POLICY PAPER 135

Accelerating Farm Mechanization to Achieve the Goal of Viksit Bharat

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI
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Preface

Indian agriculture has evolved into a globally relevant growth story—no longer just feeding the population, but also providing nutritional and health security. However, it faces pandemics, and changing food and lifestyle habits, especially the growing disinterest of youth in traditional farming. In this context, mechanization is no longer a choice, but a necessity. Simultaneously, increasing pressure from industrialization, urbanization, and infrastructure development is causing a steady conversion of agricultural land into non-agricultural use, reducing average farm sizes. Reduced farm sizes make ownership of farm machinery economically unviable for smallholders. Despite this, there is a direct correlation between farm power availability and productivity. India's current mechanization level is at about 47%—much lower than China's 59.5% and Brazil's 75% and to become a developed nation or Viksit Bharat by 2047 India must aim for at least 75% mechanization. Therefore, mechanization must be reimagined as a comprehensive enabler across production, processing, and logistics. Efficient, scalable, and context-specific mechanization can support biomass utilization, reduce labour dependency, minimize post-harvest losses, and unlock value addition opportunities, thereby promoting rural agri-industrialization.

Globally, countries are embracing precision farming technologies using AI, robotics, GPS, and sensor-based variable rate applicators to enhance efficiency and sustainability. Mechanized nursery raising, automated harvesting with colour sensors, and value chain processes like washing, grading, drying, waxing, and smart packaging are becoming indispensable. These innovations not only ensure high farm power availability, but also reduce energy consumption per unit output due to improved productivity, making agriculture more competitive and future-ready.

In view of the above, the Academy organised a brainstorming session on "Interventions for Accelerating Indian Farm Mechanization to Achieve the Goal of 75% by 2047". I take this opportunity to thank the Convener (Dr. S.N. Jha) and Co-Convener (Dr. K.P. Singh); Reviewers (Prof. Gajendra Singh and Prof. V.K. Tewari) and Editors (Dr. V.K. Baranwal and Dr. R.K. Jain) for bringing out this document in the present form.

August 2025
New Delhi

(Himanshu Pathak)
President, NAAS

Accelerating Farm Mechanization to Achieve the Goal of Viksit Bharat

1. INTRODUCTION

Indian Agriculture is now an exemplary growth story globally. It is not only feeding the world population, but also providing nutritional and health securities. Four "Cs", i.e., Climate change, Conflict between nations, COVID or similar pandemics, and Changes in food/lifestyle habits (unwillingness of youth for doing agriculture in the traditional way) are affecting agriculture adversely. In addition, farmers are ageing; majority of them in India are aged above 40 years. The average age of an Indian farmer was 50.1 years in 2016. New generation of these farmers is not taking up traditional farm practices, essentially due to high drudgery, low profitability, and inherent uncertainties. The percentage of agricultural workers to total workers, therefore, declined from 59.1% in 1991 to 39.4% in 2021 (Fig. 1), of which about 45% or more were women. The percentage of women workers in the agricultural work force is likely to be about 65% by 2047. Draft animals on Indian farms are also getting reduced fast.

Mechanization, which is an essential part of precision agriculture, saves 15-20% seeds and fertilizers, 20-30% time, increases germination by 25%, reduces weeds and labour by 20-40%, enhances cropping intensity by 5-10% and yield by 13-23%

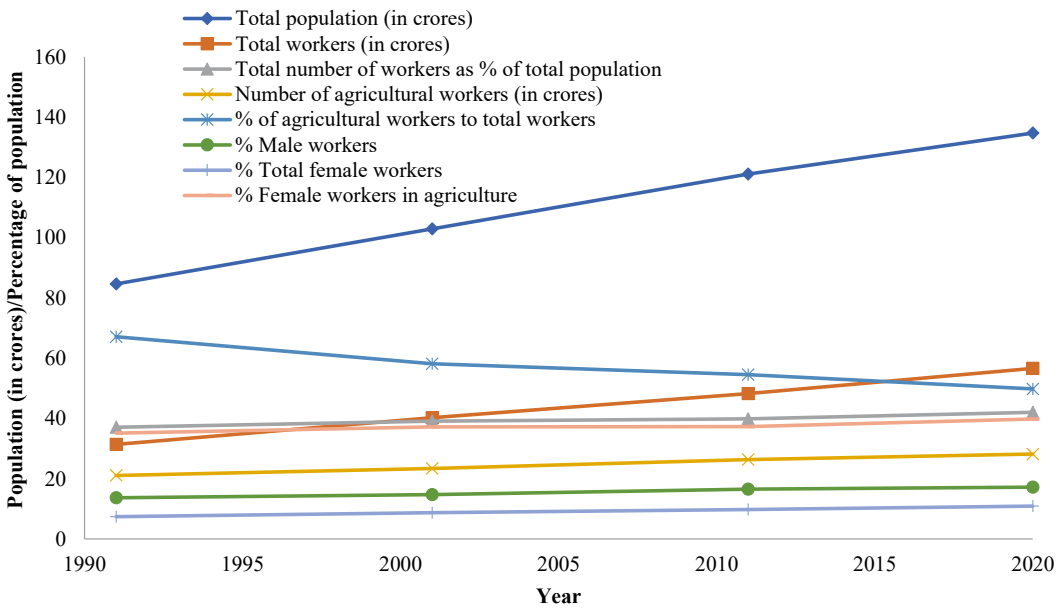

Fig. 1. Agricultural workers' dynamics (NAAS 2022; Jana and Basu, 2024)

(Singh, 2013; Tiwari *et al.*, 2019; Jha, 2023a; Jha, 2024). With India achieving significant savings at 47% mechanization level in farming (Table 1), it is evident that further improvements in agricultural mechanization will lead to even brighter agricultural scenario. Farm mechanization plays a pivotal role in enhancing cropping intensity, which is essential to meet the rising food demands of a growing population. With a view to optimizing resource utilization, reducing drudgery and labour dependency, and improving productivity, mechanization is no longer just an option but a necessity for Indian agriculture. Embracing higher mechanization levels will not only ensure food security but also drive sustainability and economic growth in the sector. In addition, it generates entrepreneurship opportunities, helps in reduction of post-harvest losses and greenhouse gas (GHG) emissions, and helps in mitigating climate change effects. The present policy paper enumerates several action points for intervention by central and state governments to achieve the mechanization targets.

