Small Farmers, Big Opportunities

SDG-7 Driven Hardware-Based Technology Innovation for Poverty Reduction in Agriculture

The Lemelson Foundation
improving lives through invention

SELCO FOUNDATION

SELCAP
Sustainable Energy Led Climate Action Program

Acknowledgement

SELCO Foundation expresses its heartfelt appreciation to all those who have contributed to the development of this insightful report. The collaborative efforts of numerous individuals have culminated in a comprehensive study that sheds light on critical aspects of sustainable energy-driven solutions in the agricultural sector.

The data collection process, involving **small and marginal farmers in Karnataka and Odisha,** as well as input from **representatives of Agri-tech enterprises,** has been meticulously executed. Their valuable insights and experiences have enriched the content of this report.

Furthermore, the rigorous validation conducted by **Collaborative Labeling and Appliance Standards Program (CLASP)** and **EnAct** ensures the reliability and accuracy of the findings. Their expertise in assessing the report's quality and adherence to standards has been invaluable.

The report underscores the pivotal role of **Agri-tech** in enhancing the livelihoods of small and marginal farmers. It also candidly addresses the challenges hindering the widespread adoption of such technologies in these farmlands.

May this report serve as a catalyst for positive change, fostering innovation and sustainable practices in agriculture. We express our gratitude to all involved parties for their dedication and commitment to advancing the well-being of farmers.

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Abstract

Lack of adequate mechanization suitable for small and marginal (S-M) farming has led to inefficiencies in farming, wastage of resources and lost opportunities to sell better quality outputs. For the 83.2 million farming households in India who cultivate parcels of land less than 2 hectares, continued dependence on manual labour leads to recurring high expenses. With declining agricultural labour force, climate variability, the cycle of unreliable cultivation each year pushes farmers further in the trap of poverty.

To understand the need for hardware-based technologies (such as nano tractors, small seeders, planter and harvesters) in this sub-sector, as well as obstacles to its development and uptake, SELCO Foundation carried out a mixed approach study. Review of secondary sources explored themes such as impact of land fragmentation on mechanisation and challenges faced by farmers due to lack of appropriate technologies.

In turn, the authors conducted interviews with two key groups. Face-to-face interviews with 18 S-M farmers explored barriers faced by farmers in adopting hardware-based technology. Telephonic interviews with representatives of 10 Agri-tech enterprises focused on hinderances in developing technology for S-M farmlands.

Chapter 1

Small & Marginal Farming in India

India is an agrarian economy where agriculture and allied activities made up 19% and 18.3% of the economy's total gross value added at current prices for 2021-2022 and 2022-2023 respectively[1]. The agriculture sector provides livelihood to 90-150 million[2] people. Small and marginal (S-M) farming in India refers to the practice of cultivating agricultural land of less than two hectares by farmers who own, rent or share the land. S-M farmers often have their land fragmented across the area they live in. Crops are grown for subsistence and surplus is sold at local markets or further via aggregators or retailers. Among the total agriculture households in India, 89.4% (83.2 million)[3] are S-M agriculture households that operate on about 47.3% of the total cultivable land (refer to Fig 1.1).

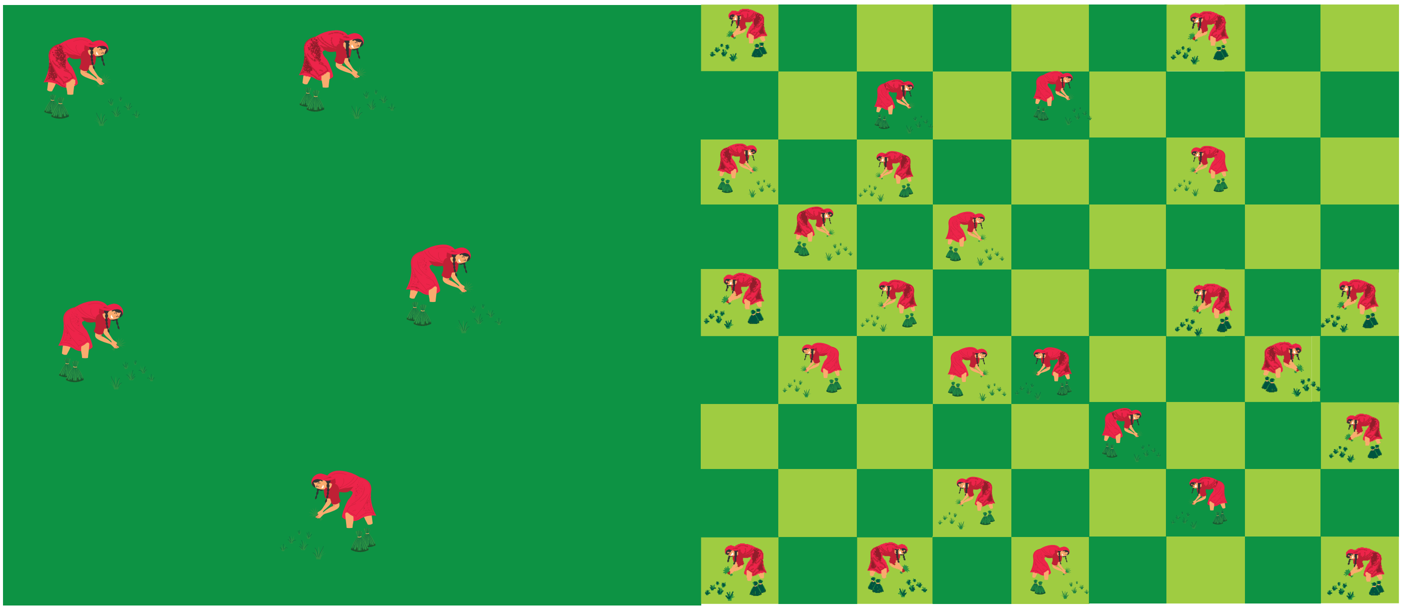

Figure 1.1 Land and Labour Distribution in Indian Agriculture

1 Press Information Bureau, Government of India, "PM to inaugurate World Sustainable Development Summit 2024 tomorrow," February 9, 2024
2 National Statistical Office, Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India, 2019 (January-December 2019) (New Delhi: Ministry of Statistics and Programme Implementation, 2021 (Exact count is not available as a large chunk of agriculture labour is footloose labour and works across sectors)
3 National Statistical Office, Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India, 2019 (January-December 2019) (New Delhi: Ministry of Statistics and Programme Implementation, 2021)

Emissions from Agriculture and Allied Sectors

The GHG contributions attributed to the agriculture sector because of farming activities and energy use cumulatively amount to 17.7% (555 Mt CO_2e) of India's emission portfolio[4].

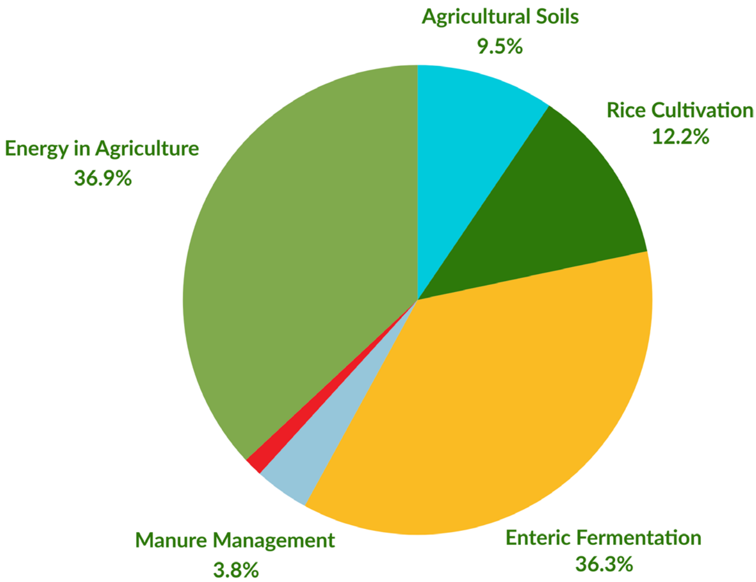

Figure 1.2 Emissions from agriculture sector[5]

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This report investigates the various challenges faced by S-M farmers that hinder adoption of technology for making their livelihoods reliable, such as a lack of access to credit, inputs, skilled labour, markets, technology and reliable, clean and affordable energy. Farmers also end up bearing the brunt of on and off-farm wastage and risks induced by climate variability.

