

Should Solar Energy Be Made Compulsory for Large Farm Holdings in Punjab?

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Abstract—Electricity subsidy played a huge role in helping agricultural intensive states like Punjab in driving India's Green Revolution resulting in a two-fold increase in the total food grain production in Punjab between 1960 and 2000. Ironically the same measure has come in for a great deal of criticism and considered unsustainable. With India facing acute power shortage it is important that large farm holdings be incentivised to install and use renewable energy for farming, to reduce the pressure on the state and national exchequer. In this paper we cite the example of Punjab, widely acknowledged as the "Food Bowl of India," and bestowed with yearlong sunshine with good solar irradiance levels (4-7 kW/m²), ideal for solar power generation. This paper examines the advantages of enforcing a statewide ruling for farmers with large land holdings to switch to Solar energy.

Index Terms—Agriculture, electricity subsidy, sustainable farming, solar energy, pollution, agrivoltaics, pollution, groundwater depletion.

I. INTRODUCTION

There is no denying the fact that electrical subsidies played a crucial role in making Punjab India's food bowl and fuelling India's Green Revolution. It incentivised farmers to grow high-yielding crops like rice and wheat which contributed to making India self-sufficient in food, as subsidised electricity enabled intensive irrigation providing the crucial water needed for water-intensive high yielding varieties of wheat and rice, significantly boosting yields (1,2).

To begin with the states including Punjab followed the principle of a subsidised flat rate based on the horsepower rating of the water pump. The system of flat rate pricing originated in the 1970s to recover costs of electricity provision. It was felt that a flat rate would be easier to implement, given the high transaction costs of installing meters on every tubewell, at a time when the electricity grid was expanding rapidly, as

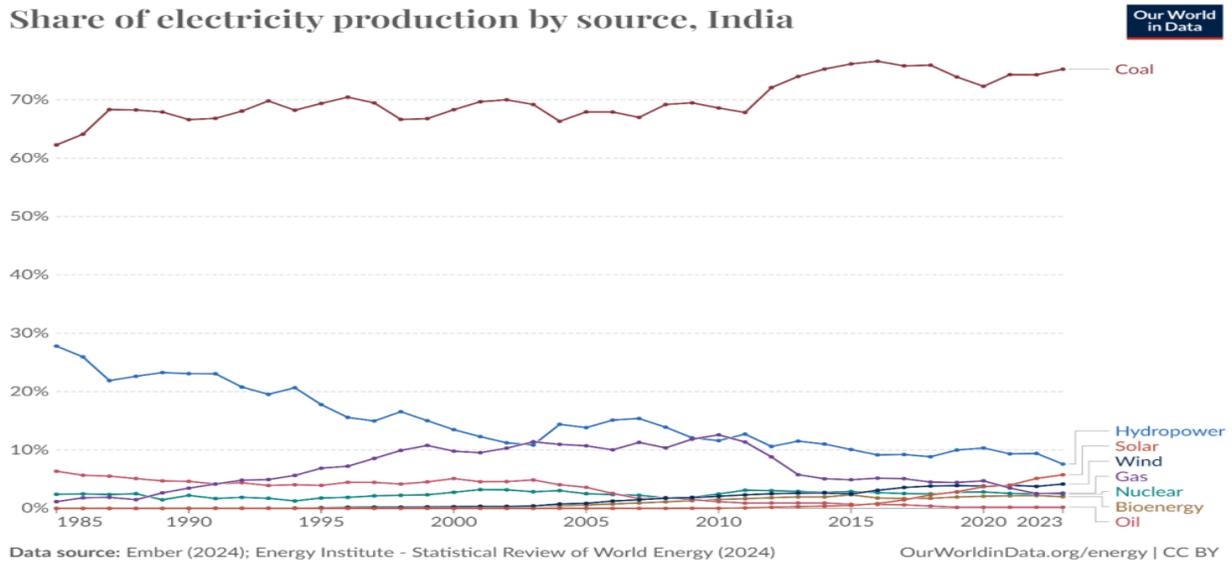
were the number of tubewells (3). While the intent was to revise these rates periodically to recover at least average costs of electricity provision, in practice this has been far from the case.

In fact, it spiralled downwards going from subsidized to free electricity since 1997. This was due to the pressure of the increasing power of the farmer's unions who started participating actively in the electoral politics to pressurise the ruling parties to fulfil their demands. The political parties responded positively and introduced such policies that were politically expedient missing out on their long-term viability as it came at the severe cost of unsustainable groundwater depletion, fiscal strain, and water-intensive cropping patterns that risk long-term food-energy-water nexus collapse (4,5,6,7,8).

