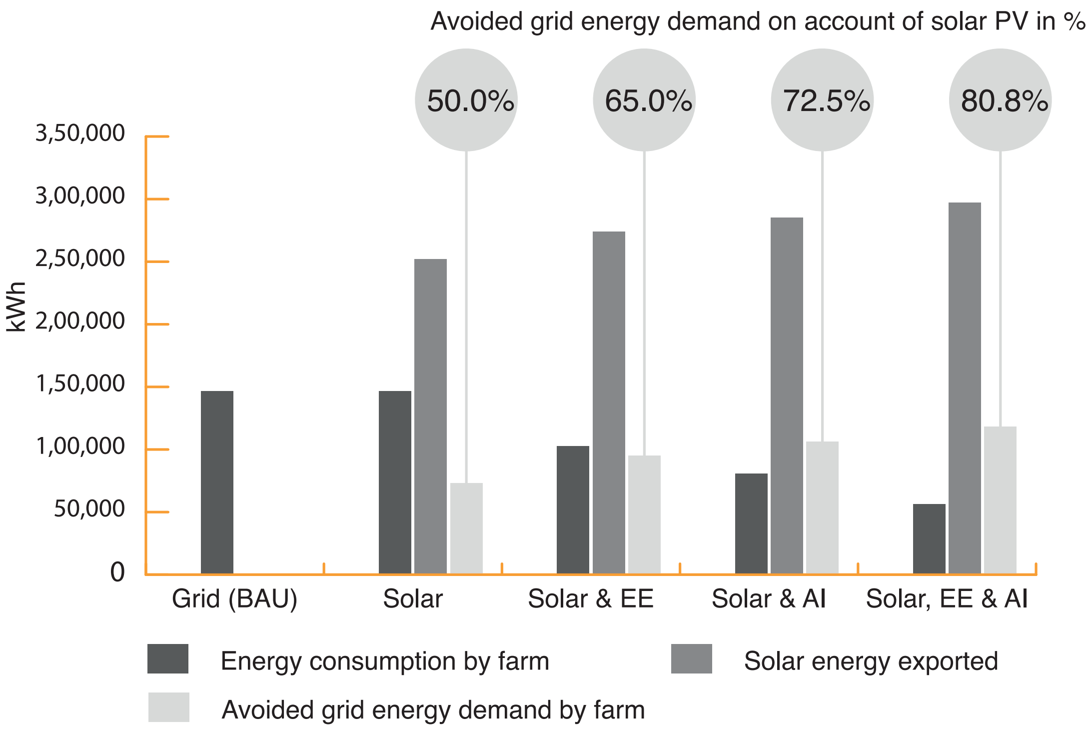


Figure 16 Cost Trajectory by scenario I 20-year time period

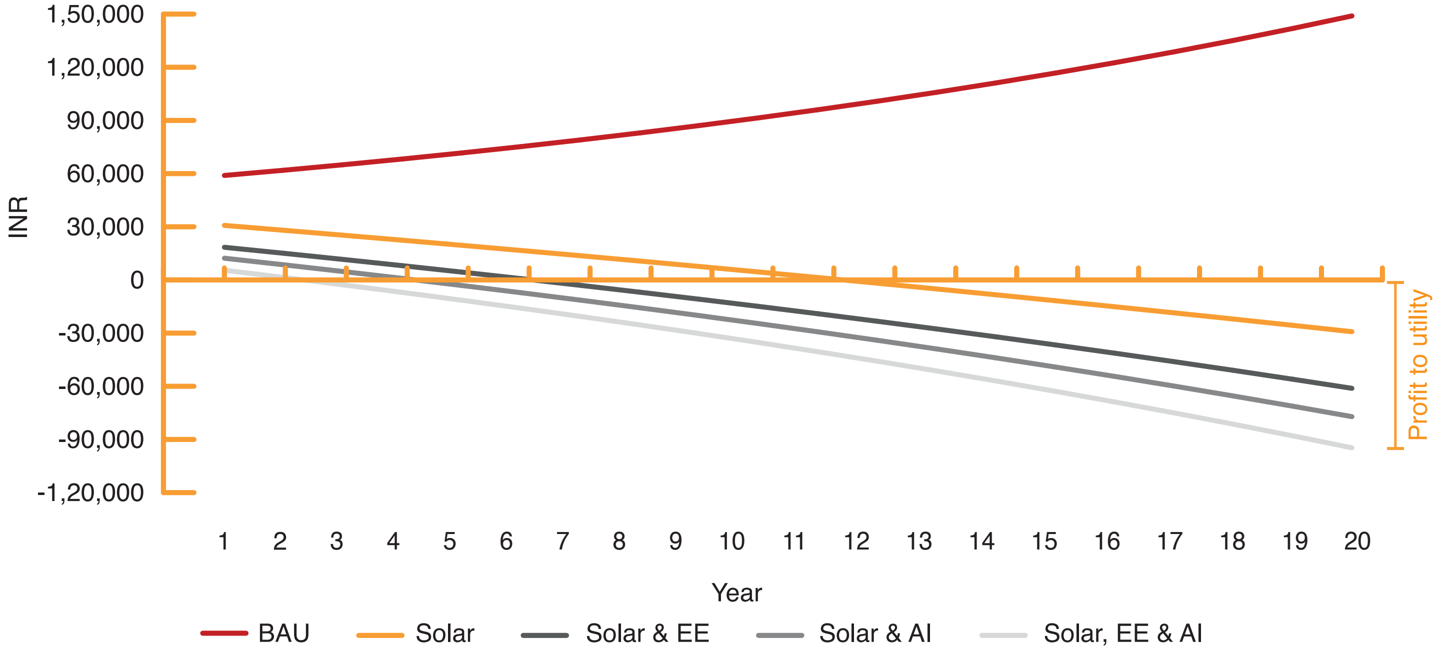


Figure 17 Gain for farmer, compared to