1.1 Farming Landscape in India

Since the Industrial Revolution, farming practices across the globe have taken a steep turn and adopted highly mechanised methods. However, the machines were designed to suit the needs of farms in the West, where the farm sizes are significantly larger in comparison with India.

The average farm size in India is small (1.6 hectares) in comparison with the European Union (14 hectares) and the United States of America (170 hectares)[6] . Even within India, farm sizes vary across states. Therefore, farming practices throughout the country vary depending on farm size, agro-climatic zone, irrigation levels of the region, availability of labour, availability of farm power and socio-economic backgrounds of the farmers.

4 Data has been synthesized from multiple reports in public domain (Energy Statistics 2023, Ministry of Statistics and Programme Implementation National Statistical Office & User Guide by Central Electricity authority by Ministry of Power, Govt of India)
5 Data has been synthesized from multiple reports in public domain (Energy Statistics 2023, Ministry of Statistics and Programme Implementation National Statistical Office & User Guide by Central Electricity authority by Ministry of Power, Govt of India)
6 R. K. Sahni et al., "Status of Farm Mechanization in Indian Agriculture," ICAR-Central institute of agricultural engineering Bhopal462038, Biotech Articles, online publish article, 2018, https://www.entomoljournal.com/archives/2018/vol6issue2/PartC/6 1-85-412.pdf.

Figure 1.3 Representation of average farm sizes in USA, Europe, India

Green Revolution introduced mechanisation in agriculture for increasing means of production rapidly through high yield variety seeds and hardware-based technologies. Hardware-based technologies are machinery engineered for novel use in agriculture, for example tractors to till, large seeders, planters and harvesters.

Across Indian states, where individuals own more than 5 acres of land[7] (e.g. in the states of Punjab and Haryana) agriculture mechanisation has become integral to crop cultivation. Hardware based technologies for large farmlands are readily available in the market. In addition to that socio-economic position of farmers with large landholdings is ample to own these technologies as an individual.

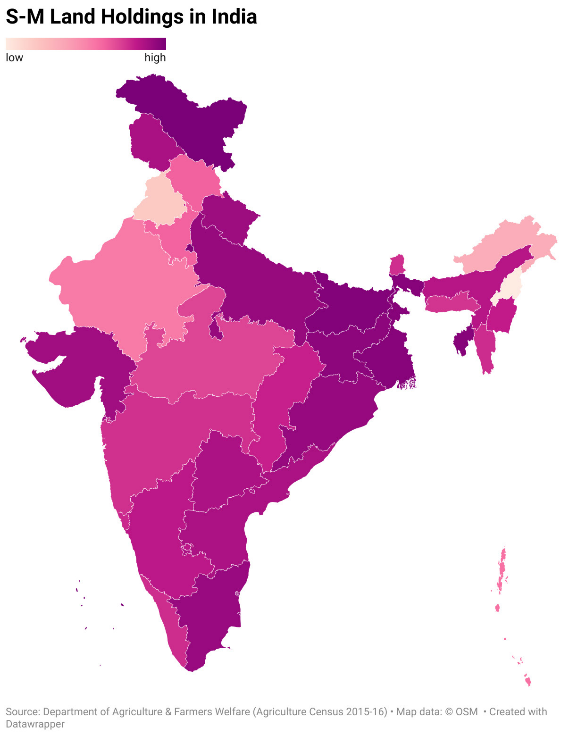

Fig1.4 State-wise share of small & marginal farm holdings

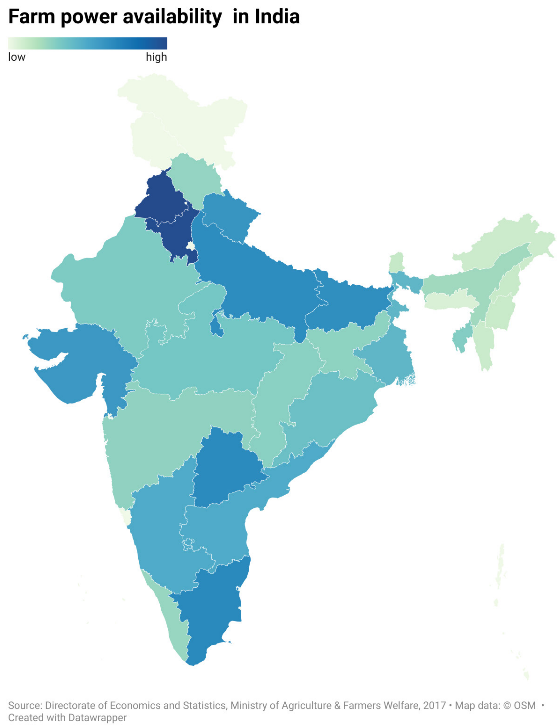

Fig1.5 State-wise farm power availability levels

In sharp contrast, states with the highest shares of S-M farm holdings (Fig 1.4) have the lowest levels of mechanisation (machine use in agriculture) (Fig 1.5). In states with a higher share of S-M land holdings, farmers rely on manual farming, draught animal-based farming and diesel-based farming.

This gap exists due to the absence of adequate hardware-based technologies for S-M farmlands.

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7 A J Vinayak, "More than 84% of geographical area in Punjab, Haryana under agriculture," The Hindu Business Line, August 17, 2021, https://www.thehindubusinessline.com/economy/agri-business/more-than-84-of geographical-area-in-punjab-haryana-under-agriculture/article35934622.ece.

Along with that, the availability of reliable and affordable energy is another major challenge that hinders smooth operation of technology. The little mechanisation they have is fuelled by conventional fossil fuels like diesel.

1.1.1 Farming Practices

Manual Farming

Manual farming involves performing agricultural tasks by hand without the use of machinery or animals. Farmers manually perform activities such as land preparation, planting, weeding and harvesting. Manual farming is labour-intensive but allows for greater control over the farming process.

Some Major Drawbacks of Manual Farming Are:

Labour-Intensive:

Manual farming is physically demanding and labour-intensive, requiring constant human effort for various tasks.

High Wastage:

Grain loss in threshing paddy manually is up to 5% depending on the labour skill. On the other hand, using a mechanical thresher reduces the grain loss to as low as 1-2%[8]

Time-Consuming:

Manual operations take longer to complete tasks than mechanised alternatives, potentially affecting productivity[9].

For instance, 4-5 labourers are needed to weed 1 acre of paddy field. However, with the help of a cono weeder[10], the same task can be done by a single person in 4 hours.

Draught Animal-Based Farming

Draught animal-based farming involves using animals like oxen, buffaloes, horses, mules, donkeys or camels to assist with various agricultural operations. Animals are used for ploughing, planting, weeding, transporting farm inputs and outputs, water-lifting, milling, logging and land excavation. Draught animal-based farming is a better alternative to manual farming as it reduces drudgery and increases efficiency. Farmers in India also have had access to animals as agriculture is an integrated livelihood with animal husbandry[11]. However, draught animal farming has its own challenges.

Animal Dependency and Welfare:

This type of farming relies heavily on draught animals, who need proper care, feeding and maintenance from the farmers adding to operational costs as well as concerns related to their welfare. Draught-animal based farming is a drudgery-driven process for both the farmers and draught animal. For instance, ploughing 1 acre of land with a pair of bullock requires 45-50 hours, paced across days, of drudgery-ridden tasks for both the farmer and the animals[12].