When studied in the light of the demand and supply situation of power Punjab faces unprecedented pressure on its power grid, with electricity demand almost doubling over the past 12 years raising fears of future grid stress. For coping with demand this year, PSPCL ramped up output from from all thermal plants and increased power purchases. After 3 decades, the Punjab government announced the addition of 1600 MW thermal plant units in public sector after dismantling existing 210MW units and announced the approval of the third of the same capacity to be set up by a private player (9,10).

Coming at a time when the India energy sector is under its worse ever stress. Rapid urbanisation and industrial growth have put additional burden on the energy demand, putting immense pressure on existing systems and outpacing supply growth. The country's heavy reliance on fossil fuels, particularly coal and oil, exacerbates the issue. Coal fired power plants alone account for over 70% of electricity generation, leading to resource depletion and increasing dependence on imports with volatile prices.

Share of electricity production by source, India



Source: Our World in Data

The energy crisis in India has far-reaching impacts on people and the environment. Environmentally, heavy reliance on fossil fuels increases pollution and greenhouse gas emissions. India is the third-largest emitter of carbon dioxide globally, with the energy sector as the largest contributor (11,12,13). Punjab is no different. The Centre for Research on Energy and Clean Air (CREA) has claimed that Punjab's coal-fired power plants are a major source of air pollution, emitting nine times more sulfur dioxide than the total stubble burning. According to CREA, Punjab burns about 7.49 million tonnes of paddy straw every year, releasing around 15 kilotons of sulphur dioxide in the air. In comparison, coal power plants in the state emit nearly 135 kilotons of SO₂, which is nine times higher than the stubble burning (14).

Out of the total electricity consumed in the country, 20% of the electricity is used for agriculture practices, mostly in irrigation. This account of electricity consumed in agriculture can go up to 50% of total consumption in some of the states. As the climatic conditions are turning out to be erratic, irrigation's dependence on monsoon has decreased and the dependence on groundwater has increased. As a result, irrigation now consumes 90% of country's groundwater. For this, the farmers have taken 12 million electricity connections, and 9 million diesel pumps sets to pump up groundwater for irrigation use. To support workforce engaged in farming activities, reforms like subsidised electricity brings down the

power tariff but also leads to piling up of losses for Distribution Companies (DISCOMs) in the long run. The low-tariff power supply is practised at night to reduce the grid load during the day, inadvertently leading to energy and water wastage throughout the night from unsupervised running of pumps (15,16). Punjab has a disproportionately huge portion in this. In Punjab, the relationship between energy and irrigation is particularly relevant as the agriculture sector receives free power. The irrigation sector consumes approximately 25 to 30 percent of the state's total electricity, with over 93 percent of tube-wells being electrically powered (17,18,19,20).

At COP26, India announced its ambition to become a net-zero emitter by 2070 an important milestone in the fight against climate change (21). This paper makes a case for enforcing laws to mandate solar energy use by large farm holdings and lead the change.

II. ADVANTAGES OF MANDATING SOLAR ENERGY USE FOR LARGE FARM HOLDINGS

Large farm holdings have the space advantage and larger resources to make the switch. The Government can identify such farmers and incentivise them to adopt solar energy and make them the hubs for transmission to the farmers with smaller landholdings who cannot afford to install their own systems. The advantages of solar energy adoption are:

2.1 Energy Independence, reliability and greater grid stability.

Punjab farmers contribute to grid instability in Punjab as free electricity and large subsidies indirectly incentivizes water-intensive paddy cultivation and irresponsible use of tubewells (22). Experts have been consistent in their demand that the state government should stop providing free power supply to the agriculture tubewells to save the underground water. There are 14 lakh agriculture tubewells in Punjab and the estimates for power subsidy in the upcoming financial year 2023-24 is more than ₹9,000 crore. They strongly recommend that the government should stop giving free power to the affluent farmers who actually do not need it and continue giving the benefit to small and marginal farmers who own 2-3 hectares of agriculture land, as with free power there was no check on usage of underground water (23). The underlying belief is that free electricity does not motivate farmers to make any change in their cropping choices and patterns. Use of tubewells peaks concentrated electricity demand for paddy irrigation during peak summer, leading to overloads, transformer failures, and power cuts.