BAU, by scenario I 20-year time period

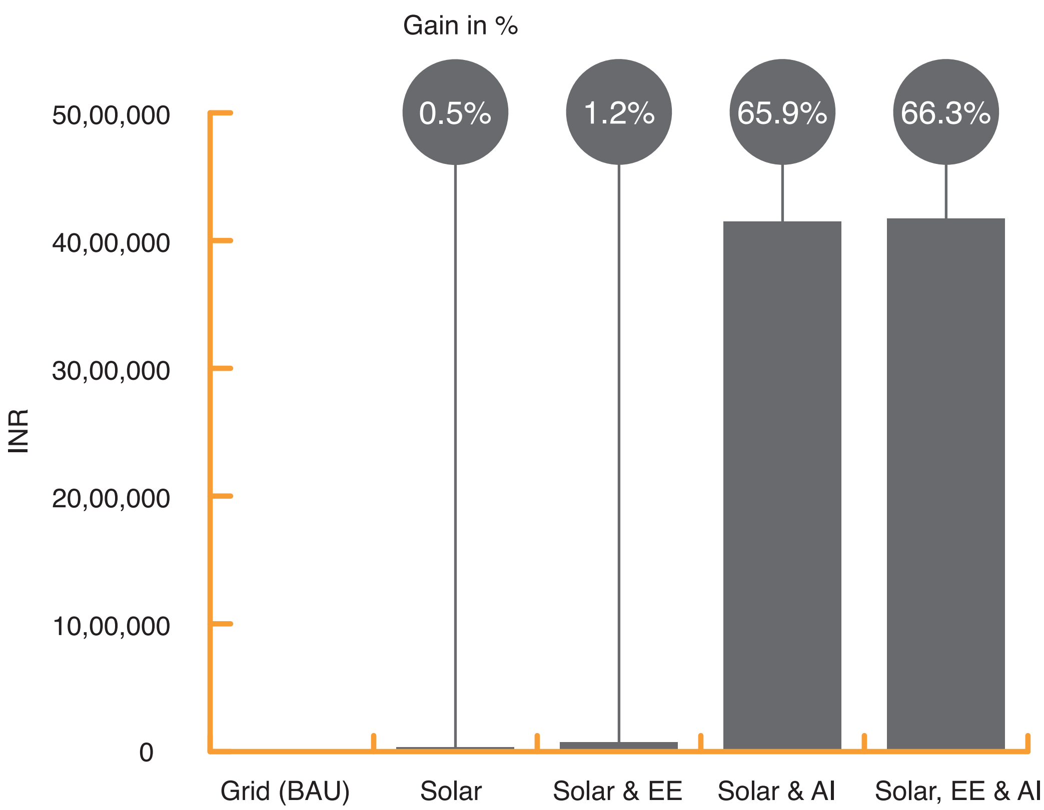
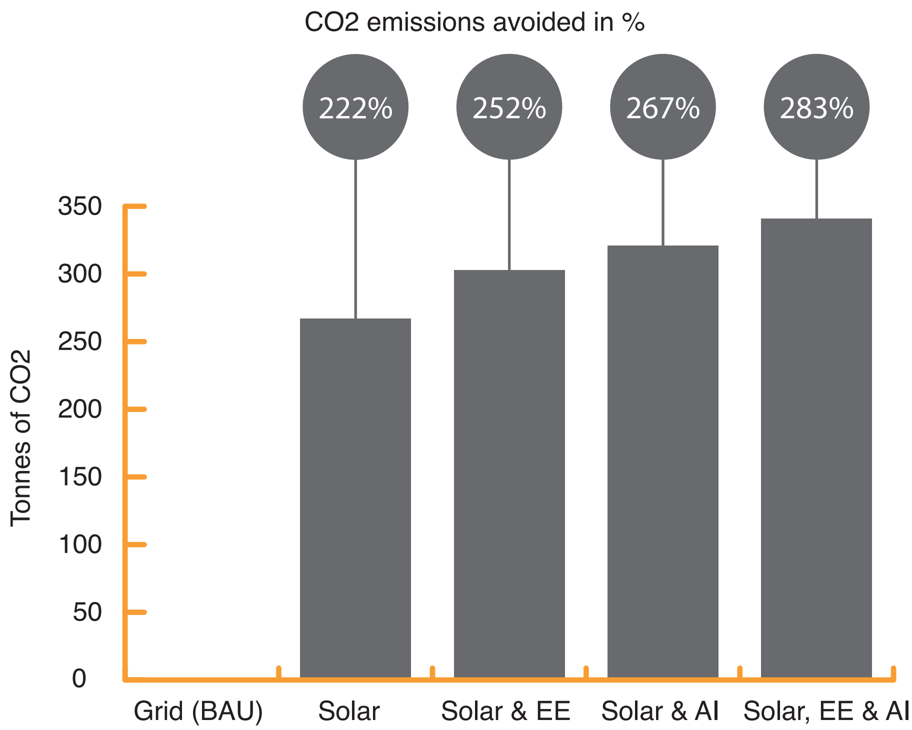


Figure 18 Avoided CO2 emission in tonnes over 20 years[22]