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8 SELCO Foundation – Agriculture Team, Field Observations, 2023-24
9 Nag, "Manual Operations in Farming."
10 The weeder is made up of two rotors, float, frame, and handle. The rotors are cone shaped, with smooth and serrated strips welded to the surface along their length. The rotors are positioned in tandem, with opposite orientations. The float, rotors, and handle are all attached to the frame. The float controls the operating depth and prevents the rotor assembly from sinking in the puddle. The cono weeder is operated by pushing it. The direction of the rotors causes back and forth movement in the top 3 cm of soil, which aids in the uprooting of weeds.
11 Nag, "Manual Operations in Farming."
12 SELCO Foundation – Agriculture Team, Field Observations, 2023-24

Diesel-Powered Mechanised Farming

Diesel-powered mechanised farming refers to the use of diesel-powered machinery for agricultural operations. It includes the use of tractors, power tillers, harvesters, irrigation pumps and other farm equipment. Mechanised farming significantly increases productivity and reduces the labour requirement. However, it has its own challenges, especially for S-M farmers[13].

High Initial Investment:

Machinery is expensive to purchase, maintain and operate, making it less accessible for small-scale farmers with limited financial resources. Combination of a diesel-powered tiller, transplanter and reaper costs approximately INR 5 lakhs or $6000, which is a very high investment for S-M farmers[14]. According to Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India, 2019 average income of farming households in India during the year 2018-19 was INR 1.2 lakhs[15] annually. The survey includes both farmers with large holding and S-M farmers therefore, income of S-M can go lower than the average.

Fuel Dependency:

Diesel-based farming relies on a consistent fuel supply, which is subject to price fluctuations and availability and accessibility issues. In remote Indian rural areas, petrol and diesel are sold in plastic bottles as fuel stations are absent in close proximities. These unorganised fuel market charges 12-15% extra for fuel than formal market price[16].

Environmental Impact:

Diesel-powered machinery contributes to massive amounts of air pollution and greenhouse gas emissions, which have adverse effects on the environment. In the year 2018 emissions from agriculture due to burning of diesel were 37.54 Mt Co2e[17].

Unavailability of Appropriate Technology:

As mentioned above, technology suited to large land holdings are readily available. The limited machinery that is available for small landholdings is expensive and often not cost-effective.

Current mechanisation trends in farming:

Farm power per hectare is the amount of energy or force available for agricultural operations on one acre. It includes all types of power utilised in farming, such as human labour, animal power, mechanical equipment, and electricity. The country's average farm power availability has increased from 0.295 kW/ha in 1971-72 to 1.94 kW/ha in 2012-13[18]. The highest share is of tractors in the year 2012-13. However, the use of diesel engines, draught animals and manual labour remains significant. The use of electric motors has also increased over time.

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13 Nag, "Manual Operations in Farming."
14 SELCO Foundation – Agriculture Team, Field Observations, 2023-24
15 Ministry of Statistics and Programme Implementation. Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India. New Delhi: Ministry of Statistics and Programme Implementation, 2019. Accessed March 22, 2024.
16 SELCO Foundation – Agriculture Team, Field Observations, 2023-24
17 GHG Platform India
18 National Bank for Agriculture and Rural Development, National Strategy Paper on Farm Mechanisation (Mumbai: NABARD, 2019), 5, https://www.nabard.org/auth/writereaddata/file/NSP%20Farm%20Mechanisation.p df.

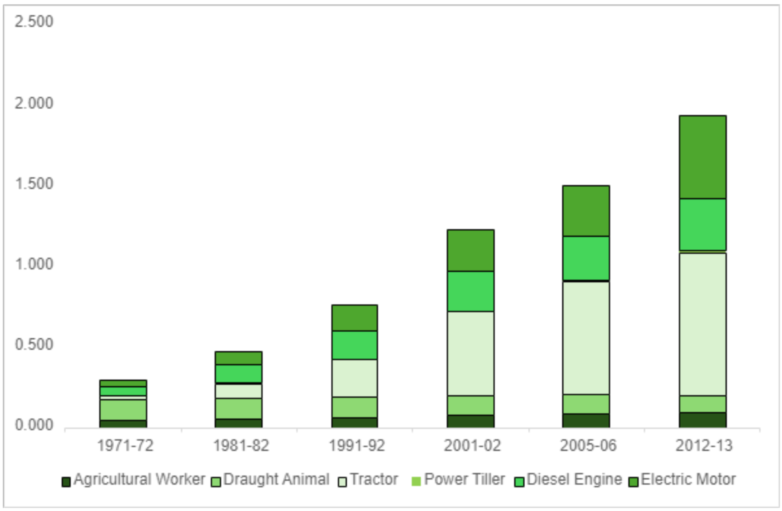


Fig 1.6. Shows availability of farm power in kWh per hectare and share of various farm power sources

(NABARD 2018)

1.2 Risk and Challenges Faced by S-M Farmers

S-M farmers throughout the country face various risks and challenges that limits productivity. These risks and challenges become a barrier to the overall sustainability of S-M farmers and farmlands.

High Input:

S-M farmers have been seen to rely on high chemical input to attain higher yield in absence of mechanical ways to manage it. For example, in the absence of a mechanised weeder, farmers use herbicides to control weeds. This practice incurs recurring expenses, is highly unsustainable as, with time, soil quality decreases due to the extensive use of synthetic fertilisers and pesticides in the fields. They are also known to leech into the groundwater table causing long lasting impact on local ecology.

Weedicide	Mechanical Weeder	Animal-based Weeding	Battery-operated Weeder
5,000 per year considering 3 crop cycles and labour cost	30,000 per year labour involved	45,000 per year considering ox rent, labour involved	47,000 as a one-time investment

Shortage of Labour:

As S-M farming gets more disincentivised, farm labourers migrate to urban landscapes as non-farm unskilled labour for daily income and subsistence.

According to the Economic Survey of India 2020-21, the share of agriculture in employment has been declining, but at a slower pace than before. The share of agriculture in total employment fell from 49.9% in 2011-12 to 42.7% in 2019-20. The biggest decline in the share of agriculture in employment happened between 2004-05 and 2011-12, from 58.5% to 48.9%[19].

19 Ministry of Finance, Economic Survey 2020-21, vol. 1 (New Delhi: Government of India, 2021), 10, https://www.indiabudget.gov.in/budget2021 22/economicsurvey/doc/vol1chapter/epreface_vol1.pdf.