In July 2025, Punjab's peak power demand reached a record 17,233 MW, nearly doubling from 2012 levels putting unprecedented pressure on its power grids. Concentrated demand leads to transformer failures and overloaded feeders, prompting the Punjab State Power Corporation Limited (PSPCL) to initiate major upgrades, including the installation of 8,000 new transformers and 25,000 km of power cables to mitigate these issues. For coping with demand this year, PSPCL ramped up output for, thermal plants which only increases the dependence on coal, a non-renewable and polluting source. Experts warn that unless energy diversification and demand-side management strategies are adopted, this could be a recurring issue (24). Farmers can reduce their need for the grid and fuel-based generators by using solar energy to produce their electricity. Solar energy is a dependable and sustainable alternative for farming operations because of its energy independence, which guarantees that operations are not interrupted by power outages or changes in energy prices. This makes their cropping schedules more consistent and stable.

Besides making them self-reliant, Solar can become a viable revenue generator for farmers via net metering and by setting up smaller microgrids. Agricultural

lands have massive surface areas that can be used to employ high-yielding solar panels. In open fields, the solar output can be higher than rooftop installations, as there will be less shading and poor orientation incidents. Farmers can generate an ample amount of electricity and transfer the surplus power to the local grids/DISCOMs to make money from it (25). Once the pressure on existing electric supply from farming is reduced, it can make a lot of difference in grid stability. Because it enables farmers to power their operations independently of the grid, solar energy is revolutionizing off-grid farming. Everything from refrigeration devices for preserving fresh fruit to irrigation systems can be powered by solar panels. In addition to keeping farmers competitive, this creates new chances for agricultural growth in isolated areas (25,26,27,28,29).

2.2 Cost Reduction and increased profitability

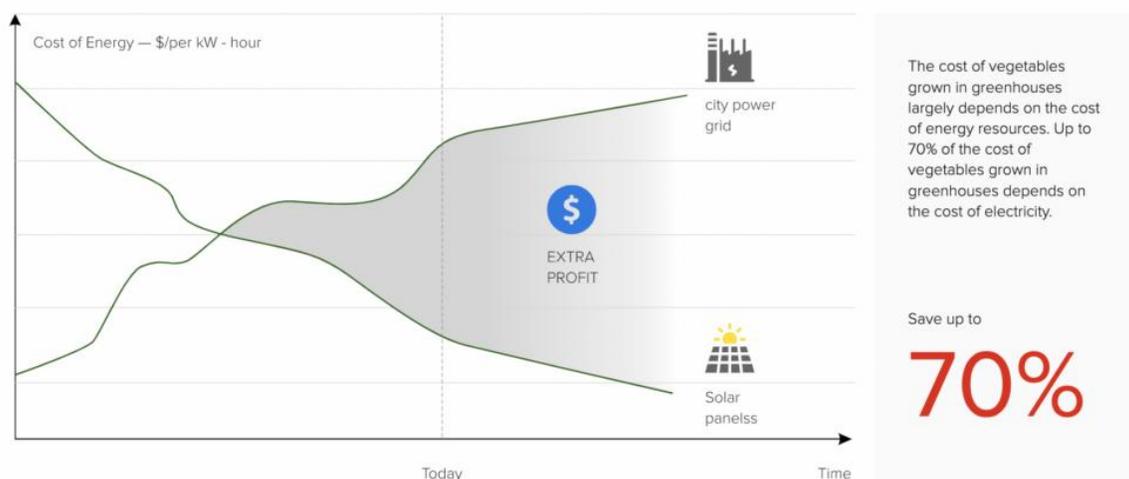
Agriculture is an energy-intensive sector since it requires a lot of energy for processing, irrigation, and mechanization. Farmers have historically relied on expensive energy sources like grid electricity or diesel-powered pumps.

In the absence of regular electric supply from grid electricity due to pressure on thermal plants in the face of increased demand, the farmers have to use diesel fuel for operating their tractors and other machines. The rising diesel prices has left farmers in Punjab a worried lot. The raised prices increase their production costs and have a cascading effect on the markets. Over 70 per cent farmland in Punjab depends on artificial irrigation. Most of the farmers in the state use tractors to plough their field and generators run on diesel for irrigation. Farmers say the hike will increase the input costs up to 2000 rupees per acre on an average making farming unprofitable. Fearing that rising costs will put additional burden, the farmers now want an increase in the minimum support price for their products to evade debt crisis causing yet another confrontation with the government. The rising diesel prices is also directly linked with Punjab's problematic stubble burning. The government's solution against stubble burning has been agri-machinery like "Happy Seeders", "Super seeders", "Mulchers", etc which require investment in heavy tractors and a lot of diesel. The Happy Seeder requires about 10 litres of diesel per acre and can only do about 10-12 acres a day. The Super Seeder and Straw Management System (SMS) based machines are

even heavier, and apart from requiring over 65 HP tractors, consume a lot more diesel. Till about 2018, it costed an additional Rs 1,000-1,500 per acre to mulch and clean the straw, now it's over Rs 2,500. Small and marginal farmers, which are about 80% of Punjab, are thrown into a dilemma – environmental conservation or survival? The sharp increase in fuel prices had already eaten into their meagre incomes and now an additional Rs 2,500/acre for straw mulching has left them with no real choice (30, 31, 32,33,34,35,36,37,38,39).