7. STATE-WIDE APPLICATION

To estimate the total impact of the interventions in farms across the state, the assumptions made have been listed in the Annexure. Compared to the case study of a single banana farm in Section 6, an average gross revenue of INR 1,65,300/acre and average input costs of INR 75,100/acre have been used for the state-wide study, based on a recent survey of agricultural households in the state by NABARD.[23]

7.1 Solar PV

With a total of 21 lakh agricultural pumps in Tamil Nadu, they account for a connected load of 11.94 million hp and an average pump load per farm of 5.7 hp.[3] Installing solar plants of twice the pump capacity in kW, the total solar capacity required for the agricultural sector of Tamil Nadu is 17,760 MW, generating solar energy of 26,448 MU in Year 1. Compared to BAU, this would result in savings to the state government on the cost of free electricity supply of INR 2,038 crore in Year 1. These savings are projected to increase substantially over time as the cost of solar energy is estimated to be stable over a 20-year period whereas the cost of grid supply is expected to increase over time. The estimated savings (at NPV) over 20 years are INR 68,370 crore or 71.7% (refer to *Table 4 & 5*).

The green job potential for rolling out state-wide solar in agriculture is estimated at 4.85 lakh FTE (refer to *Table 6*).

7.2 Solar PV with energy efficient pumps

With 21 lakh agricultural pumps, the energy efficiency potential in the state is huge. Changing the existing pump sets to more efficient ones along with solar PV, and assuming a 30% increase in efficiency as a result, there is a potential to reduce the annual electricity demand for the agricultural sector by 12,604 MU (2016 data) to 8,823 MU. This equals savings to the state government of about INR 2,919 crore in Year 1. The estimated savings (at NPV) over 20 years are INR 95,407 crore or 100%.

Replacing all existing pumps with efficient pumps has a green job creation potential of 13,300 FTE (*Table 6*).

7.3 Solar PV with advanced irrigation

The estimated total agricultural area under irrigation is 35,82,600 hectares, accounting for about 60% of the total cultivated area. It is estimated that the cultivated land under irrigation grows by 5% annually.[24] Bringing all the currently irrigated land under advanced irrigation technology, along with solar PV, will reduce the annual energy demand by the agriculture sector from 12,604 MU to 6,932 MU. This will save the state government INR 5,539 crore in Year 1. The estimated savings (at NPV) over 20 years are INR 1,11,730 crore or 117%.

Further, this intervention is expected to reduce the water consumption by approximately 27,406 billion litres. (This assumes an annual water requirement of 1,700 mm for irrigation, which converts to 60,904 billion litres of water for the land area under irrigation in Tamil Nadu.)

Deploying advanced irrigation technology has a green job creation potential of 1.61 crore FTE (*Table 6*).

Over 20 years, the integrated approach results in avoided costs of INR 1,23,797 crore or 130%.

7.4 Integrated approach

The integrated approach combines installation of Solar PV, efficient pump sets and advanced irrigation technology. This results in savings to the state government of INR 6,387 crore in Year 1. Avoided costs (at NPV) over 20 years is estimated at INR 1,23,797 crore or 130%.

Over 20 years, the integrated approach eliminates 253 million tonnes of carbon emissions, reduces water consumption by approximately 27,406 billion litres, reduces energy demand for agriculture from 2,52,080 MU to 48,525 MU, and would export 4,33,080 MU surplus solar energy to the grid (refer to *Figure 20*). It further increases the farmer income on account of increased crop yield, reduces input costs and revenue from solar energy export by INR 7,05,580 crore (at NPV) or 70.2% (refer to *Figure 21)*.

An added benefit to the DISCOM is that it allows the introduction of electricity meters at the farms, which in turn will provide more reliable data on actual electricity consumption in the agricultural sector.

The combined green job creation potential stands at 1.66 crore FTE (*Table 6*).

Table 4 Cost and avoided cost by scenario

Impact	Grid (BAU)	Solar	Solar & EE	Solar & AI	Solar, EE & AI
Cost of energy supply to farms, Year 1 (INR crore)	7,575	5,537	3,416	2,036	1,188
Avoided cost of energy supply, Year 1 (INR crore)		2,038	4,159	5,539	6,387
NPV of cost of energy supply to farms, 20 years (INR crore)*	95,372	27,002	-36	-16,359	-28,425
NPV of avoided cost of energy supply, 20 years (INR crore)		68,370	95,407	1,11,730	1,23,797

**Negative cost of supply over the 20-year time period indicates a profit to the utility.*

Table 5 Impact by Intervention in % I 20-year time period

Impact	Units	Grid (BAU)	Solar	Solar & EE	Solar & AI	Solar, EE & AI
Prosumption	%	0.0%	191%	273%	347%	496%
Farm energy savings	%	0.0%	0.0%	30.0%	45.0%	61.5%
CO_2 emissions reduction	%	0.0%	191%	221%	236%	253%
Water savings	%	0.0%	0.0%	0.0%	45.0%	45.0%
Savings for state government	%	0.0%	71.7%	100%	117%	130%
Increase in farmer income	%	0.0%	0.2%	0.9%	69.8%	70.2%