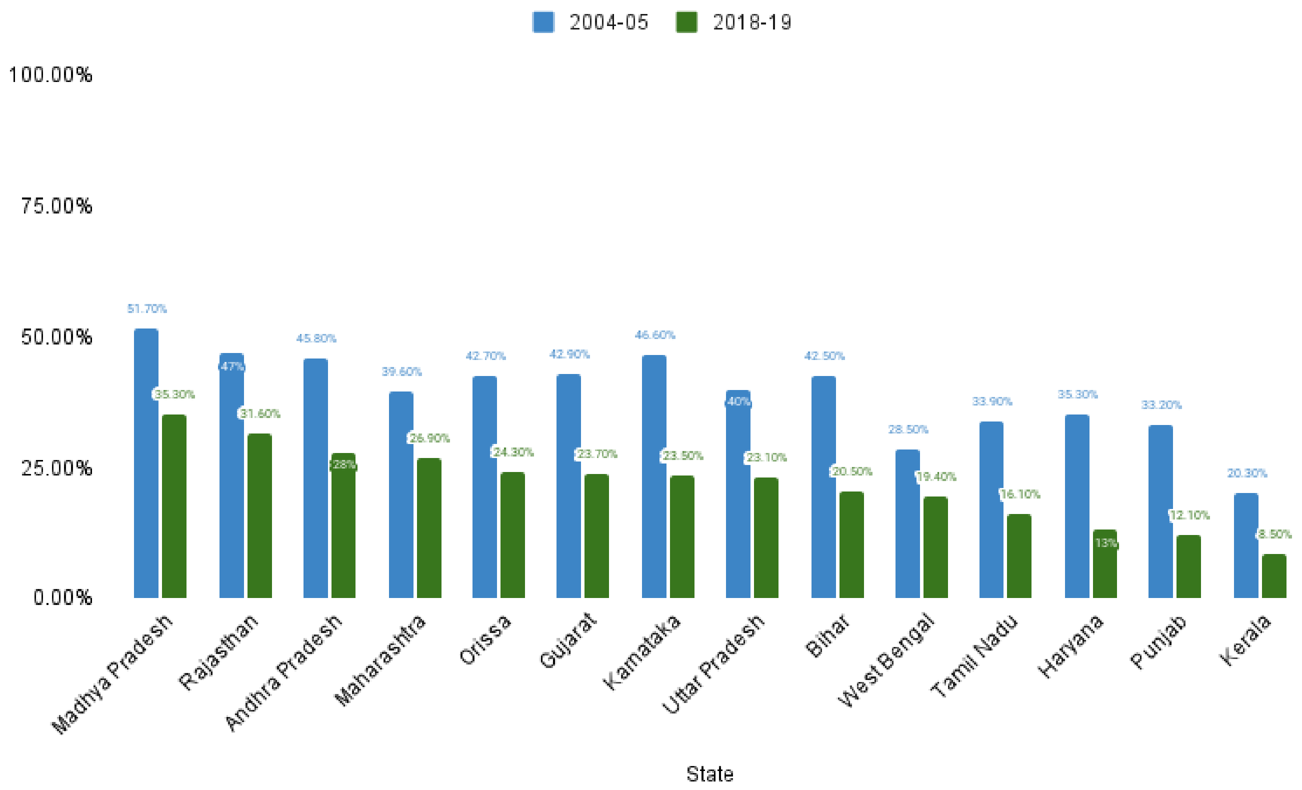


Fig1.7. % of prime working age population (20-59 years) in agriculture employment for the years 2004-05, 2018-19

There has been a steep decline in agriculture employment across India from 1951-2019. The ageing agriculture workforce would necessitate faster mechanisation of Indian agriculture going ahead, but fragmented farm sizes in India may pose a problem[20].

Dependency on Monoculture:

Due to limited resources, small farmers are compelled to focus on a single crop (monoculture). More than 85% of S-M farmers grow rice, wheat, pulses, spices, vegetables and other grains through monocropping[21]. This dependence makes them vulnerable to market fluctuations and pest outbreaks, posing risks to their income and food security.

Wastage:

In the absence of labour and machines to support agriculture, S-M farmers use inefficient farm management practices. For instance, manual broadcasting of seed spreads the seed unevenly, making germination of all seeds uncertain leading to unoptimised production.

Other practices like manual dehusking and separation of grains, also lead to significant on-farm and post-harvest crop losses at each stage, resulting in declining yield and sellable product.

20 A J Vinayak, "Workers are moving off Indian farms but where are they going?," The Hindu Business Line, March 25, 2021, https://www.livemint.com/opinion/online views/workers-are-moving-off-indian-farms-but-where-are-they-going 11616603448650.html.
21 Outlook India, "Food Production In India Faces Twin Challenge Of Pesticide And Waste Management," Outlook India, February 5, 2024

Climate Variability:

S-M farmers are particularly vulnerable to the impacts of climate change. Erratic weather patterns, extreme events (such as droughts or floods) and changing temperature affects crop yields, livestock, overall farm productivity and labour activity on field. Rising heat stress has incurred losses up to **$3.75 billion dollars for farmers** in India[22].

The above-mentioned issues do not exist in isolation but intersect with each other at various points. To tackle these challenges, it is essential to look at the problems through a systemic lens so that interventions can be designed at different nodal points of the system to make S-M farming profitable. It is also equally critical to highlight various underlying factors that create these challenges for S-M farmers in the first place.

Women farmers discussing on farm fields.

22 Climate Transparency, "G20 Climate Performance Report 2022," Climate Transparency, November 9, 2022

Chapter 2

Study Framework and Methodology

This study uses the systems thinking approach for problem identification. The Systems Thinking approach is a way of understanding and solving complex problems by examining the interactions and interdependencies within a system, rather than focusing on individual components in isolation. It involves viewing a situation holistically and recognising that changes in one part of the system can have ripple effects throughout the entire system.

Objectives of the Study

The study has two major aims:

- Understand the need for hardware-based tech on S-M farms
- Identify factors hindering hardware-based technology innovation and adoption for S-M farms

Study Methodology

To better understand the challenges, risks and needs of S-M farmers, a mixed method approach was applied. The respondents were identified through purposive sampling based on following

Characteristics:

- Size of landholding – farmers with less than 2 hectares of land
- Gender of the farmer
- Ownership of technology

Some of the Key Themes Explored Through Secondary Sources Include:

- Challenges faced by S-M farmers in adopting hardware technology.
- Unravelling factors contributing to the reluctance or barriers hindering the adoption of hardware technology among S-M farmers.
- Landscape of hardware technology in agriculture, including examining enablers and barriers within the policy framework and supply chain
- Diverse range of stakeholders involved in driving innovation in agricultural technology, from policymakers to entrepreneurs and farmers.

To gain a holistic understanding of the scope for hardware technologies to solve challenges and reduce risks of S-M farmers, two sets of in-depth interviews informed this study.

Semi-structured interviews with 18 S-M farmers (i.e. end-users) who have adopted clean energy technologies and some decentralised hardware-based technologies for off-farm, post-harvest or agri-allied activities. All farmers were from Karnataka and Odisha.

Telephone interviews with 10 sector experts and clean energy enterprises that develop and deploy agriculture machinery focusing on small scales: e.g. nano tractors, hydroponics system, electric tillers, solar dryers.

SN	Stakeholder group	No. Interviewed	Areas of Enquiry	Tool
1	End user (small and marginal farmer)	18	Challenges in manual farming, Technologies used by Farmers, Adoption process of technologies.	Face-to-face interviews
2	Agri-Tech enterprises	10	Challenges and opportunities in innovation and development of technology	Telephonic interviews