Solar energy offers a less expensive substitute. Farmers can save a lot of money over time by installing solar-powered systems, which will significantly lower their energy costs. These savings can be put back into other parts of the company, such as improved agriculture equipment, seeds, or irrigation systems. Solar photovoltaic (PV) systems can reduce electricity bills by up to 70% for an on-grid configuration. By harnessing renewable energy from the sun, solar PV systems provide a sustainable and cost-effective solution for meeting energy needs (40,41,42,43).

Solar-powered greenhouses are less expensive to operate than conventional greenhouses because their systems are fueled by renewable energy. Moreover, by maintaining constant temperatures and lighting, solar-powered greenhouses can prolong the growing season for crops, enabling farmers to cultivate crops all year long increasing their profits. Farmers can optimize crop development circumstances in solar-powered greenhouses'-controlled environments, producing higher-quality crops with fewer pests and diseases. Farmers can keep constant temperatures and lighting in greenhouses powered by solar energy, giving crops the best possible conditions for growth increasing their yield. Additionally, with the aid of this technology, farmers are able to cultivate crops in crowded urban areas or in locations with less ideal growing conditions, enabling them to create year-round crop production. Green house farming is done in a very controlled environment which lowers total water consumption and wastage by capturing and reusing water runoff (44,45,46,47).



Source: <https://neosun.com>

Moreover, the solar energy can be put to multiple other uses by the farmers that increases its cost effectiveness and farmer profitability. Solar Energy-Powered Water Pumps reduce the demand for conventional thermal power and diesel run pumps helping in saving cost. It can also be used for animal husbandry as it can be used to keep the most desired temperature for livestock and dairy operations saving costs incurred on electricity bills (48,49,50).

Using sunlight to dry crops and grains is one of the oldest applications of solar energy used by farmers. While this is a completely free, viable method that can easily be employed, it has a risk of exposing the crops to the wind, rodents, impurities, etc. contaminating them. With advancements in technology today, there are solar dryers that can help in harnessing maximum solar energy and concentrating it in a closed container where trays are used to dry the produce. These systems

will also help in accelerating the process and reducing the time required (51,52).

In many cases, farmers face huge losses due to the lack of availability of proper refrigeration and cooling systems in their farms. Indian farmers are struggling with the lack of cold storage facilities for vegetables and fruits. India also has low per capita availability of fruits and vegetables due to post-harvest losses because of less cold storage facilities. Cold storage is one of the highly energy-intensive operations, and it is commonly used in all food industries and households. Conventional cold storage systems usually require a consistent electric supply to operate refrigeration systems effectively. The main issue with conventional cold storage is that it requires a huge amount of power supply, typically supplied by local grid or diesel generators. Its higher energy consumption restricts its adoption to various farmers' communities. Even if they have a refrigeration system, it becomes very difficult to power them all day with constant power cuts and outages which destroys perishable items in their produce before they can reach the consumer. Poor cold storage infrastructure leads to massive post-harvest losses, which directly affects the income of farmers. An increasing number of cold storage owners are calling the activity unviable as it needs huge amount of power to operate. Moreover, it affects the state's potential to export fresh produce (due to export bans/restrictions on key commodities), losing out on significant foreign exchange. Solar-powered cooling systems can be used to ensure that these are well maintained so that they can keep their produce fresh for a longer time even if it is not sold immediately on harvest (53,54,55,56,57).

2.3 Improved proficiency and productivity

The lack of regular electricity supply continues to disrupt agricultural productivity in Punjab, primarily due to aging infrastructure, rising peak demand during the paddy season, and frequent protests of federal power reforms. Frequent outages during the day affects sowing of paddy and farmers are compelled to use diesel generators. High diesel prices have made this an unviable long-term solution, significantly reducing profit margins and increasing overall input costs. This also impacts their productivity. Reliable power is critical for crops like paddy, basmati, cotton, and maize. Shortages during peak summer months lead to inadequate irrigation, creating drought-like

conditions even when canal water is available, as many fields rely heavily on tube-wells, most of which are in areas where declining water tables necessitate longer pumping times, making farmers even more dependent on consistent electricity. The situation reached a state where farmers are furious over not getting regular power supply at their agriculture pumpset (AP) feeders during paddy season and not facing power cuts for domestic demand, farmers in parts of Punjab attacked grids and employees at power grids, thus halting power supply to feeders meant to provide electricity to industry and domestic sectors (58, 59).