2. STATUS OF AGRICULTURAL MECHANIZATION, IMPACT ON ECONOMY, AND CHALLENGES

India, despite having just 2.4% of the world's geographical area, supports approximately 17% of the human and 15% of the livestock populations globally. Agriculture in India remains a crucial sector, contributing 18% to the GDP in 2022-23, with about 45% of the population relying on it for principal source of income. However, agricultural growth (2.9% CAGR) lags industrial and service sectors, widening the rural-urban income gap. The current overall mechanization level estimated is only 47% (Table 1) and

Table 1: Percent mechanization levels of different operations in different crops

Crop	Seed bed preparation	Sowing/ Planting/ Transplanting	Weeding, Intercultural & Plant Protection	Harvesting and Threshing	Crop wise average
Rice	80	35	35	60	53
Wheat	85	65	50	75	69
Maize	70	45	40	30	46
Sorghum	60	30	20	20	33
Pulses	65	40	25	35	41
Oilseed	65	40	20	30	39
Cotton	70	40	35	-	36
Sugarcane	65	25	30	20	35
Overall	70	38	31.8	33.7	47.0

Source: Estimated and compiled by Authors based on data presented by Tiwari *et al.*, 2017; Tiwari *et al.*, 2019; Vermireddy and Choudhary, 2023

horticulture among all crops is least mechanized, particularly in harvesting and value addition operations. Mechanization levels in livestock and fishery sectors are very low.

India's GDP has seen a remarkable rise from approximately $137 billion in 1974 to over $4.27 trillion in 2024 (Fig. 2), driven by rapid industrialization, technological advancements, and a booming services sector. Agriculture, although historically the backbone of the Indian economy, has transitioned from a primary contributor to a supporting pillar, currently accounting for around 15-18% of GDP while sustaining nearly half of the workforce. To achieve a $30 trillion economy level till 2047, upward transformation of agricultural economy is crucial. Key steps include horizontal and vertical expansion of mechanization across different sub-sectors of agriculture, precision farming, enhanced irrigation infrastructure, widespread adoption of AI (Artificial Intelligence) and IoT (Internet of Things) in farming, diversification into high-value crops, boosting Agro-Processing industries, and strengthening rural supply chains. Additionally, policy reforms, land consolidation, improved credit accessibility, and investment in Agri-tech startups will enhance productivity and rural prosperity, ensuring agriculture remains a vital engine of India's economic ambitions.

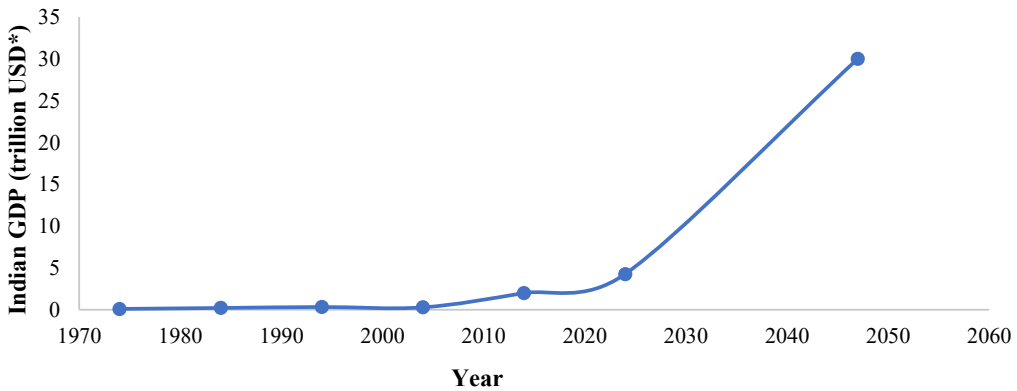

Fig. 2. Year wise GDP growth of India

*Projected GDP of India has been taken $30 trillion till year 2047

Source: https://www.macrotrends.net/global-metrics/countries/ind/india/; https://en.wikipedia.org/wiki/Economy_of_India https://databank.worldbank.org/home.aspx; https://factodata.com/gdp-of-india-1960-to-2023-a-growth-story/; https://www.mospi.gov.in/

India's economic structure has undergone a significant transformation since 1974, reflecting a shift towards a knowledge-driven economy (Fig. 3). Agricultural mechanization has played a crucial role in this transition by enhancing productivity, reducing manual labour dependency, and enabling surplus labour migration to industry and services. The adoption of tractors, harvesters, precision farming, and AI-driven technologies has improved efficiency, leading to higher yields and better income for farmers. This mechanization has directly fuelled industrial growth through demand of farm equipment and Agro-processing, while also supporting services through Agri-fintech, supply chain

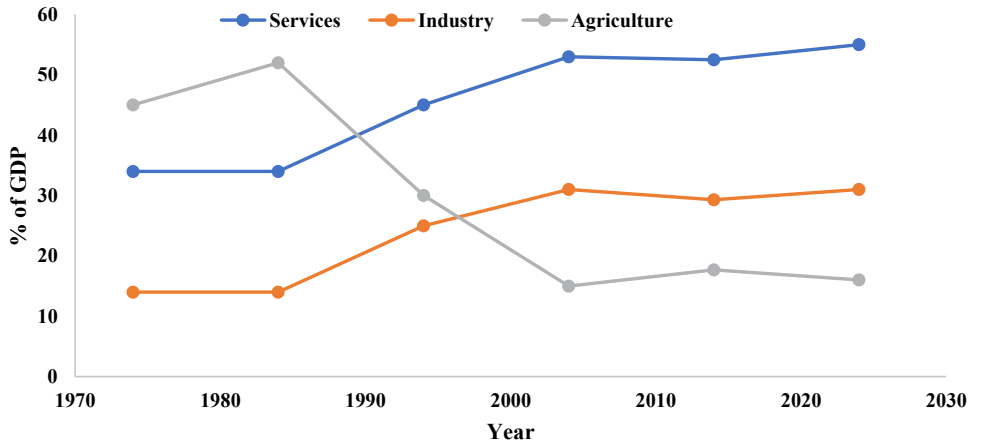

Fig. 3. Contributions of different sectors in Indian GDP (Wagh and Dongre, 2016; https://www.mospi.gov.in/data; Khan, 2021, Recent data estimated by Authors using CAGR)

logistics, and rural e-commerce. Further advancements in mechanization will be essential to sustain inclusive agricultural productivity while facilitating India's march towards a developed nation. Failing to expand the mechanization net across all the sub-sectors of Indian agriculture would throttle not only the agricultural growth in the country but the whole Indian economy.

The 58th Parliamentary Standing Committee on Agriculture, Animal Husbandry, and Food Processing (2022-23) convened a special meeting to evaluate the progress of small farm mechanization in India. Small and marginal farms constitute more than 85% of all farms in India. Therefore, mechanization solutions for small and marginal farms are a very important component of overall strategy. To address the issue of small farm mechanization, a strategic approach must be developed with inputs from site-specific management and technologies that cater to regional crops, cropping patterns, and their off-farm applications. The strategies need to necessarily include technological advancements, e.g., robotics, sensors, AI, and food processing, that continue to evolve at an unprecedented pace. A national program on agricultural mechanization must address the following challenges:

- Pace of mechanization is hindered by fragmented land holdings and the absence of mechanization-friendly crop varieties (Singh and Zhao, 2016). There are small and fragmented land holdings. The average farm size has declined from 2.82 hectares in 1970-71 to 1.08 hectares in 2015-16, making individual ownership of machinery uneconomical.
- Agricultural workforce is getting reshaped by a shifting demography marked by increasing female participation and declining interest from the younger generation.