Figure 19 Financial impact on state government by scenario I 20-year time period

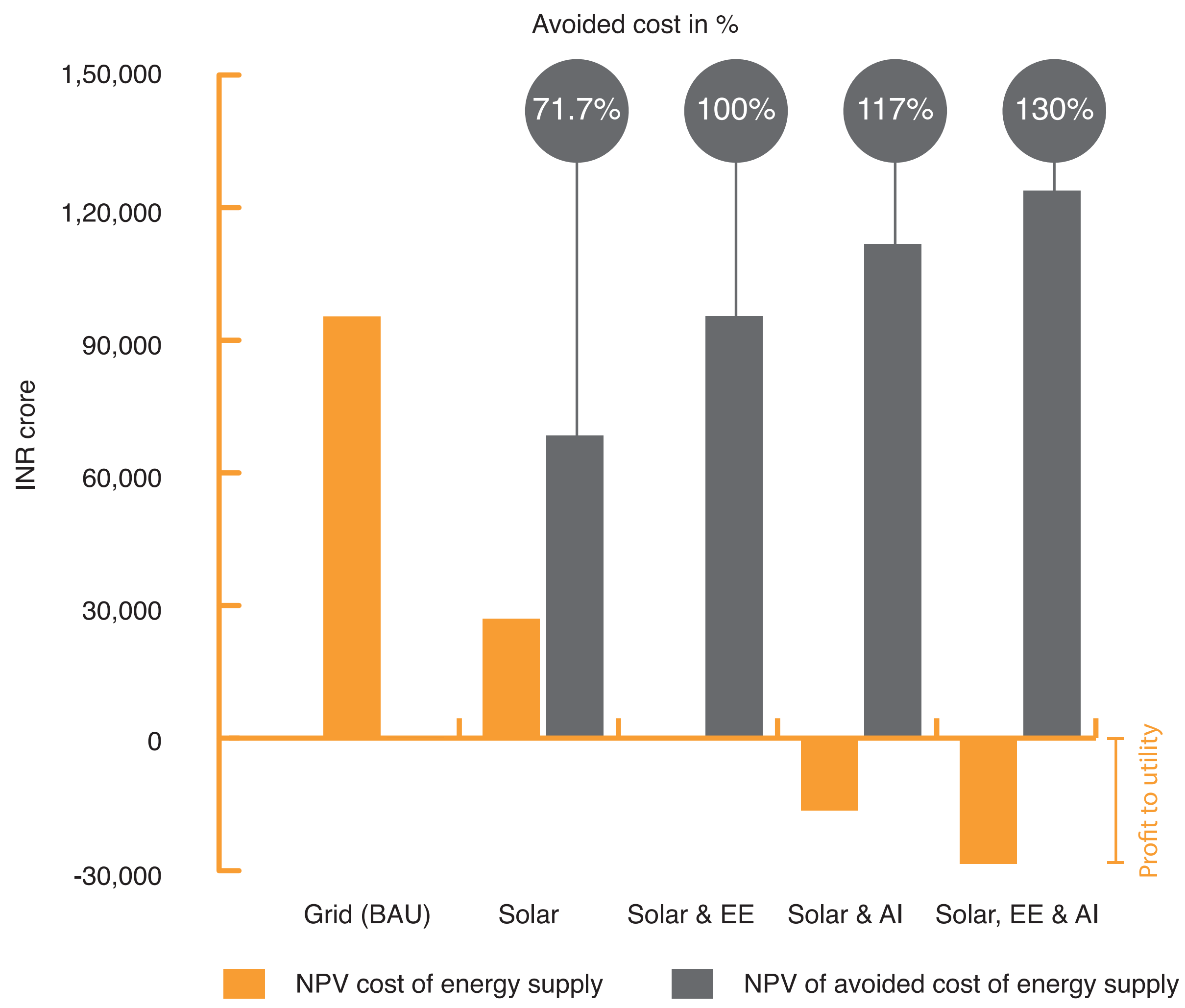


Figure 20 Energy consumption by the farms and avoided energy demand from the gird by scenario I 20-year time period