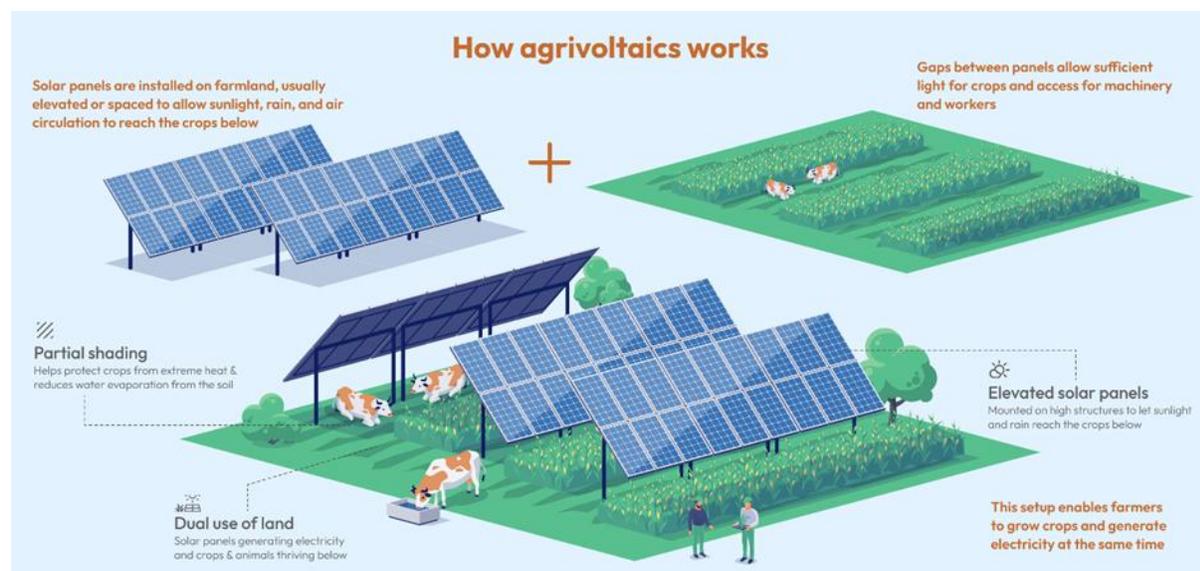
In 2025, farmers in Punjab continue to face severe agricultural and economic hardships due to frequent electricity disruptions. These issues stem from a combination of infrastructure failures, policy protests, and seasonal demand surges. Unscheduled power cuts have left tube wells dry, making it impossible to irrigate crops like paddy and sugarcane, which require constant water supply. Farmers report receiving only 1–2 hours of supply despite government promises of 8 hours. Forced to use diesel, their investment goes up invariably during this season. If they don't use diesel the quality of their produce goes down and is left unsold (60,61).

Prolonged power outages not only damage crops but also impact their livestock which is very crucial for small farmers who need the extra income source and quite often use them for farming. Such incidents can be avoided only if the farmers pivot to more renewable sources like solar energy. Farmers can be encouraged to use agrivoltaics, a fast-emerging practice that combines agriculture with solar power. By installing solar panels for agriculture over farmland, agrivoltaics not only helps generate clean energy but also supports sustainable farming. As climate change pressures mount and the demand for renewable energy rises, this smart use of space through agrivoltaics farming is gaining attention across the globe. By installing solar panels for agriculture above or between crops, or on grazing land. This allows food production and clean energy to happen side by side. This approach maximizes land use, helps protect crops by providing shade, and supports farmers by creating new income sources. By reducing conflicts between farming and energy development, this dual use helps achieve solar capacity targets without compromising precious farmland. The land under the solar panels has partial shade, cooler temperature and more moisture content

in the soil making it very conducive for growing vegetables and herbs that don't need direct sunlight, alongside staples like wheat and rice. Shade tolerant vegetables like beetroot, calabrese, kale, kohlrabi, Little Gem lettuce, radish, spinach and herbs - chives, mint and parsley etc. this can yield extra income to the farmers (62,63,64,65,66).