- Regional disparities in mechanization levels and technology adoption rates persist, exacerbated by high costs, particularly for imported and large-capacity machinery. Punjab and Haryana lead in mechanization, while others lag due to policy and infrastructure gaps.
- Climate change poses challenges, affecting the mechanical, electronic, and sensor components of farm equipment while altering crop characteristics and input requirements.
- Inefficiencies in power utilization, mismatched machinery, and improper use of tractors diminish the impact of mechanization.
- Agricultural mechanization suffers from inadequate infrastructure for repair, maintenance, storage, and training at the local level. Leading to underutilization, frequent breakdowns, and productivity loss.
- Fragmentation of key departments, e.g., soil conservation, farm machinery, irrigation, food processing, energy, and value addition creates inefficiencies, with crucial areas like drainage receiving little attention.
- Poor work assignments further hinder progress, with engineers managing seed and fertilizer distribution, horticulturists handling food processing, agronomists overseeing horticultural schemes, and civil engineers tasked with minor irrigation projects. Addressing these challenges through a well-structured, technology-driven, and policy-backed approach is essential for the holistic advancement of farm mechanization in India.
- Absence of clear and well-defined farm mechanization policies and roadmaps at the state level. Difficulty in implementing a uniform national farm mechanization policy for integrating state-specific needs with broader national framework.
- Inadequate qualified manpower and institutional framework resulting in poor monitoring and implementation of agricultural mechanization schemes.
- Lack of structured mechanism at the state level to facilitate absorption and subsequent promotion of rapidly evolving agricultural technologies without long gestation periods
- There is a limited Farm Machinery Manufacturing Capacity in the country predominantly driven by small-scale industries. The machinery production lacks standardization and quality control.

There is a sense of urgency to address the aforesaid challenges effectively in a time-bound manner to achieve the mechanization targets by 2047.

3. REAPING BENEFITS OF FARM MECHANIZATION

Availability of power plays a crucial role in determining cropping intensity and overall agricultural productivity as they are directly proportional (Table 2). Reliable and sufficient power supply ensures the seamless operations of equipment, irrigation systems, and

Table 2. Cropping Intensity and Power Availability on Indian Farms

Year	Cropping intensity (%)	Grain productivity (t/ha)	Power available (kW/ha)	Power per unit production (kW/t)	Net sown area per tractor (ha)
1975-76	120.00	0.94	0.43	0.46	487
1985-86	127.00	1.18	0.65	0.55	174
1995-96	131.00	1.50	0.98	0.65	84
2005-06	132.00	1.65	1.54	0.93	47
2015-16	141.25	1.80	2.34	1.30	22
2025-26	150.49	1.95	3.14	1.67	20

Source: Singh and Sahni 2019, 2025-26 data estimated by the authors using CAGR

post-harvest processing units, all of which contribute to timeliness of agricultural operations, increased efficiency and higher yields. This underscores the importance of mechanization as a definitive solution to overcoming challenges concerning agricultural production and productivity. By integrating mechanized solutions in the existing as well as improved farming practices, farmers can optimize resource utilization, reduce labour dependency, and enhance operational efficiency, ultimately leading to higher income, improved livelihoods, and better quality of life. Therefore, promotion and investment in mechanization is not only essential for ensuring sustainable growth in agricultural output but also for enhancement of long-term economic growth in the farming sector.

On the other side of India's development story, increasing demand for industrialization, urbanization, housing and infrastructure is forcing conversion of agricultural land to non-agricultural uses. Farm holding size is continuously getting reduced, thereby, forcing the mechanization of small and non-contiguous groups of farms to go against the 'economies of scale' concept for individual ownership of farm machinery. There is a strong correlation between the farms power availability and productivity. The 58th Parliamentary Standing Committee on Agriculture, Animal Husbandry, and Food Processing (2022-23) convened a special meeting to assess the status of small farm mechanization in India and set a target to achieve 75% mechanization and 7.5 kW/ha farm power by 2047. The present overall farm mechanization level of the country is about 47% which is lower than that of other developing countries such as China (59.5%) and Brazil (75%) (Fig. 4).

Mechanized solutions equipped with sensors, AI and robotics suitable for small farms are being developed in the country. India has emerged as a net exporter of farm machinery including tractor recently. However, the country needs attention to increase the development, manufacturing, and marketing of small farm machinery, tools and machines to meet the needs for a large number of specific mechanization needs.

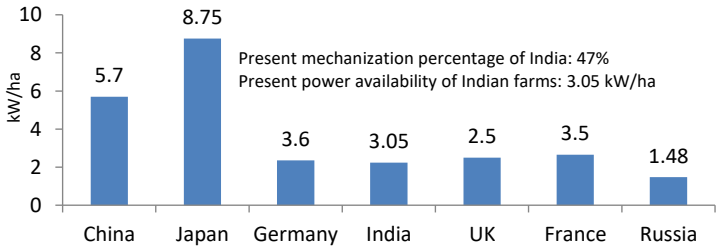

Fig. 4. Present farm Power status of some countries

(Source: NAAS 2022; Recent data estimated by the authors using CAGR)

4. MECHANIZATION AND EXPORT OPPORTUNITIES

In 2024, the Indian agricultural equipment market reached $15 billion, with projections to grow to $ 80 billion by 2047, reflecting a CAGR of 8.63%. However, AI in agriculture market is set to expand at a much faster pace, rising from $ 2.1 billion in 2024 to $ 204 billion by 2047, achieving a CAGR of 23.1% — three times the growth rate of traditional farm machinery like tractors and harvesters. This rapid expansion highlights the transformative role of AI in precision farming, automation, predictive analytics, and supply chain optimization. While mechanization will continue to enhance productivity, AI-driven innovations will revolutionize Indian agriculture by optimizing resource use, reducing wastage, and improving overall efficiency, making it a key driver in India's journey toward a knowledge-based economy.

India has emerged as the global leader in tractor production and export, driven by its strong manufacturing base, cost-effective production, and high domestic demand (Figs. 5 and 6).