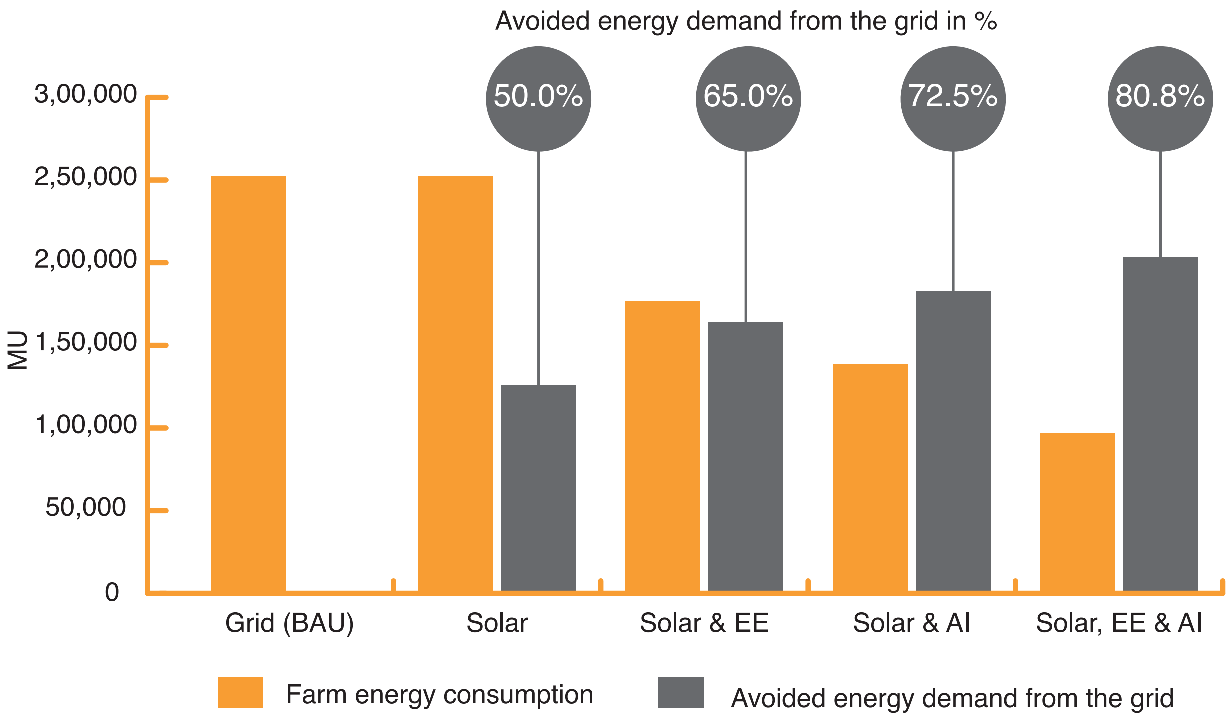


Figure 21 Gain for farmers, compared to BAU, by scenario I 20-year time period

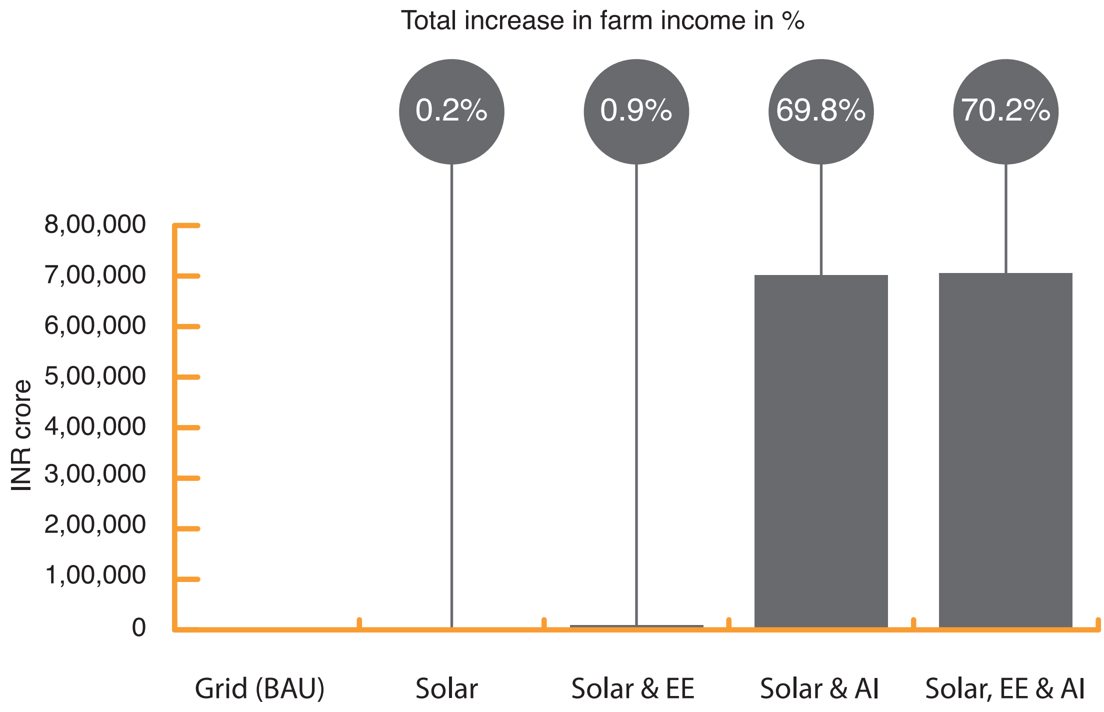


Figure 22 Avoided CO2 emission in million tonnes I 20-year time period[22]