Majority of research indicates that the average air temperature in AVS remains lower than the average temperature in the open field, with the temperature differences more significant during the hotter periods (67,68). Similarly, the daily fluctuation in air temperature in AVS was smaller than that observed in an open-field condition. For instance, the minimum

temperature at night was 0.5–2.4 °C higher (69,70) whereas the maximum air temperature during the day was 1.5–6 °C lower in AVS than in open-field (71). The cooling effect during the day in AVS results from reduced solar radiation under the solar panels and crop transpiration via exchange of latent heat for vaporization of water molecules (72). Similarly, the warming effect at night is attributed to the greenhouse sheltering effect of solar panels, which prevent radiative cooling and reduce conductive heat loss (73). The cooler daytime temperatures can offer benefits to crops and livestock by alleviating thermal stress during hotter periods.



Source: <https://www.tatapower.com>

This is good for the livestock too as they can graze beneath solar agriculture panels, enjoying the shade and protection they provide. This is because the forage quality in AVS was higher than in the open-field pasture, as the pasture grown in AVS had better digestibility (74). Shade provided by solar panels can offer cooling for livestock when temperatures are high and effectively relieve them from heat stress (75,76). Besides, by providing shade, solar agriculture installations improve comfort and safety for farm workers spending extended periods of time outside by shielding them from intense heat and damaging UV rays.

Crop diversification in Punjab can play a pivotal role in addressing the carbon footprint associated with

traditional cropping patterns. Depleting water tables, deteriorating soil quality and air pollution and shrinking land holdings requires farmers to adopt technologies like vertical farming and greenhouses powered by solar energy. The farmers with large land holdings can take the first few steps to set an example for the smaller farmers and become their hand holders in the transition by becoming their energy saviours (75,76).

Greenhouses are energy intensive and hence can only be adopted if the farmers use solar energy. One of the primary advantages of greenhouse cultivation is the ability to extend growing seasons beyond the limits imposed by natural outdoor conditions. Greenhouses create a controlled environment that allows for year-

round crop production even in the harsh summers and winters of Punjab meeting consumer demand and reducing reliance on imports. The Year-round production allows for multiple crop cycles, resulting in higher overall yields compared to traditional outdoor cultivation methods. Off-season production enables growers to capitalize on higher market prices when supply from outdoor sources is limited. Green houses also require less water, have less pest problems reducing the use of pesticides. By creating a controlled environment, greenhouses minimize the risk of crop damage or failure due to unfavorable weather events. This consistency promotes healthy plant growth and development and the controlled environment within greenhouses allows for the implementation of integrated pest management (IPM) strategies, which combine biological, cultural, and chemical control methods to minimize pest and disease outbreaks leading to improved crop quality, healthier plants and higher-quality crops, meeting consumer demands for visually appealing and nutritious. Advanced greenhouse technologies include soilless cultivation like hydroponics and aeroponics. This technology has gained popularity in greenhouse systems due to its potential for maximizing resource efficiency and increasing crop yields with significant water savings compared to traditional soil-based cultivation which is essential in water stressed Punjab. These greenhouses also provide for indoor vertical farming (hereafter VF) which can help farmers produce more in a limited space (77,78,79,80,81,82).

2.4 Climate impact:

The Centre for Research on Energy and Clean Air (CREA) has claimed that Punjab's coal-fired power plants are a major source of air pollution, emitting nine times more sulfur dioxide than annual stubble burning. Despite this, all 15 of the state's thermal power units have been exempted from installing critical pollution control technology. This is the outcome of the excessive pressure coming from the farmers of Punjab as agriculture in the land locked state is dependent on thermal power sources. The high demand, particularly during the paddy cultivation season, strains the state's power grid and necessitates the operation of all available thermal power units at full capacity. Over 96% of Punjab's net sown area is irrigated, with a vast majority (over 72%) relying on tube wells and bore wells. The state has around 14 lakh

active tube wells, which consume massive amounts of electricity, especially for water-intensive crops like rice. Farmers are not motivated to make a change as they get free electricity and rice and wheat get them better returns (83,84).