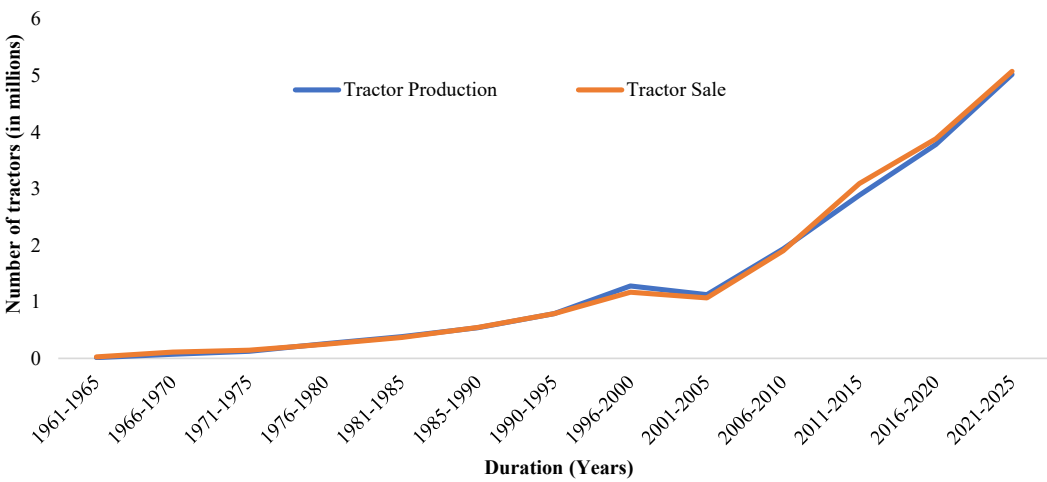

Fig. 5. Production and sale of tractors in India

(Source: NAAS 2022; https://tmaindia.in/)

Fig. 6. Tractor import and export in India
(Source: https://tmaindia.in/; https://tradestat.commerce.gov.in/)

It is manufacturing approximately one million tractors annually and exporting over 100,000 units each year. India accounts for nearly one-third of global tractor sales, making it the largest producer and consumer of tractors worldwide. Leading Indian manufacturers, such as Mahindra & Mahindra, TAFE, Sonalika, and Escorts Kubota, have established a strong presence in North America, Europe, Africa, and Southeast Asia, exporting tractors to over 100 countries (Gulati and Juneja, 2020). Strong presence of tractor manufacturers in the international market highlights India's significant role in the agricultural machinery sector.

Major destinations for Indian tractor exports include the United States of America, the Netherlands, South Africa, Brazil, and Bangladesh. The country's competitive edge lies in producing affordable, fuel-efficient, and durable tractors suited for both smallholder and commercial farming. Government support through initiatives like Make in India, Production-Linked Incentive (PLI) schemes, and export promotion policies has further strengthened India's position in the global market. Indian companies are investing in advanced technologies, precision agriculture solutions, and electric tractors, enhancing their competitiveness in international markets. With continuous innovation, strong R&D (Research and Development), and expanding global footprints, India is set to maintain its leadership in the global tractor industry, boosting both agricultural mechanization and economic growth.

While the country has immense potential for expanding its agricultural machinery production, it currently remains a net importer of such equipment when tractors are excluded. By unlocking the full potential of Indian agricultural machinery manufacturers and focusing on producing high-quality, export-standard equipment, India can further strengthen its foothold in the global market. Enhancing exports in this sector will not

only contribute to economic growth but also promote the adoption of advanced farm machinery within the country. The production, export, and import trends of tractors and agricultural machinery are illustrated in Figures 7-9.

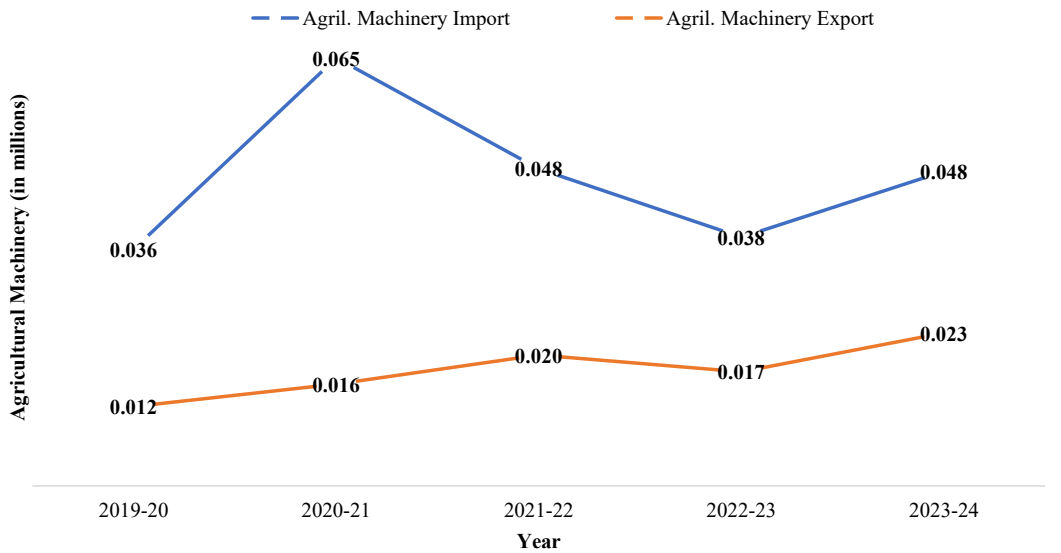

Fig. 7. Import and export of agricultural machinery, other than tractors in India

(Source: https:/tradestat.commerce.gov.in/)

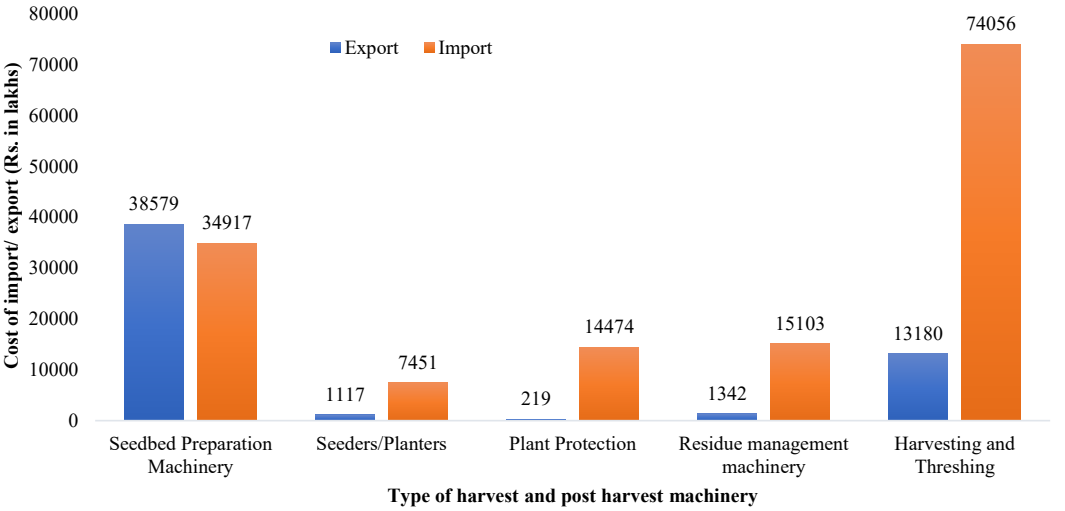

Fig. 8. Import-export of seed bed preparation machinery, planters, harvesters and residues management equipment