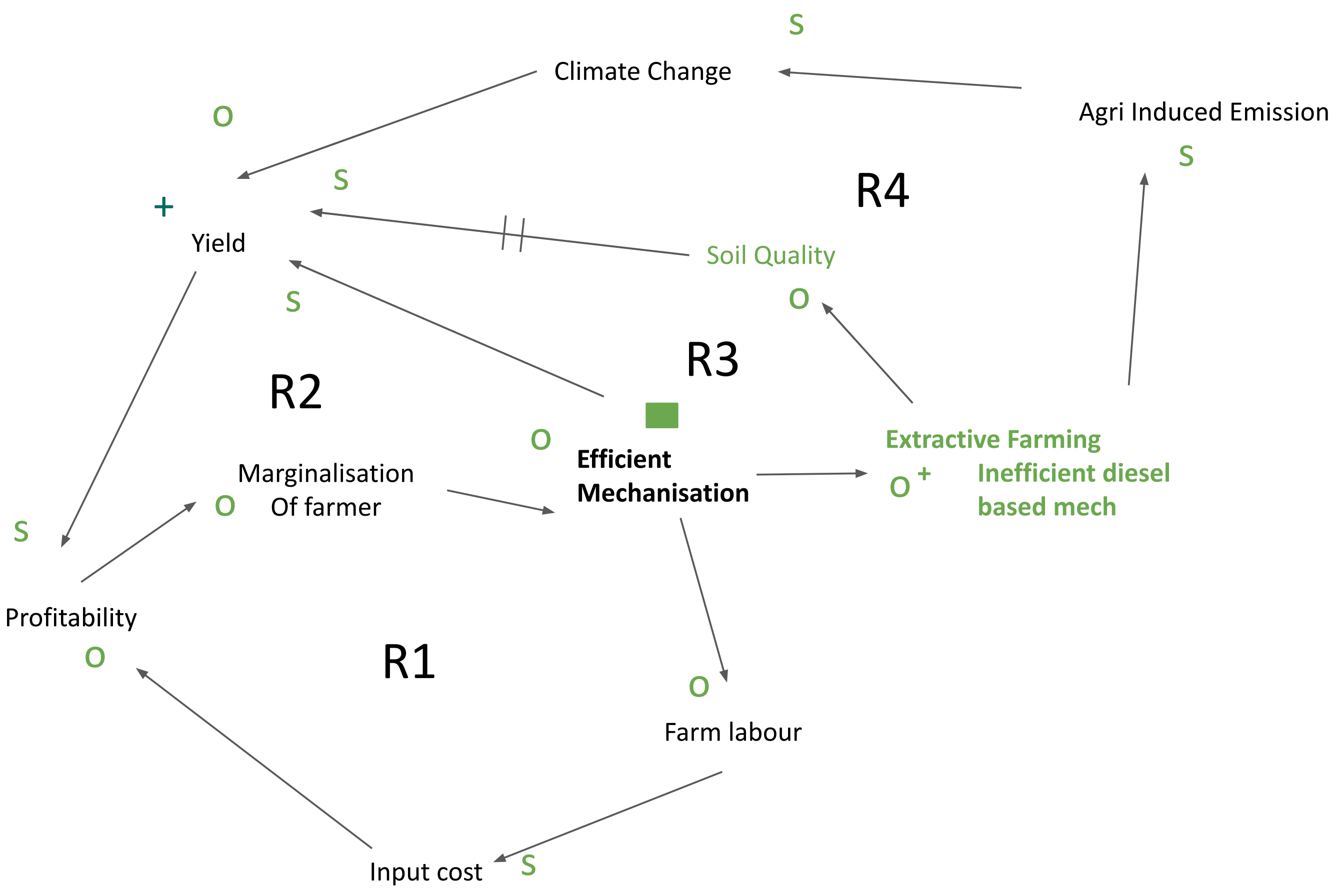
Chapter 3

Challenges in Small & Marginal Farming – A Farmers' Perspective

3.1 Exploring Causal Loops in S-M Farming

A causal loop diagram is a visual representation of variables assembled in a chain format where one variable affects the second, the second affects the third, and this goes on till the loop is complete. It is an effective way to explain causality among a set of variables in a system and the nature of their relationships.

The causal loop diagram below consists of multiple balancing loops that display the challenges faced by marginal farmers. They represent the hurdles that impede agricultural growth and entrench farmers in cycles of marginality and poverty.



Loop R1

Marginality in farming can be defined as a concept that describes the condition of agricultural lands or areas that are less favoured such as hilly terrains and undulated lands or disadvantaged for crop production due to biophysical or socioeconomic factors such as class, caste and gender, or both. As discussed previously marginality poses a challenge for efficient mechanisation for S-M farms. The absence of mechanised technologies escalates the demand for farm labour, driving up input costs and diminishing profitability for S-M farmers.

Loop R2

Yields suffer due to lack of mechanisation in S-M farms. This decline in productivity exacerbates the marginalisation of S-M farming enterprises.

Loop R3

In numerous instances, the absence of mechanisation tailored for small-scale farms prompts the utilisation of inefficient diesel-powered machinery. This, coupled with the excessive use of synthetic inputs such as chemical-based fertilisers high in uric acid content, degrades soil quality over time, further reducing yields.

Loop R4

The usage of inefficient diesel-based machinery exacerbates the emission of carbon into the atmosphere, exacerbating the challenges posed by climate change and adversely affecting yields.

Use of casual loops depicts how one problem feeds into others, makes it extremely inevitable for S-M farmers to exit the interconnected loops of disincentivised farming, losses, drudgery and loss of livelihood.

3.2 Challenges Faced by S-M Farmers at Different Stages of Farming

This section examines challenges in the agriculture value chain at three stages: land preparation, on-farm and post-harvest. Land preparation involves tilling, adding fertilisers to land and seeds for planting, while on-farm activities involve the growth and development of crops. Post-farm activities add value to harvested crops, such as processing, packaging, marketing, transportation and distribution, thereby increasing shelf life and profitability. The challenges mentioned below are identified by triangulating contemporary literature, farmer testimonies and expert opinions.

3.2.1 Challenges in Land Preparation

The lack of mechanisation is a significant challenge for S-M farmers during land preparation. The study highlights the following challenges faced by S-M farmers:

Manual Labour Dependence:

S-M farmers often rely heavily on manual labour for operations due to the limited adoption of modern agricultural machinery. This dependence on manual labour makes the sowing process time-consuming, labour-intensive and less efficient. The study highlights, that due to a shortage of farm labour and high labour costs, farmers work on the plots individually or involve family members. As all farms in a vicinity need labour at the same time, a labour crunch is experienced by most farming communities. It results in untimely sowing of seeds or hurried distribution of seeds on farms. In the broadcasting and transplanting method of paddy cultivation, broadcasting engages 2 agricultural labourers per day for one acre of land while transplanting engages 4-5 labourers. However, with the help of a drum seeder the same task can be performed by one person in a single day[23].

23 SELCO Foundation – Agriculture Team, Field Observations, 2023-24

Increased Drudgery in Land Preparation:

Mechanised equipment, such as tractors, tillers and ploughers can facilitate faster and even land preparation. Without access to such machinery, S-M farmers resort to traditional methods of land preparation like tilling and ploughing using draught animals. This slows down the preparation process and is physically taxing. Heat stress induced due to climate change has an adverse effect on drudgery increasing it even further. As it effects on-farm activities and farmers' wellbeing, manual processes do not ensure an even land preparation throughout the plot . (Refer to section 1.1).

Overreliance on Chemicals for Fertigation:

To increase the fertility of the soil, before sowing the seeds, fertilisers are applied to the soil. Existing technologies like sprayers and drip systems only facilitate the application of chemical-based fertilisers, while technologies that can help in preparing organic fertilisers and pesticides or integrating organic forms of matter into the soil are still emerging (Refer to section 1.2).

3.2.2 Challenges in On-Farm Activities

During the sowing and the growth period, farmers face multiple challenges:

Application of Fertilisers and Pesticides:

Due to the absence of technology, fertilisers and pesticides are applied manually. This often leads to uneven application and overuse of chemical fertilisers, which further depletes the soil's health.

Drudgery:

This stage involves tedious activities like weeding. The absence of weeding machinery for S-M farms puts the burden of weeding on manual labour, which is usually done by **women** as the task is **tedious** and does not require much physical strength.

Irrigation:

One out of four small-scale farmers rely on diesel engine-based pumps for irrigation, which increases the input costs and is polluting in nature. Additionally, this might also increase the burden on the underground water table if done incessantly.

Low Productivity:

Manual sowing methods lead to uneven seed placement, varying seed depths and lower seed-to-soil contact. It also involves very high amounts drudgery. These factors result in lower germination rates and overall crop productivity. Mechanised sowing ensures more precise and uniform seed placement, optimising the use of seeds. In paddy cultivation, the broadcasting and transplanting method gives a yield of 14-16 quintals/acre, while a drum seeder increases the yield to 18-20 quintals/acre[24].

24 SELCO Foundation – Agriculture Team, Field Observations, 2023-24

Impact of Climate Change:

A significant amount of crop loss happens during this stage of crop cultivation in case of unseasonal flooding or extended periods of drought. In kharif 2023, the state of Karnataka saw a crop roil of 42 lakh hectares which was worth INR 30433 crore due to deficit rainfall[25].