The coal available in India is of poor quality, with very high ash content and low calorific value, and most of the coal mines are located in the eastern part of the country. Whatever good quality coal available is used by the metallurgical industry, like steel plants. The coal supplied to power plants is of the worst quality and the combustion of this coal at thermal power plants emits mainly carbon dioxide (CO₂), sulphur oxides (SO_x), nitrogen oxides (NO_x); CFCs other trace gases and air borne inorganic particulates, such as fly ash and suspended particulate matter (SPM). CO₂, NO_x and CFCs are greenhouse gases (GHGs) High ash content in Indian coal and inefficient combustion technologies contribute to India's emission of air particulate matter and other trace gases, including gases that are responsible for the greenhouse effect. And mercury which is a dangerous metal released by this coal combustion (85,86,87,88). Air pollution accompanied by extreme ground water depletion due to excessive dependence on ground water for irrigation has only added to their problems. In the attempt to increase yield and profits farmers of Punjab use chemical fertilizers and pesticides that have led to massive changes in the soil composition and its degradation (89,90). With its consumption of chemical fertilisers being twice the national average, it's a race against time for Punjab to revive organic fertility in its soil (91) and this where solar energy and the use of greenhouses and other latest techniques can help farmers diversify their produce and plan more strategically instead of following the monochromatic pattern of wheat and rice. Punjab, which accounts for 10.12 per cent foodgrains produced in the country, will see a decrease in yield between 13 and one per cent in its major Kharif and Rabi crops by 2050 due to climate change impacts. And by the year 2080, this reduction in yield will almost double for most of these crops, a new study by Punjab Agricultural University has found (92). The farmers are being forced to change the growing seasons and patterns due to rising temperatures, which results in lower-quality and lower-yield food. Farmers in the area are finding it difficult to adjust to these changes, which has a big effect on their incomes. For instance, rising

temperatures in recent years have resulted in a decrease in the yield of crops like cotton and wheat that are susceptible to changes in yield. This has impacted the region's food security in addition to the revenues of farmers (93,94). The situation requires urgent remedial measures and switching to renewable solar power would be a step in the right direction.

2.5 Water Conservation:

A National Green Tribunal (NGT) monitoring committee announced recently that Punjab's groundwater will drop below 300 meters by the year 2039. A 2020 block-wise groundwater resources assessment by the Central Ground Water Board (CGWB) found that most of the districts in Punjab had over-exploited the groundwater levels. In some districts, the groundwater level was marked as critical. Groundwater extraction in Punjab has already reached 150-200 meters in most places in central Punjab with experts warning of a major threat to India's food security if Punjab's groundwater goes dry (95).

Irrigation in agriculture has always been a backbone of India's food security. Given the status of India's declining water tables, in this case most specifically in Punjab, India's food bowl, the importance of water-use efficiency in irrigation has never been greater. India's agriculture consumes nearly 80% of the country's freshwater resources, making water conservation projects critical for long-term sustainability (96).

From tubewell irrigation to canal systems, farmers are provided with the water they need to grow crops throughout the year. Yet, rising energy costs, depleting groundwater, and unpredictable rainfall have pushed rural communities to rethink how irrigation can be made more efficient and sustainable. This is where solar-powered irrigation systems are changing the story. By combining clean energy with efficient irrigation methods such as drip and sprinkler systems, farmers can achieve higher productivity while conserving water. Unlike diesel pumps, solar irrigation pumps provide a cost-effective, reliable, and eco-friendly solution that empowers small-scale farmers to reduce risks and secure their livelihoods. The solar water-saving drip irrigation system utilises solar energy resources, reduces dependence on traditional energy sources, achieves precision irrigation through intelligent control, improves water use efficiency, reduces operation and maintenance costs, and improves crop yield and quality. The system adopts

photoelectric tracking and automatic tracking technology to improve the utilisation of solar energy and combines intelligent irrigation with soil moisture monitoring to achieve precise irrigation (97,98). Solar drip irrigation can conserve 50%-60% water compared to conventional irrigation systems. By replacing polluting diesel pumps, farmers will be able to lower their carbon footprint and air pollution. Moreover, by precise watering of roots, there are less leaf borne diseases in plants resulting in a boost to crop health and yield and farmers can cut on water wastage that is rampant in Punjab (99,100,101,102,103).

2.6 Animal Husbandry support:

Animal husbandry in Punjab diversifies farmer income, contributing over 38% (up to 40% per to the agricultural GVA with a robust 5.76% annual growth rate. It provides a stable, high-income alternative (avg. ₹5,303/month), reduces reliance on volatile MSPs, and addresses ecological challenges like water depletion and stubble burning (104). Given the stress in power supply from the local grids, farmers are faced with a difficult choice to choose between livestock and immediate farming needs. Climate change and its extreme weather events such as drought, flood, and long heat waves in Punjab have been adversely affecting crop and livestock productivity. Global warming is expected to reduce livestock food production due to cattle mortality, competition for limited fodder and water resources, pastureland degradation, and livestock diseases and Punjab is no different (104,105,106).