(Source: https:/tradestat.commerce.gov.in/)

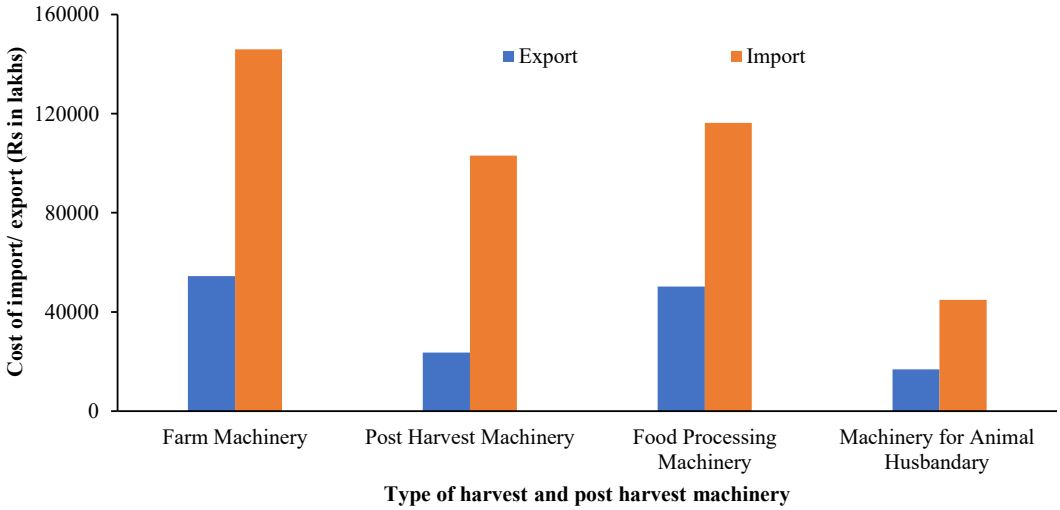

Fig. 9. Approximate sectoral export import of machinery
(Source: https:/tradestat.commerce.gov.in/)

5. EXISTING POLICY INITIATIVES AND GOVERNMENT INTERVENTIONS

Government of India has in the recent past taken several initiatives to boost agricultural mechanization in the country as indicated below:

5.1 Sub-Mission on Agricultural Mechanization (SMAM)

Launched in the XII Plan (2012-17) with a budget of Rs. 2000 crore, focusing on bringing mechanization to small and marginal farmers and promoting custom hiring services. SMAM is a government initiative aimed at promoting the adoption of modern farm machinery to enhance productivity and reduce labour-intensive practices in Indian agriculture. Launched under the National Mission on Agricultural Extension and Technology (NMAET), SMAM provides financial assistance, including subsidies of up to 50% for individual farmers and up to 80% for CHCs (Custom Hiring Centres) and FPOs (Farmer Producer Organizations), ensuring access to advanced equipment such as tractors, seed drills, harvesters, and drones. The scheme particularly benefits small and marginal farmers by facilitating the establishment of Farm Machinery Banks (FMBs) and CHCs, enabling them to hire machinery at affordable rates. SMAM promotes skill development through training programs on the efficient use and maintenance of farm equipment. Independent reviews of SMAM have indicated that the Sub-mission has been playing a crucial role in modernizing Indian agriculture and enhancing farmers' incomes, reducing manual labour dependency, improving efficiency, and minimizing post-harvest losses.

5.2 Custom Hiring Centres

The increasing demand for farm machinery during peak agricultural seasons poses a significant challenge, particularly for smallholders, leading to increased drudgery. Leveraging digital platforms for the 'Uberization' of farm equipment and custom hiring services can enhance accessibility to mechanization at farmers' doorsteps. This model benefits all stakeholders — small farmers gain easy access to machinery, while large farmers with tractors and equipment can optimize asset utilization and boost revenue. The Indian government is actively promoting mechanization through initiatives like CHCs, which have significantly improved farmers' profitability. As of October 2021, only over 70,382 custom hiring service providers and 1.64 lakh farm equipment had been registered, highlighting the need for further expansion. Additionally SMAM program is playing a crucial role in ensuring last-mile delivery of mechanization to small and marginal farmers. Given that small and marginal landholdings constitute 86% of total holdings in India, with the average operational land size declining to less than one hectare in 2025, such initiatives are essential for increasing productivity and resource efficiency in Indian agriculture.

5.3 Research and Development Initiatives

R&D in farm machinery plays a crucial role in advancing agricultural mechanization, improving efficiency, and reducing drudgery for farmers in India. Given the dominance of small and marginal farmers, constituting 86% of total landholders, the development of cost-effective, region-specific, and precision-driven farm equipment is essential. Indian government, along with research institutions and private sector players, has been actively investing in R&D to enhance farm mechanization and promote sustainable agricultural practices.

Indian Council of Agricultural Research (ICAR) and its affiliated institutes, such as Central Institute of Agricultural Engineering (CIAE) and Central Farm Machinery Training & Testing Institute (CFMTTI) have been at the forefront of farm machinery R&D. These institutions focus on developing innovative and affordable machinery suited for diverse agro-climatic conditions across India. Technologies such as small multi-functional tractors, laser land levellers, precision planters, and drone-based spraying systems are being researched and introduced to enhance farm productivity. ICAR, in collaboration with state agricultural universities (SAUs) and *Krishi Vigyan Kendras* (KVKs), is working on region-specific machinery to cater to diverse production and value addition activities.

SMAM, launched by the Ministry of Agriculture, promotes R&D and innovation in farm machinery while facilitating its adoption through subsidies and training programs. Furthermore, the National Innovation on Climate Resilient Agriculture (NICRA) project by ICAR encourages the development of climate-smart mechanization solutions to address challenges posed by climate change. The government has also set up

Agri-Startup incubation centres under the *Rastriya Krishi Vikas Yojana* (RKVY) to support entrepreneurs in farm mechanization innovations.

Private sector participation in farm machinery R&D has also gained momentum, with major companies investing in automation, precision agriculture, and digital farming solutions. Collaborative efforts between industry and research institutions have led to the development of smart farming technologies, including GPS-guided tractors, AI-driven farm equipment, and IoT-enabled monitoring systems. To ensure widespread adoption of R&D-driven innovations, the government has emphasized capacity building and training programs. Agricultural mechanization training centres across the country provide skill development programs for farmers, machinery operators, and rural youth, enabling them to efficiently use and maintain modern farm equipment. Strengthening research efforts, promoting public-private partnerships (PPPs), and scaling up innovative solutions will be key to enhancing farm productivity, ensuring resource efficiency, and making agricultural mechanization accessible to all, especially small and marginal farmers.