3.2.3 Challenges in Harvest and Post-Harvest

- **Slow Harvesting Process:**
  Without the assistance of modern harvesting machinery, the harvesting process is slower. This results in delays in getting the produce to market, leading to potential quality deterioration and reduced market value. Lack of storage for harvested produce is also seen, especially in areas with high heat stress or prolonged rainfall.

- **Physical Strain on Farmers:**
  Manual harvesting places a significant physical burden on farmers, especially during peak seasons when long hours of labour are required. This leads to fatigue, health issues and a reduced capacity for farmers to engage in other essential farm activities.

> "We used to have constant pain in our hands due to tedious work of manually cleaning grains."
> - Bibi Fathima, Millet Processing Unit User, Thirthi, Karnataka

- **Post-Harvest Losses:**
  S-M farmers experience difficulties in handling, storing and transporting harvested crops, increasing the risk of spoilage, damage or deterioration in quality. (Refer to section 1.1)

- **High Labor Costs:**
  Manual labour for harvesting is costly, especially during peak seasons when demand for labour is high. S-M farmers face financial constraints in hiring the required workforce, impacting their overall profitability.

3.3 Scope of Hardware-Based Technologies in Solving for S-M Farming

Both secondary literature review and in-depth interviews conducted during this study confirmed that hardware-based technologies can improve S-M farming as a reliable primary livelihood.

Adopting hardware-based technology for farm mechanisation delivers multiple benefits in terms of increasing productivity and building climate resilience. Mechanisation can increase the crop yield and income of farmers by improving the quality and timeliness of farm operations and reducing losses and wastage. According to a report by the Malabo Montpellier Panel, using data from 16 African countries, found that agricultural mechanization can **increase crop yields by up to 50%, reduce post-harvest losses by up to 20%, and increase farm income by up to 60%[26].**

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25 ET Bureau, "Drought roils crops in 42 lakh hectares in Karnataka worth Rs 30,433 crore," The Economic Times, October 5, 2023
26 Malabo Montpellier Panel, Mechanized: Transforming Africa's Agriculture Value Chains (Dakar: Malabo Montpellier Panel, 2018), 12, https://www.mamopanel.org/media/uploads/files/MaMo2018_Mechanized_Transf orming_Africas_Agriculture_Value_Chains.pdf.

Hardware-based technology can reduce greenhouse gas emissions and conserve natural resources by adopting climate-smart practices such as precision farming, zero tillage, drip irrigation, mulching, using organic inputs etc. For example - a report by the Food and Agriculture Organization (FAO), 2016, found that zero-till planter can **reduce greenhouse gas emissions by up to 70% in wheat and paddy cultivation**[27][28]**.**

Drudgery Reduction:

Manual labour inflicts serious physical strain, resulting in issues such as muscle pain, fatigue, dehydration etc. Chronic pain developed can also lead to decreased working years for farmers. Among 18 participants surveyed, 16 expressed relief that machinery reduced physical exertion in their tasks. For instance, adopting hydroponic systems eliminated the need to manually transport heavy feed bundles from farm to shed, as they could now grow feed inside the shed. Additionally, many female labourers cited chronic neck and back pain during prolonged paddy transplanting sessions. These findings underscore the pivotal role of mechanisation in mitigating the burdens of laborious agricultural activities.

Reduced Time to Perform Tasks:

The integration of machinery instead of manual labour significantly reduces task duration. All 18 participants noted a remarkable decline, averaging 70-80%, in the time required for activities such as destoning millets and arranging green feed for cattle after adopting the technology. This surplus time can be redirected towards enhancing other aspects of farmer's lives.

Improved Produce Quality:

Hardware-based technologies improve the quality of the produce as they eliminate irregularities from the production process and increase the overall efficiency of the process.

Increased Produce Quantity:

Machines increase the on-farm production capacities of people (refer to section 3.2.2). Out of the 12 participants, 8 believe that there has been a substantial increase in the amount of produce even when the input and working hours remain the same. An increase in the quantity of produce increases income potential of the people engaged in various livelihood activities. Proper access to markets ensures incomes.

Building Climate Resilience Among Farmers:

Technological advancements including climate-smart irrigation systems, bio-fermenters, solar-powered cold storages and weather monitoring systems play a pivotal role in fortifying farmers against climate variability. Moreover, they diminish dependence on extractive, high emission farming practices, thereby promoting sustainable agricultural practices. For example, poly houses and solar dryers can insulate the farmers against harsh weather externalities for multiple purposes. During the interviews, 12 participants highlighted the issue of reduced and irregular rainfall causing massive scarcity of water for growing feed for cattle. However, hardware-based technology like the hydroponics stand was able to address and solve the problem by providing good quality green feed with water usage as low as 2-3 litres a day.

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27 Food and Agriculture Organization of the United Nations, The State of Food and Agriculture 2016: Climate Change, Agriculture and Food Security (Rome: FAO, 2016), 14,

28 CGIAR. "Zero tillage to reduce air pollution in India." CGIAR. 2023. https://www.cgiar.org/innovations/zero-tillage-to-reduce-air-pollution-in-india/. February 16, 2024.

Table 3.1: Existing technologies for various aspects of S-M farming:

REDUCE DRUDGERY & TASK DURATION	
Land Prep	Bio-fermenters*, micro tillers, nano tractors
On-farm	Transplanter, Weeder,
Harvest	Micro Harvesters, Micro Thresher cum Winnower
Post Harvest	Micro Sorter, Grader, Polisher, Pulveriser
Storage	Controlled Atmospheric Storage*, Decentralised Cold Storages*
Livestock Management	Milking Machine, Hydroponics for fodder*
RESOURCE OPTIMISATION	
Precision Agriculture*	Spraying Drones, Drip Irrigation System, Moisture Sensors, Automated Irrigation Controllers
Monitoring*	Spectro-photo Metres, Moisture Metres, Pest Detection Systems
Waste Management*	Bio-digestor (provides alternative and clean cooking fuel too)

All technologies marked * add to on-ground adaptation against climate variability for farmers.

Farmer using a battery-operated weeder on her field.

Case Study 1 Hydroponics for Cattle Feed

Dharmendra

owns 2 acres of land in Chikkahullegere, Dharwad, Karnataka, which he uses to grow crops and raise cattle. Dharmendra has been raising cattle for the past 10 years. He currently has 3 cows, 2 calves, 20 goats, and 2 sheep. He sells the milk at the local dairy for Rs. 30 per litre. He is 46 and has a family of 8 people, including, his parents, his wife, two sons and two daughters.

Experience and Challenges

The lack of green fodder is one of the challenges that he faces on the farm, particularly as lower rainfall in recent years has made it difficult to grow green fodder. As a result, he must buy fodder – at high costs – from the commercial dairy. The time and labour required to bring feed from the field takes him 2-3 hours a day. This takes away time from other activities, such as tending to his crops or other productive uses.

Technology Adoption Experience

In April 2023, Dharmendra adopted a hydroponics system to grow green fodder for his cattle. The system consists of 24 stacked trays, filled with a nutrient solution and seeds. There are sprinklers that spray water in regular intervals and the system is powered by solar energy.

He believes that the quality of the feed grown in the system exceeds what he was buying from the dairy and has noticed an increase in the milk production with increased fat content of his cows.

Technology Impact on Livelihood

The hydroponics system has made it easier for Dharmendra to grow cattle fodder and saved substantial time as he no longer has to buy feed from the dairy, this has also reduced his input costs. He believes that the quality of the feed grown in the system exceeds what he was buying from the dairy and has noticed an increase in the milk production of his cows.

Conclusion

Satisfied with the performance of the hydroponics system, Dharmendra plans to expand cattle farming in the future. He is also thinking of getting a milking machine to improve the efficiency of his dairy operations.

Case Study 2 Building Climate Resilience Through Millets

Bibi Fathima SHG was formed in October 2019 with the support of Sahaja Samruddha NGO. The group consists of 14 women from the same village who got together to promote millet cultivation in the village. Consumed locally, millets are resilient to stresses caused by climate change. The SHG preserve high-quality indigenous seed varieties of millet, create market linkages, and add value through processing.