Solar energy benefits livestock primarily by reducing heat stress through panel-provided shade, improving welfare, and lowering operational costs. Agrivoltaic panels offer shade for livestock in the summers and protects them during harsh winter hail or wind. The shade from panels also reduces soil evaporation, keeping the area relatively moist potentially increasing grass growth and extending grazing periods. Additionally, Solar-powered, UV-based water sterilization can improve sanitation for livestock operations. Solar energy reduces or eliminates reliance on the grid for powering barn ventilation, heating, and lighting, leading to significant savings (107,108).

Research showed that 69% of consumers believe that animal welfare is important and is perceived to result in safer, healthier, and higher quality food products and hence this additional advantage can go a long way

in supplementing the income of the farmers. To encourage animal comfort and welfare practices by companies and farmers, the Humane Farm Animal Care organization (certificating more than 160 companies and 5500 farms in the USA, Canada, Chile, Peru, and Brazil) developed the Certified Humane Raised & Handled Certification (HFAC). Among the requirements for this certification (HFAC, 2012, HFAC, 2013, HFAC, 2014a, HFAC, 2014b) is access to shade areas that can accommodate all animals simultaneously. Similarly, the Animal Welfare Committee of Australia with the Primary Industries Standing Committee (PISC) recommends the provision of shades for livestock exposed to heat stressful conditions (PISC, 2004). Punjab can emulate these practices and build greater trust in the consumers (109,110,111,112).

Modern dairy operations use significant amounts of electricity for milking machines, milk cooling, water heating, ventilation, and lighting. With energy costs continuing to rise, solar power offers a way to take control of your farm's energy expenditure while moving toward a more sustainable operation. Solar energy solutions significantly decrease reliance on costly traditional energy sources for running equipment like milking machines, refrigerators, and water pumps. Studies have shown that A 50 kW solar system in a dairy farm, can reduce monthly electricity bills by up to 50-70% (113,114).

III. CONCLUSION

Punjab, often referred to as the “Granary of India”, continues to hold a pivotal role in the country’s agricultural landscape and the nation’s food security, primarily through its dominant rice-wheat cropping system. Covering over 80% of its cultivated land, this intensive farming practice has contributed 21% of India’s rice and 31% of its wheat production despite occupying a mere 1.5% of the country’s geographical area. This makes Punjab the largest contributor of wheat and rice to the central pool, which sustains India's Public Distribution System (PDS) (115,116).

However, despite its agricultural success, Punjab faces formidable environmental challenges, and the intensive farming practices that historically led to high yields have presented sustainability concerns. Monoculture cropping, especially the repetitive cycle

6. References:

of wheat and paddy, is associated with soil degradation, declining groundwater tables, and pest proliferation all major challenges to future productivity. Today, Punjab is emblematic of the unsustainability of the food energy water nexus in India. From 2017 to 2021, farmers in Punjab used more than 12,000 gigawatt-hours of free electricity every year (117,118). Shortage of coal, empty coffers, faulty transmission lines and poor infrastructure holds a grim future in the face of escalating demand for energy. The agricultural sector is estimated to consume approximately 25 to 30 percent of Punjab's total electricity and subsidy for farming (around ₹10,000 crore) is significantly higher than that for industry (₹2,893 crore) and domestic use (₹7,614 crore). Since the farmers also control most of Punjab’s land, a change in their consumption patterns could go a long way in bringing the much-needed sustainable change (119).

Although the government launched the Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhayan (PM-KUSUM) scheme, in 2019 with the ambitious goal of solarising agriculture in India, the scheme has not made much headway in Punjab. One significant hurdle has been the availability of cheap electricity, which diminishes the incentive for farmers to switch to solar pumps. Additionally, farmers are often forced to opt for larger-than-needed pumps, increasing their financial burden. Centralisation of the implementation model poses another challenge as the farmers feel that the policy is being imposed on them without proper understanding of the ground challenges and requirements. Delays in project clearances, inconsistent policy frameworks, and financing barriers are also reported to have discouraged investors. The PM-KUSUM scheme holds the potential to reduce carbon emissions by 5.2 million tonnes, making its successful implementation crucial for India's climate action efforts. Punjab has abundant renewable energy potential, and it would be a pity to not take the opportunity and preserve its agrarian future. The onus lies on the farmers with larger landholding to come forward and embrace the change and help the smaller farmers in their areas to also take advantage of its benefits listed in the paper. Farmers must do this for themselves and to protect their own future first and foremost (120,121,122).

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