5.4 State Government Mechanization Programs

State governments in India play a crucial role in promoting farm mechanization by implementing region-specific policies and programs tailored to the needs of their agricultural landscapes. Recognizing the importance of mechanization in enhancing productivity, reducing labour dependency, and improving farm efficiency, various states have launched dedicated schemes to make modern agricultural equipment accessible to farmers, especially small and marginal landholders. These programs complement central government initiatives such as the SMAM and CHCs by offering subsidies, financial assistance, and training to encourage mechanization adoption.

Several states have introduced custom hiring service models to facilitate access to farm machinery. For instance, Punjab and Haryana, known for their high mechanization levels, have promoted initiatives like subsidized tractor and equipment banks, and incentives for conservation agriculture tools such as Happy Seeders and Super SMS to curb stubble burning. Uttar Pradesh and Bihar have implemented programs to support smallholder farmers through subsidies on power tillers, seed drills, and irrigation pumps, ensuring mechanization reaches fragmented landholdings.

In southern India, Tamil Nadu's Farm Mechanization Scheme provides up to 50% subsidy on various agricultural implements, along with training programs for farmers to enhance machinery utilization. Karnataka's Krishi Yantra Dhare program has set up custom hiring centres across districts, allowing small and marginal farmers to hire equipment at affordable rates. Similarly, Andhra Pradesh and Telangana have focused on digital platforms and cooperative models to promote mechanization, offering financial aid for drones, harvesters, and precision farming tools.

In eastern and north-eastern states, where mechanization has traditionally lagged, state governments are actively promoting farm machinery adoption. West Bengal's Matir Katha initiative integrates farm mechanization with crop planning, while Assam and Odisha offer heavy subsidies on small-scale equipment such as power weeders, transplanters, and mini rice mills to cater to local farming needs. Jharkhand and Chhattisgarh have established agri-machinery banks in rural areas to ensure availability of essential tools.

Madhya Pradesh, Maharashtra, and Gujarat have also launched extensive farm mechanization subsidy programs. Maharashtra's Dr. Panjabrao Deshmukh Agricultural Mechanization Scheme provides financial support for purchasing modern equipment, while Gujarat promotes solar-powered agricultural machinery to encourage sustainable farming practices. Rajasthan's Agro-Processing and Farm Mechanization Scheme facilitates large-scale mechanization adoption through subsidies and cooperative models.

To further streamline access to farm machinery, many states have introduced mobile apps and digital platforms to connect farmers with machinery service providers. These platforms, similar to the central CHC Farm Machinery Mobile App, ensure that smallholder farmers can hire equipment within their locality at subsidized rates. State governments conduct awareness campaigns and training workshops to educate farmers on the benefits of mechanization and proper use of modern equipment. With increasing farm power availability and growing mechanization demand, state government initiatives play a vital role in bridging the mechanization gaps across different regions. Strengthening financial incentives, expanding rental services, and integrating digital solutions will be key to ensuring that every farmer, regardless of landholding size, has access to modern farm machinery to enhance productivity and profitability.

5.5 Promotion of Gender-Inclusive Mechanization

Women constitute about half of the agricultural workforce today and their share is going to increase further. Therefore, gender-inclusive mechanization is essential for effective participation of women in agriculture. Contribute significantly to various farming operations, including sowing, transplanting, weeding, harvesting, and post-harvest processing. However, traditional farm tools and machinery had historically been designed considering the ergonomic needs and physical capabilities of men. Use of the same tools and machines by women workers, therefore, may not suit them leading to increased drudgery and reduced efficiency. To address this challenge, Indian government, state agencies, and research institutions are attempting to make gender-friendly farm mechanization available through policy interventions, technological innovations, and capacity-building programs.

ICAR and CIAE have been actively involved in designing and developing women-friendly farm equipment, such as lightweight power weeders, pedal-operated threshers, seed drummers, and ergonomic sickles, which reduce physical exertion and improve work

efficiency. Additionally, the All India Coordinated Research Project on Home Science (AICRP-HS) focuses on designing farm tools that enhance safety, comfort, and ease of operation for women farmers.

Under the SMAM, the Indian government provides financial assistance and subsidies for women farmers to procure gender-friendly farm machinery. States like Tamil Nadu, Karnataka, Odisha, and Maharashtra have introduced special schemes offering higher subsidy rates (up to 50-60%) for women farmers on agricultural equipment, promoting their access to mechanization solutions. CHCs and cooperative models have also been established exclusively for women's SHGs (Self Help Groups) and FPOs, enabling collective ownership and shared use of farm machinery. Digital platforms are further strengthening gender-inclusive mechanization by connecting women farmers to rental services for farm equipment. The CHC Farm Machinery Mobile App allows women to access agricultural tools on a pay-per-use basis, eliminating the need for upfront investment in costly machinery. Agri-startups and NGOs are playing a pivotal role in training women in operating farm machinery, thereby promoting their active participation in mechanized farming.

To encourage gender-inclusive mechanization, extensive training and skill development programs for women are being conducted by KVKs, Agricultural Technology Management Agencies (ATMAs), and rural training centres. These initiatives focus on building technical knowledge and hands-on experience for women in operating and maintaining modern farm equipment. Bringing gender-inclusive mechanization to the doorsteps of women farmers and workers will not only enhance farm productivity but also empowers women economically by enabling them to engage in agri-preneurship, mechanized farming services, and post-harvest processing enterprises.

6. STRATEGIES FOR ACHIEVING 75% AGRICULTURAL MECHANIZATION BY 2047

As shown earlier, higher level of agricultural mechanization is linked to higher agricultural productivity and profitability leading to a higher rate of agricultural growth in the country. Parliamentary Standing Committee on Agriculture, in their wisdom, set the target of 75% level of agricultural mechanization in India to be achieved by 2047. Considering the wide gap between the existing and the targeted levels of agricultural mechanization for bridging by 2047, there is need for well-orchestrated strategic interventions at government, industry, and farmers' levels.

6.1 Establishment of Directorate/Department of Agricultural Engineering in each State of the Country

Establishing a Directorate of Agricultural Engineering is essential to drive systematic planning, implementation, and monitoring of agricultural mechanization and engineering interventions at ground level. A dedicated Directorate would serve as a central

coordinating body to integrate research, policy formulation, and field-level execution of mechanization programs, ensuring greater accessibility of advanced farm machinery to small and marginal farmers.

With rapid advancements in precision agriculture, AI-driven automation, and climate-resilient mechanization, there is a pressing need for a specialized institution in each state to bridge the gap between innovation and practical implementation. Such an institution in the form of a Directorate in the state would work in collaboration with ICAR institutes, SAUs, KVKs, and private sector stakeholders to promote research, training, and capacity building in agricultural mechanization. The Directorate/ Department would also help in strengthening CHCs, facilitating PPPs, and ensuring efficient disbursement of financial incentives for the mechanization services.