Motivation for Tech Adoption

The group decided to adopt technology to improve their efficiency and productivity. Their aspirations were aided by the Indian Institute of Millet Research (IIMR) as they provided free machinery to the SHG. Due to issues in irregular power supply and prolonged power cuts, the group decided to install solar energy system to power the machines. SELCO Foundation covered for 80% cost of the whole system.

Technology Adoption Experience

The group received a set of machinery in 2020 from IIMR, including a thresher, a winnower, a polisher, and a grader. They also received training on how to use the machinery from ICAR. The group initially struggled to use the machines, but they eventually became proficient in their use over time.

Impact of Technology on Livelihood

The adoption of technology has had a positive impact on the livelihood of the group. They are now able to process millet much more efficiently, which has reduced the time and labour required. This has freed up the women to focus on other activities, such as marketing their products. The group's income has also increased significantly from 8,000 – 10,000 Rs/Month to 20,000 – 25,000 Rs/Month, allowing them more income and investment for their entrepreneurial aspirations. They are now carrying out operations in packaging and branding.

Persisting Challenges

- The group still faces some challenges, such as a lack of market linkages for processed millet products. They are currently selling the processed products by putting stalls at Krishi Melas (Farmers' Fair)

- AS the scale of production has increased, they are struggling to lift heavy weights (of millets) in machines over their height. They are planning to install a lift to address this challenge.

Conclusion

The Bibi Fathima SHG is a success story of how technology can be used to improve the livelihood of women farmers. The group has been able to increase its income, reduce its labour requirements, and improve the quality of its products through the adoption of technology.

Chapter 4

Barriers in Hardware-Based Technology Innovation and Adoption for Small & Marginal Farmers

The sections above highlight the need and the scope for hardware-based technology solutions specifically for S-M farmers that form the majority of those engaged in agriculture. However, the developments for the same have been significantly limited. Contemporary literature suggests the following gaps that hinder technology adoption and innovation for S-M farms:

Limited Financial Resources:

S-M farmers typically have limited financial resources as they live hand to mouth with minimal savings. Investing in machinery and equipment can be expensive, and these farmers may struggle to afford the upfront and recurring costs associated with purchasing, operating and maintaining agricultural machinery.

Lack of Credit Access:

Access to credit is a significant challenge for S-M farmers. Without the ability to secure loans or credit from formal sources due to low credit score and lack of assets, they may find it difficult to invest in mechanisation, which often requires substantial upfront capital.

Fragmentation of Land Holdings:

S-M farms are characterised by fragmented land holdings. The small size and irregular shapes of these plots make it challenging to use large-scale machinery efficiently. Small tractors or equipment may not be economically viable for such small and scattered parcels of land.

Low Scale of Operations:

The scale of operations on S-M farms is generally lower compared to larger farms. Mechanisation is more economically viable on larger farms where the cost of machinery can be spread over a larger area of cultivation. On smaller farms, the benefits of mechanisation may not justify the investment, unless unique use and ownership models are looked at (such as hiring centres, farmer community owned machines etc).

Lack of Information and Training:

S-M farmers may lack awareness of the benefits of mechanisation or may be unfamiliar with modern agricultural practices. Inadequate training and information on the proper use and maintenance of machinery can also be a barrier to adoption.

Inadequate Infrastructure:

Many S-M farmers operate in regions with limited infrastructure, such as poor roads and inadequate storage facilities. This lack of infrastructure can hinder the transportation of machinery and make it challenging to use and maintain equipment effectively.

Preference for Traditional Methods:

Some S-M farmers may prefer traditional farming methods and be resistant to change. Cultural and traditional practices can influence the adoption of new technologies, and farmers may be more comfortable with manual labour or traditional tools.

Risk Aversion:

S-M farmers often operate in environments where there are high stakes associated with expenditures and uncertainty of income. The adoption of new technologies, including mechanisation, involves a degree of risk. Farmers may be hesitant to invest in machinery without assurances of increased productivity and profitability[29][30].

All the points mentioned above give a nuance idea of the hinderances that are faced by the farmers in adoption and use of hardware-based technology. But to curate interventions that fill the gaps it is essential to look at the problem from demand and supply side perspectives simultaneously. In terms of different stakeholders, S-M farmers are at the demand side of the chain and Agri-tech enterprises are at the supply side of the chain, while policy and schemes act as enablers or barriers to adoption. Both sides face different set of challenges that become an obstacle in the convergence of the demand and supply side. The challenges and gaps faced by both demand and supply side can be bucketed into three different categories policy, design and program.

Farmer using a sprayer for his paddy field.

29 C. Ganeshkumar et al., "Investigating the Adoption Barriers to Industry 4.0 Technologies in Farmer Producer Organisations," Journal of Global Business and Competitiveness 18, no. 2 (2023): 162-174, https://doi.org/10.1007/s42943-023 00083-1.
30 Vinaya Kumar Hebsale Mallappa and Tapan Bharatkumar Pathak, "Climate smart agriculture technologies adoption among small-scale farmers: a case study from Gujarat, India," Frontiers in Sustainable Food Systems 7 (2023): 1202485, https://doi.org/10.3389/fsufs.2023.1202485.

4.1 Identified barriers for farmers in adopting technologies

Key Stakeholder: S-M Farmer		
Ecosystem Component	**Challenge**	**Gaps**
Policy	Affordability	Machines and equipment for agriculture has high upfront cost, S-M farmers do not have capital readily available for such investments.
		Hardware technology for S-M farms are newer innovations and developed by start-ups, therefore, loans and subsidies are not available for such tools.
		Goods and Service Tax on agriculture equipment has been raised from 5% to 12% in India this further increase the cost.
		EV based tractors fall out of agriculture equipment category therefore tax rate on them is 28%. Due to separate categorisation, EV tractors cannot be availed under agriculture equipment schemes.
	Capacity of Users	Exposure to any kind of technology has remained limited in rural Indian landscapes particularly in poor farming communities. Due to which there is a lack of required skillset among farmers.
		Existing agriculture training programs focus on training farmers on farming techniques and products to use as input. Training on technology use is provided by technology vendor which is very brief and does not serve the purpose adequately.
Design	Inadequate Design for Indian Agriculture Machinery	Design of agriculture machinery in Indian markets replicate designs of machinery in European markets. However, Indian topography is different from Europe and has a huge diversity withing the country. There are 7 agro-ecological with further intra-zonal diversity. Along with that plot sizes in India are also small. Therefore, availability of right kind of technology is an issue
	Gender Gap in Design	Gender inclusivity poses a noteworthy obstacle. The physical limitations faced by women in handling heavy machinery and the absence of gender inclusive customised technology hinder the widespread adoption of hardware-based solutions among this demographic.
Program	Lack of Market Linkages	While hardware-based innovations promise enhanced productivity and quality, inadequate market linkages for processed products such as flour, flakes, oil, hinder economic viability.
	Lack of group farming models	Issue of small and fragmented land holdings has unique set of challenges in different context. However, group farming models can tackle some of them in a way where farmers can jointly work of field and make efficient use of technology.
	User adoption and use model	Technology is provided by organisations through sales, service models are very less or do not exist. 90% of the Agri-Tech enterprises involved in this study functions on a sale only model. There is no way through which farmers can dodge the upfront cost and use machines on rental or subscription bases