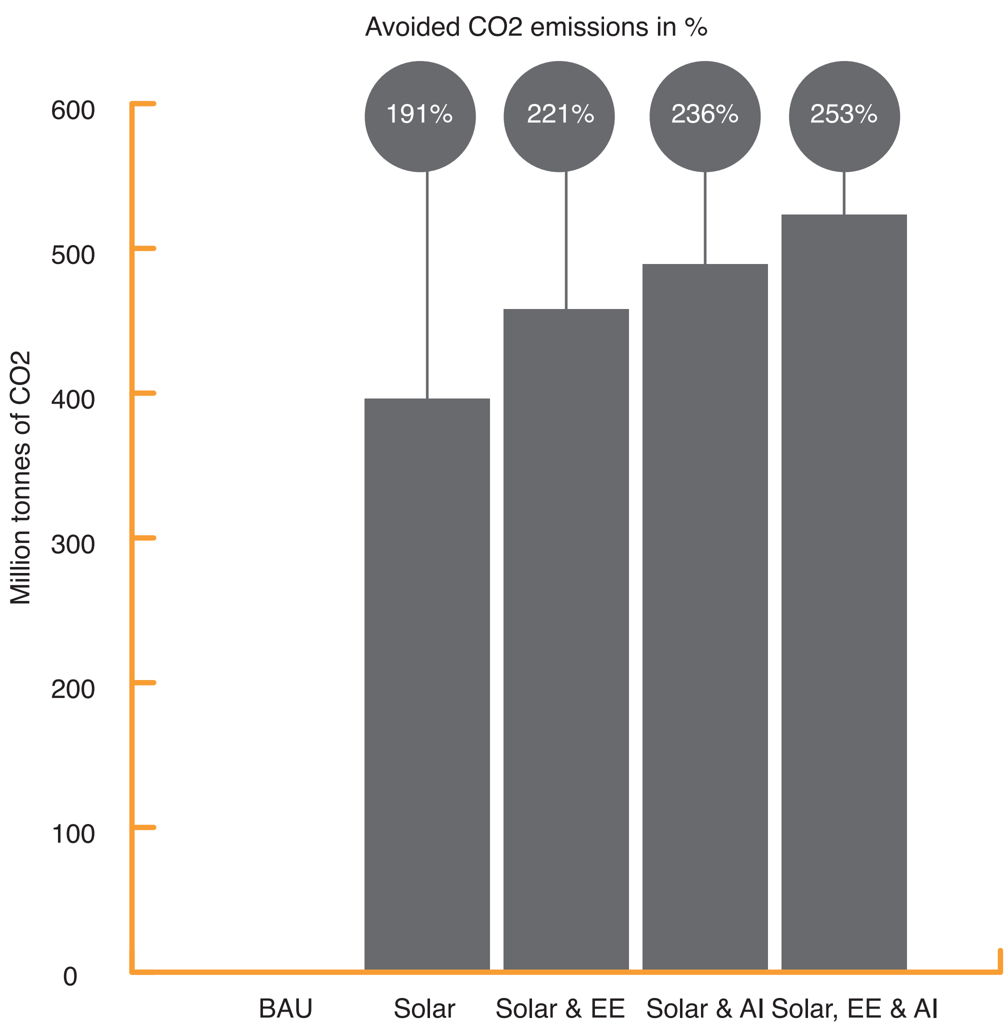


Table 6 Green job creation by intervention

Intervention	FTE	Investment (INR crore)	FTE per INR crore of investment
Solar[22]	4,85,205	71,040	6.83
Energy Efficient pumps	13,300	8,355	1.59
Advanced Irrigation[23]	1,61,21,600	53,117	303.51
Total	**1,66,20,205**	**1,32,512**	**125.42**

8. CURRENT CENTRAL GOVERNMENT SCHEMES

Multiple Government schemes and programs have been introduced to address issues related to the WELL nexus in the agricultural sector. These schemes are conceived and implemented by various departments and agencies with little or no attempts to converge them.

Pradhan Mantri Krishi Sinchayee Yojna (PMKSY)

The Pradhan Mantri Krishi Sinchayee Yojna (PMKSY) was launched in July 2015. The Cabinet Committee on Economic Affairs (CCEA), chaired by the Prime Minister, gave its approval for the scheme for the period 2015-16 to 2019-20. The objective of the scheme is "to achieve convergence of investment in irrigation at the field level, expand cultivable area under assured irrigation." The outlay for the five-year period has been slated as INR 50,000 crore (US$ 7.8 bn), with an outlay of INR 5,300 crore (US$ 826.6 mn) set for 2015-16. There are a few opportunities that the government is hoping to exploit, which led to the launch of the scheme. These include the facts that

i. only about 20 percent of rainfall is utilised,

ii. 10 percent increase in irrigation can bring an additional 14 mn hectares under assured irrigation, and

iii. 202 bn cubic meters of ground water potential is still to be tapped.

In order to achieve the goal of bringing irrigation water to every farm, the government feels there is a need to converge all ongoing efforts and to bridge gaps through location specific interventions, which is what PMKSY aims to do.

Kisan Urja Suraksha evam Utthaan Mahabhiyan (KUSUM)[25]

The KUSUM scheme developed by the Ministry of New and Renewable Energy (MNRE) was approved by the Government in February 2019. It comprises of following components:

Component A. Installation of 10,000 MW of decentralised ground-mounted grid-connected solar power plants of intermediate capacity of 0.5 – 2 MW; aggregate capacity of 10,000 MW.

Component B. Installation of 17.50 lakh standalone solar powered agriculture pumps of capacity up to 7.5 HP; aggregate capacity of 8,250 MW.

Component C. Solarisation of 10 lakh grid-connected powered agriculture pumps of up to 5 HP capacity; aggregate capacity of 7,500 MW owned by farmers and surplus power being sold to the grid.

Under Component C for solarization of existing pumps, the solar plants can be sized up to twice the pump size in kW. Further, 30% of the benchmark or tender cost, whichever is lower, comes from Central Finance Assistance (CFA). The state government provides further 30% subsidy.

Agriculture Demand Side Management (AgDSM) Programme

Energy Efficiency Services Limited (EESL) has undertaken replacement of agricultural pumpsets under the Agricultural Demand Side Management Program (AgDSM). The objective of the AgDSM programme is to reduce peak demand, and ultimately the total energy consumption in the agriculture sector. Under the programme, inefficient agricultural pump sets are replaced with BEE star-rated energy efficient pump sets. EESL plans to advance the programme and distribute the EEPS along with Smart Control Panels over the counter. The Smart Control Panels benefit farmers by allowing remote monitoring and control of the pump sets.

9. FINANCING MODELS & POLICY RECOMMENDATIONS

Considering the political economy of free electricity supply to the farmers in Tamil Nadu on one hand and the financial stress on the state electricity utility and the state government, suitable financial mechanisms have to be utilised. A properly designed finance mechanism will ensure substantial financial benefits to the state government and the state electricity utility and an attractive additional revenue stream for the farmers.

Today, there is no incentive for farmers to invest into solar PV plants, considering that the farmers get the electricity supply at free of cost. Further, due to the financial distress of many of the state's farmers, even providing an attractive solar feed-in tariff to the farmer may not create enough incentive and enabling conditions for the farmer to invest into solar plants. The investment for deploying solar plants at the farm level will have to be made by the utility (refer to *Figure 23*) or a RESCO. The RESCO will enter into a long-term power purchase agreement with the utility. The utility pays the RESCO a fixed tariff per kWh of solar energy. In this study, a tariff of INR 4.60/kWh has been used. In case capital subsidy by the central or state government is available, the tariff would reduce. The utility will benefit from a lower cost of supply on account of solar energy (Figure 9) and from the re-introduction of electricity meters. The proposed solar farmer incentive offers the farmer a financial benefit for allowing solar to be installed at his farm. If well designed, it may also incentivise the farmer to invest in efficient pumps and advance irrigation technology.