A well-structured Directorate is envisaged to play key role in monitoring regional mechanization trends, assessing regional requirements, fostering innovation, enhancing institutional support, formulating data-driven policies, and streamlining policy execution.

6.2 Promoting Precision and Smart Farming Technologies

Precision and Smart Farming Technologies are today available to keep pace with the latest technological developments for enhanced agricultural mechanization in India. Precision farming techniques leverage GPS-guided tractors, AI-powered automation, IoT-based monitoring, and drone technology to enable site-specific farm management, optimal input utilization, and reduced operational costs. Smart sensors and data-driven analytics help farmers monitor soil health, detect crop stress, and optimize irrigation and fertilizer applications in a sustainable manner.

Government initiatives like the Digital Agriculture Mission, coupled with PPPs and Agri-tech startups, can accelerate the adoption of smart farm machinery, autonomous equipment, and robotics. Expanding financial incentives under the SMAM for AI-integrated farm tools, automated seeding systems, and smart harvesting solutions will encourage next generation of farmers to embrace the state of art mechanization. Integration of precision agriculture into CHCs and cooperative models will make advanced technology conveniently accessible to small and marginal farmers.

6.3 Strengthening Institutional Framework

Strengthening the institutional framework is crucial for achieving the goal-post set for 2047. This requires a multi-dimensional approach involving policy framework, R&D, financial accessibility, digital innovations, and skill development. Expanding the SMAM with increased budget allocations and targeted subsidies will facilitate wider adoption of mechanization, particularly among small and marginal farmers. Research institutions like CIAE, and SAUs must be empowered to develop affordable, energy-efficient, and climate-resilient farm machinery, while PPPs should drive innovation in AI, IoT, and automation-based mechanization.

Scaling up CHCs, FPOs, and SHG-led cooperative models will ensure shared access to expensive farm equipment, bridging the mechanization gap. Enhancing digital platforms like the CHC Farm Machinery Mobile App, integrating blockchain and AI-based solutions, and expanding financial assistance through subsidized loans, microfinance schemes, and solar-powered equipment incentives will further boost mechanization adoption. Additionally, KVKs and farm machinery training centers must focus on capacity building to equip farmers, rural youth, and entrepreneurs with technical expertise in modern equipment usage and maintenance. Establishing a National Mechanization Mission (NMM) to monitor progress, evaluate adoption rates, and recommend policy interventions will be a game-changer in this endeavor. The National Mechanization Mission could create functional linkages among central and state governments, research bodies, financial institutions, and private stakeholders for realization of the intended results.

6.4 Make in India Initiative for Agricultural Machine Manufacture

With a view to ensure high rate of improvement in the level of agricultural mechanization in India between now and 2047, domestic manufacturing of agricultural machines and equipment needs a boost. India has been importing agricultural equipment either as complete units or in parts. Though this helps Indian Agriculture, it is important that a conducive ecosystem is created for indigenous manufacturing to provide machines and equipment at affordable cost.

Most of the Agricultural machinery and equipment excluding tractors, combine harvesters, and food processing machines are manufactured and supported by MSME. Most Agricultural tools, processing and mechanical/ electrical accessories are supported by tiny industries. It is necessary to ensure sustained growth in these sub-sectors. While most of these are manually operated today, we need to convert them to power operated. Then, there is need to upgrade our hardware and software to the level of precision farming to achieve conservation of water, fertilizer and chemical inputs. For an example, although there are several irrigation pump manufacturers in India today, the need is there to incentivize efficiency improvement of these pumps. Sustainable automation is required in water and fertilizer applications. Following are a few suggested steps to improve our indigenous agricultural mechanization industry:

(i) Standardization of equipment is an important factor to be considered from the beginning while promoting local manufacturing. Though several initiatives are already taken to increase testing facilities, the increase in cost of testing should not be a discouraging factor. We should consider subsidizing testing costs to incentivize manufacturers. We should encourage Indian manufacturers to adopt BIS standards in a structured way.

(ii) Currently, many suppliers avail themselves of subsidies offered by the State and Central government for importing and distributing imported equipment and machinery. This adversely affects local manufactures and in fact discourages them

as imported machines are produced in large volumes in those countries. It is proposed to discontinue subsidies on imported equipment. Government subsidies must be permitted only for Indigenously manufactured products. If necessary, there should be a timeline for complete indigenization of agricultural machinery manufacturing in India and the percentage use of imported components could be phased out.

(iii) Many imported machines are relabeled to show them as manufactured in India. This affects fair competition by Indian manufacturers. Proper administrative steps are required to monitor and control such manufacturers and products.

(iv) Support must be extended like capital assistance and subsidies to the MSME manufacturers to promote Make in India initiative. Similar assistance is also required in plant construction and the procurement of manufacturing equipment.

(v) Farm mechanization is an interdisciplinary activity and there is need to promote co-operation between manufacturers and research institutions. It is important to facilitate development of equipment suitable for Indian conditions and practices. This involves grants and financial incentives for research projects aimed at optimizing agricultural inputs and reducing agricultural wastage and credits for researchers who collaborate with industries.

(vi) Currently subsidies are offered to farmers to buy equipment. Though Custom hiring centers are promoted and subsidies offered to procure equipment, they face challenges in servicing and upgrading equipment. Most of the farm equipment needs are seasonal. We should consider subsidizing 'Services' instead of purchase of equipment. For example, instead of subsidizing a farmer to purchase a sprayer, the subsidy can be given to a CHC or even a Manufacturer- Service provider for carrying out the spraying operation on a farmer's field.

6.5 Encouraging Public-Private Partnerships

Encouraging PPP is crucial for accelerating farm mechanization in India, ensuring widespread access to modern agricultural equipment, and bridging the gap between innovation and implementation. Private sector, with its expertise in technology development, manufacturing, and service delivery, can complement government efforts in scaling up mechanization, improving affordability, and expanding reach to small and marginal farmers. PPP models can facilitate the establishment of CHCs, machinery rental services, and agri-tech startups that provide farm equipment on a pay-per-use basis, reducing the financial burden on individual farmers. Collaborations between government institutions like ICAR, SAUs, and private manufacturers can drive R&D in precision agriculture, AI-driven automation, and climate-smart mechanization. Digital platforms backed by PPP initiatives can further improve farm machinery access, predictive maintenance services, and data-driven advisory solutions for farmers. By leveraging

financial incentives, joint ventures, and technology-sharing agreements, PPPs can play a vital role in enhancing mechanization adoption, skill development, and infrastructure creation, ultimately contributing to the higher farm mechanization levels.