4.2 Barriers in Technology Innovation: Agri-Tech Entrepreneur’s Perspective

Key Stakeholder: Agri-Tech Enterprise		
Ecosystem Component	**Challenge**	**Gaps**
Policy	Categorization Challenges to access subsidies	Novel technologies for farming face an issue of categorisation as in current guidelines for schemes and subsidies categories for farm equipment have been pre-defined with less scope for addition of complex and sophisticated technology that is sector and operation-agnostic. Venkat Rai from Inav Agro highlighted this issue with his EV tractor that falls in the category of advance electric motorised vehicle, and it is not eligible for subsidies. Along with that tax on battery operated nano tractor is 28%.
	Operational Issues	Indian agriculture policies are pro-farmers and promote technology adoption for agriculture. However, the lacuna lies in access to these policies in difficult and remote geographies.
	Goods and Service Tax (GST) Categorisation	The absence of a defined category for hardware-based agriculture equipment in the GST brackets poses a financial challenge. Entrepreneurs, like Venkat Rao from Inav Agro, are compelled to charge end-users directly, contributing to the financial burden on S-M farmers.
	Market Linkages and Training Needs of Farmers	Agri-Tech entrepreneurs mentioned challenges related to limited market linkages and the need for training and capacity building for end-users. This indicates that the success of technology adoption is contingent not only on the technology itself but also on the surrounding support infrastructure and user knowledge.
Manufacturing & Design	Lack of suitable benchmarked technologies	Designers from technology enterprises highlighted the absence of existing or working technology that serve as benchmark to customise further for various farmer needs. They expanded on the challenges of accessing sophisticated and efficient machinery, particularly when local brands are scarce in the Indian market. This hurdle reflects the limitations within the market ecosystem that affect the development and deployment of advanced agricultural technologies. Most of the existing high-quality technology caters to farmers holding large tracts of lands.
	Compromising on quality	Agri-Tech enterprises shared that they were forced to compromise on the quality of the parts and the technology to bring down the costs and make the technology cost-effective.

	Unavailability of small parts across the manufacturing process	Enterprises discussed about low availability of good quality small parts, tools or attachments in existing Indian markets. This poses a major production challenge in a diverse country like India where technology requires hyper localisation according to the geography, crop produced and soil type. They also highlighted that there is no standardisation of part producers forcing enterprises to use Chinese counterparts that are inexpensive and easily available against importing from Europe. This indicates the multifaceted hurdles in the entire process, from conceptualisation to execution, that can impede the smooth development of hardware-based technology. **There is a high cost to product development that is borne by the innovator.**
Program	Inadequate working capital for innovation, research and product development	Tech enterprises face challenges related to insufficient working capital for crucial phases such as research, development and testing. This constraint hampers the ability to invest in cutting-edge technology and limits the scope of innovation. A third of Agri-Tech entrepreneurs involved in the study highlighted this issue
	Capacity, Training and Feedback	Technology providers reported that farmers or operators in rural areas do not know how to always use the technology efficiently. Therefore, there is no or little feedback on the machine while it's in use. Feedback is relayed only when there is a breakdown.
	Service and Troubleshooting	Most enterprises reported that **delivering of a technology is not an issue, installation is.** They highlighted that there is a **high need of trained personnels for installation and troubleshooting** across the duration of usage. This highlights opportunities for local employment available with sufficient training.
	Talent Shortage and HR Issues	Another major challenge technology enterprises face relates to a **shortage of talent and HR.** This shortage of skilled personnel and lack of expertise can hinder the development and deployment of effective technology solutions.
	Use Models	Agri-tech enterprises focus on individual sales models for technology adoption and use. However, a service model option where farmers can hire adequate technologies either from enterprises or from public/private custom hiring centres will enhance technology adoption. 90% of the sample works on individual or group sales model. Only 10% offered a service model for the farmers. "If you are working for small and marginal farmers, you should have a service model, if pain to gain ratio is 3 or more services can be scaled." (Vasanth, Hydrogreens)

Recommendations

S-M farmers constitute 89.4% of farming households and cultivate 33%[31] of cultivable land. However, according to NASSCOM only 450 Agri-Tech enterprise exist to cater mechanical needs of such vast audience[32]. Although the agriculture policy promotes technology adoption, we have some recommendations that can incentivise both hardware-based technology innovation and adoption for Agri-Tech enterprises and farmers.

Government Bodies & Policy Makers

- Current definitions of agricultural technology often exclude sector agnostic innovations vital to farming, such as battery-operated nano tractors. By revising existing guidelines, policymakers can ensure these innovations are recognised and supported within agricultural policies.

- The current tax structure for small-scale agriculture machinery may act as a deterrent to both producers and users. By reevaluating tax rates and providing exemptions or reduced rates for agricultural technology, policymakers can incentivise innovation and alleviate financial burdens on farmers. Exemptions or support are needed across the entire manufacturing process, not just the end product, to make agricultural technology more affordable.

- In addition to tax reforms, policymakers should explore avenues for providing financial incentives and subsidies to small-scale technology producers. These incentives can include grants for research and development, investment subsidies for machinery production and support for technology adoption programs. By empowering small-scale producers with financial resources, governments can catalyse innovation and drive the development of tailored solutions that address the specific needs of smallholder farmers.

- Training programs aimed at farmers on the use and maintenance of hardware-based agricultural technology are essential for successful adoption. Policymakers should invest in comprehensive training initiatives that cover not only technology operations but also troubleshooting and repair skills. By partnering with agricultural extension services, NGOs and technology providers, governments can ensure that training programs reach rural communities and are accessible to farmers of all backgrounds. Inclusive programs ensure women participation.

- Agriculture varies significantly across regions, with each locality presenting unique challenges and requirements. Public institutions play a crucial role in providing farmers access to machinery and equipment such as government operated custom hiring centres. To maximise the effectiveness of these centres, policymakers should conduct thorough need assessments of different geographic regions. By tailoring machinery availability to local farming practices and environmental conditions, governments can optimise resource utilisation and support sustainable agricultural development.

31 Hebsale Mallappa and Pathak, "Climate smart agriculture technologies."
32 Nasscom, Nasscom Tech Start-Up Report 2022 – Rising Above Uncertainty: The 2022 Saga Of Indian Tech Start-Ups (New Delhi: Nasscom, 2023), 10, https://www.nasscom.in/knowledge-center/publications/nasscom-tech-start-report 2022-rising-above-uncertainty-2022-saga.

- The availability of standardised, high-quality parts is essential for the efficient manufacturing and maintenance of agricultural machinery. Policymakers should establish standards for small part producers, ensuring that components meet quality and performance requirements. By promoting standardisation, governments can facilitate interoperability between different machinery brands and reduce downtime caused by part unavailability and gives way to more localised production.

- Small-scale technology producers often face challenges related to access to capital and market competitiveness. To support these enterprises, policymakers can implement incentive programs such as tax breaks, grants and preferential procurement policies. By creating a supportive ecosystem for small producers, governments can foster innovation, create employment opportunities and promote local economic development.

Agri-Tech Enterprises

- Technology innovators need to understand the problem statements in context to the local geographies while developing technologies as the physical environment and socio-economic ecosystem of people engaged in agricultural changes with change of location. For example, developing technology for hilly terrains should be designed to suit fragmented slopy and undulated land. Another example would be, developing technology for women farmers need much more consideration in terms of product design so that it suits well with their physical orientation.

- Enterprises working for developing hardware-based technologies for S-M farmers should explore usage models other than sales to individuals or groups. Service models like rental or subscription of hardware-based technology can enable the adoption of technology by farmers and become a good source of revenue generation for the enterprise simultaneously. A similar use model can be provided through public and private custom hiring centres that house adequate technologies.

- Technology enterprises should simplify technology user manuals and create resource for capacity building in easy to consume formats like videos. They should also tell the farmers on what indicators to notice while using these technologies so that they can provide adequate feedback.

NGO's

- NGOs should design and implement capacity-building and skill development programs tailored to the specific needs of S-M farmers such as efficient usage of technology and how to integrate technology into their farming practices.

- Recognising the financial constraints faced by S-M farmers, NGOs should work to facilitate access to financial resources for technology adoption. This can include partnering with microfinance institutions, banks and government agencies to provide farmers with access to affordable credit, loans or subsidy programs specifically earmarked for the purchase of agricultural technologies.

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