For a successful rollout and implementation, a utility-driven approach will be key.

Table 7 provides the payback period for the different intervention scenarios in the virtual case study. In the case of energy efficient pumps, an investment by the farmer (on the basis of additional income from the solar farmer incentive) has a payback of 6.8 years. This may not be lucrative enough for the farmer to make the investment on their own. Providing a capital subsidy or an increase in the solar farmer incentive would increase the probability of an investment by the farmer into efficient pumps. Alternatively, the utility or an Energy Service Company (ESCO) may invest. In the ESCO model of financing, the ESCO will be paid for every unit of energy consumption avoided. For the payback period given in *Table 7*, a tariff of INR 3/kWh for every unit of energy avoided has been assumed for the ESCO. If the financing of energy efficient pumps is undertaken by the utility, the payback period

Table 7 Green job creation by intervention

Scenario / Financing by	Solar PV (years)	Solar + EE (years)	Solar + AI (years)
Farmer (self financing)	>20 >20, with subsidy	6.8	0.9 0.4, with subsidy
ESCO	6.0 2.4, with subsidy	6.9	18.9 9.7, with subsidy
Utility	4.1 1.7, with subsidy	1.3	5.0 2.3, with subsidy

In the case of Solar + EE and Solar + AI, the payback period is for the investment in EE or AI only, assuming the solar PV and the solar farmer incentive are already in place.

on account of the avoided cost of free electricity supply.

For advanced irrigation technology, self-financing by the farmer is very viable, as they are able to recover their investment back in less than half a year (considering a 90% subsidy on the micro irrigation equipment) – owning in large part to the higher crop yield and lower input costs from advanced irrigation. Alternatively, advanced irrigation along with solar PV can be utility driven, funded from its savings.

As demonstrated, the integrated approach has substantial potential to reap financial benefits for all stakeholders, the state government, the electricity utility and the farmer. It also reduces water consumption in the agricultural sector and increases crop production and farmers income. For a successful role out and implementation, a utility-driven program approach will be key. Fair and realistic gross feed-in tariff for consumer segment solar PV and a well-crafted solar farmer incentive need to be determined by the regulators and policy makers. Subsidy for efficient pumps may be required, and the inclusion of precision irrigation technology under PMKSY is recommended.

Fair and realistic gross feed-in tariff for consumer segment solar PV and a well-crafted solar farmer incentive need to be determined by the regulators and policy makers.

Table 8 summarizes the implementation, financing and policy/regulatory aspects of the different interventions.

Table 8 Implementation, financing and policy aspects of the different WELL interventions

	Solar PV	Energy efficient pumps	Advanced irrigation
Implementation	Utility inform farmers about benefits of farmer incentive Aggregate demand Introduce grid-connected solar at farms – Utility or/and RESCO driven	Utility informs farmers about financial benefits of adding energy efficient pumps Sharing of list of empanelled service providers	Utility informs farmers about financial benfits of adding advanced irrigation Sharing of list of empanelled service providers
Financing	RESCO or utility financed Avail of central and state government subsidies	Farmer financed on account of solar farmer incentive Alternatives are utility or ESCO financing	Financed by farmer on account of farmer incentive and existing subsidy schemes Alternatively, advanced irrigation may be financed/co-financed by utility
Policy & Regulations	Introduce solar gross feed-in tariff for agriculture Determine farmer incentive (refer to pp. 29)	Introduce subsidies for efficient pump sets	Include advanced irrigation under PMKSY subsidy scheme

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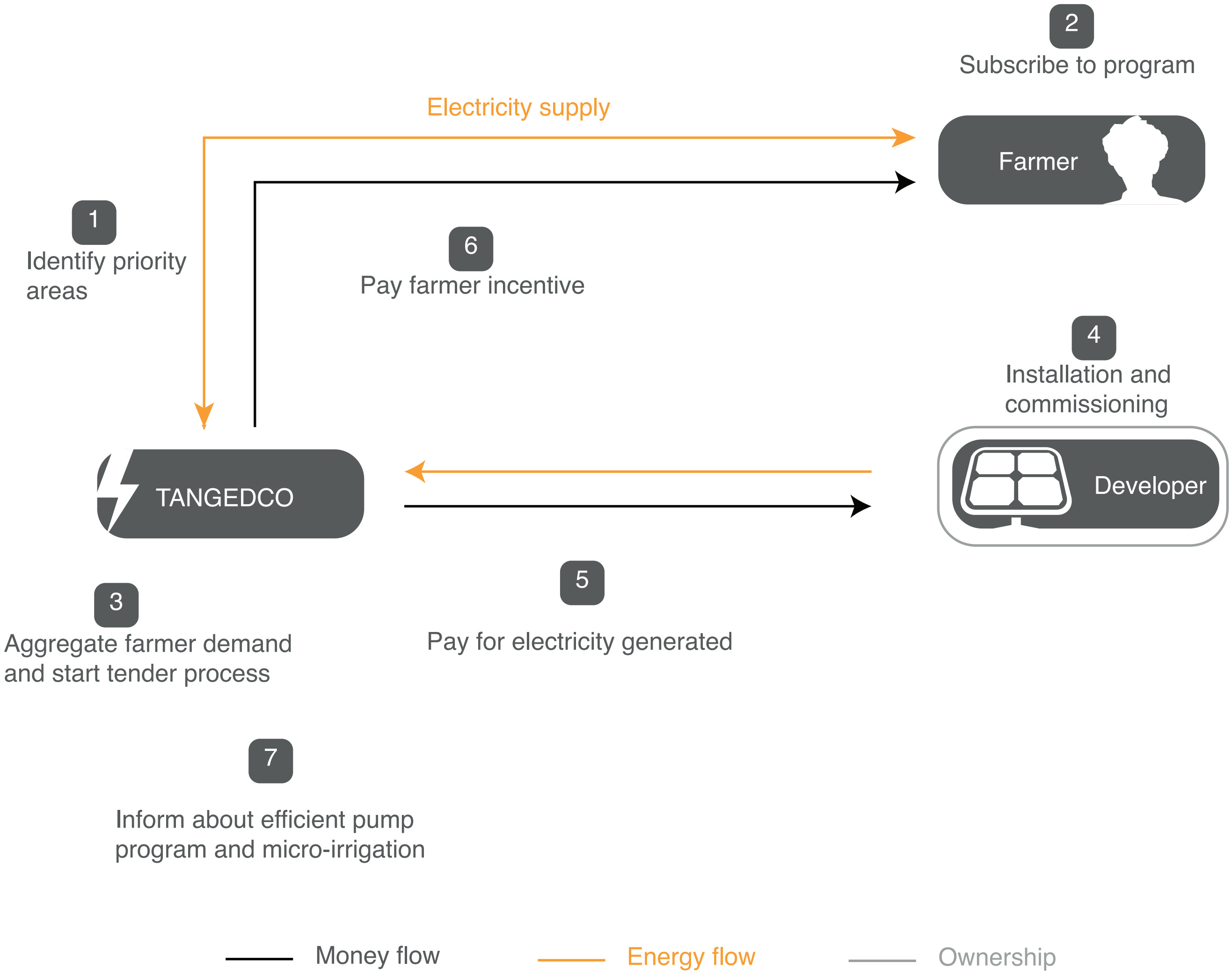
Figure 23 Flow of transactions for utility-driven installation of solar PV in farms



10. CONCLUSION

Strategic technology interventions in the agricultural sector aimed at providing equitable and quality power supply along with an increase in water and energy efficiency, crop productivity and farmer income offers an opportunity to leapfrog towards a sustainable WELL Nexus in Tamil Nadu. It further offers a unique intervention point to meet several Government of India targets such as doubling farmer income, meeting solar energy targets, increasing water and food security, curb greenhouse gas emissions and providing green jobs. Currently considered a problem, the power supply for agriculture has the potential to be turned into an opportunity to improve the livelihood of millions of farmers and to transition the state into a decentralized and sustainable energy future. Strong and decisive political and administrative support aligning all stakeholders along a common goal, and convergence of existing Government schemes will be required. Multiple implementation programs that are inclusive, sustainable and equitable, which enable context-specific responses, along with innovative financing schemes are needed for fast deployment.

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ANNEXURE

General assumptions for the study:

Distribution losses of utility	10%
Average power purchase cost for utility	INR 5.78/kWh
Overhead cost of utility	INR 1.40/kWh
Average cost of supply to utility	INR 8.04/kWh
Average billing rate of utility	INR 6.01/kWh
Inflation	5%
Discount factor	9.53%
Weighted average emission factor	820 g/kWh

Assumptions for the virtual 5-acre banana farm case study:

Average gross revenue for banana crop	INR 1,20,000/acre
Input costs for banana crop	INR 20,000/acre
Water requirement for irrigation	2,000 mm/year
Pump capacity	7.5 hp
Pump load factor	15%
Solar PV capacity*	12 kW
Capital cost for solar PV	INR 40,000/kW
Subsidy available for solar PV	60%
CUF for solar PV	17%
Solar panels degradation	1%
Levelised cost of solar energy to the utility	INR 4.60/kWh
Land requirement for solar	10 m2/kW
Farm energy demand met from solar by consumption at the point of production	50%
Farmer incentive for solar generation**	INR 1.00/kWh
Energy savings from efficient pump	30%
Capital cost of efficient pump	INR 52,500/hp
Average cost of micro irrigation	INR 40,000/acre
Average cost of smart irrigation	INR 20,000/acre
Subsidy available for micro irrigation	90%
Water savings from advanced irrigation	45%
Reduction in farm input costs from micro irrigation	10%
Increase in crop yield from micro irrigation	52%
Equipment (EE/AI) replacement after	10 years
Inflation	5%
Discount factor	9.53 %
Weighted average emission factor	820 g/kWh
Jobs created in solar PV	24.72 FTE/per MW
Jobs created in energy efficient pumps	0.28 FTE/pump
Jobs created in irrigation	4.5 FTE/hectare

**The solar plant has been sized to twice the pump capacity in kW.*

***Solar farmer incentive is defined in the case study on the basis of solar generation less farm energy consumption minus export of solar energy to the grid.*

Assumptions specific for analysis of all farms in Tamil Nadu:

Annual agricultural energy consumption	12,604 MU
Area under cultivation in the state	64.88 lakh hectares
Percentage of cultivated area under irrigation	60%
Average water requriement for irrigation[19]	1,700 mm/year
Average gross revenue for farmers	INR 1,65,300/acre
Average input costs for farmers	INR 75,100/acre
Number of pumps	21,00,000
Pump load	1,19,35,536 hp
Solar PV capacity required	23,100 MW

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