6.6 Enhancing Financial Support and Credit Facilities

Enhancing financial support and credit facilities to local manufacturers is essential for accelerating agricultural mechanization in India, especially for small and marginal farmers, who often face financial challenges in accessing modern farm equipment. Expanding subsidized loan schemes, low-interest financing, and microfinance options under initiatives like the Agriculture Infrastructure Fund (AIF), RKVY, and NABARD-supported credit programs can significantly boost mechanization adoption. Increasing direct benefit transfers (DBTs) and higher subsidy rates for farm machinery under the SMAM will further ease the financial burden on farmers.

Encouraging collaborations with banks, NBFCs, and fintech startups to develop customized credit solutions, flexible repayment models, and digital loan processing can ensure faster and more accessible financing for farm equipment purchases. Additionally, strengthening PPPs to create leasing and rental models through CHCs and Agri-Tech platforms will allow smallholders to access mechanization without heavy capital investment. By improving financial accessibility, introducing risk-mitigation measures like insurance for farm machinery, and ensuring timely credit disbursement, the government can effectively drive higher mechanization levels.

6.7 Developing Skilled Workforce

Developing a skilled workforce is crucial for accelerating agricultural mechanization in India, ensuring the efficient operation, maintenance, and management of modern farm machinery. With the increasing adoption of precision farming, AI-driven automation, and IoT-enabled equipment, there is a growing need for technically skilled personnel, machine operators, and rural agri-technicians. Expanding training programs through KVKs, Farm Machinery Training & Testing Institutes (FMTTIs), and ATMAs will equip farmers and rural youth with hands-on experience in mechanized farming, drone technology, and smart irrigation systems.

PPPs with agri-tech startups, machinery manufacturers, and skill development organizations can further enhance on-the-job training, certification courses, and apprenticeship programs tailored to farm mechanization. Additionally, integrating mechanization-focused curricula in agricultural universities, ITIs, and vocational training centres will create a pool of skilled professionals ready to support India's mechanization drive.

6.8 Establishing Rural Mechanization Hubs

Establishing Rural Farm Mechanization Hubs is a transformative step toward enhancing agricultural mechanization in India, particularly for small and marginal farmers who lack

access to modern farm equipment. These hubs, set up at the village or block level, will function as one-stop centres providing farm machinery rental services, training programs, repair and maintenance facilities, and digital advisory support. By integrating CHCs, FPOs, and SHGs, these hubs can enable collective ownership and cost-effective access to agricultural machinery.

Leveraging PPPs and government support under the SMAM will ensure that these hubs are equipped with advanced technologies, IoT-enabled farm tools, and AI-driven automation solutions. Additionally, they will serve as skill development centres, training farmers and rural youth in modern mechanization practices, smart farming techniques, and machinery maintenance, thereby generating employment opportunities. Strengthening rural mechanization hubs will bridge the mechanization gaps.

6.9 State-Specific Policy Interventions

Considering the diverse agro-climatic conditions, cropping patterns, and farmer demography across different regions, State-specific policy interventions are essential for driving agricultural mechanization in India. Each state must design customized mechanization solutions that cater to its unique agricultural needs, ensuring targeted subsidy distribution, region-specific equipment promotion, and localized R&D. States with high labour shortages, such as Punjab and Haryana, should focus on automation and precision farming, while states with small and fragmented landholdings, like West Bengal and Kerala, should promote compact and multi-functional farm machinery.

Expanding the networks of state-funded CHCs, FPOs, and cooperative models can ensure shared access to expensive machinery for smallholders. Additionally, states should incentivize agri-tech startups, PPPs, and skill development programs to enhance technology adoption. Strengthening financial support through state-level credit schemes, interest-free loans, and flexible financing options will further boost mechanization. By implementing data-driven policies, monitoring mechanization trends, and integrating digital platforms for equipment rental and advisory services, state governments can effectively complement national efforts to achieve the desired mechanization levels by 2047.

6.10 Focus on Renewable Energy in Agriculture

To achieve India's net-zero emission target by 2070, solar and biomass energy will play a crucial role in the agricultural sector. With India's solar energy potential reassessed at 4000 GW and an installed capacity of 100 GW, the agro-voltaic solar system can significantly contribute to securing energy needs in agriculture. However, adopting agri-voltaics requires redesigning farm equipment and machinery to adapt to limited space, necessitating government policies that provide financial support for energy generation without compromising grain productivity. Additionally, crop residues hold the potential to produce 50 million tonnes of hydrogen annually, and decentralized biogenic hydrogen

production can drive rural economic growth, contributing to India's vision of becoming a developed nation by 2047.

Renewable energy-based technologies must be developed and integrated into farm activities such as field operations, irrigation, and primary processing to reduce carbon footprints. Mechanization should focus on enhancing productivity with minimal energy and resource inputs, necessitating a structured timeline for transitioning from conventional to renewable energy in farming. Policies for hill agriculture and horticulture should adopt a renewable energy-centric approach for sustainable development. Large-scale field demonstrations of renewable technologies, such as PCM-based energy storage, high-temperature concentrators for industrial green steam generation, and portable solar-based off-grid cold storage, are essential. Advancements in battery materials like sodium phosphate should be explored for high-density energy storage. Additionally, improving fuel properties of crop residues to align with the SAMARTH scheme will enhance their utilization in thermal power plants.

A comprehensive gap analysis is necessary for the effective dissemination and deployment of farm machinery nationwide. The integration of automation, artificial intelligence, and the IoT with renewable energy and farm machinery is crucial for attracting youth to the agricultural sector. Finally, establishing a dedicated Renewable Energy discipline under the National Agricultural Research and Education System (NARES) is essential to train skilled professionals who can address the dynamic challenges in the renewable energy sector within Indian agriculture.

7. RECOMMENDATIONS

Status of agricultural mechanization in the country, bottlenecks in its growth, future needs, and pathways to reach the destination have been addressed in the foregoing sections. Followings are the recommendations for implementation by Government and other agencies:

- To accelerate the pace of farm mechanization in India, a comprehensive national survey must be conducted periodically, say every five years, to assess the actual mechanization levels, available farm machinery, and its utilization patterns.
- In view of the emerging scenario of agricultural mechanization and related technologies, a National Institute of Agricultural Robotics and AI in Agriculture needs to be established to drive research and innovation to benefit agriculture.
- Strengthening the engineering cadre scientists in NARES – A threshold numbers should be decided and appointed. In view of the multifold expansion of agricultural mechanization landscape, the present strength of agricultural engineering scientists needs to be tripled.
- To bridge the gap in the availability and the demand in skilled manpower, B. Tech and diploma programs in Agricultural Engineering should be introduced in all SAUs, IITs, and NITs.

- To establish Directorate/Department of Agricultural Engineering in each state encompassing on-farm mechanization, post-harvest processing, value addition, farm irrigation including micro-irrigation, drainage, and soil conservation.
- Appointment of agricultural engineers at block and district levels in adequate numbers is essential to ensure their availability at field level for successful implementation of mechanization programs.
- Each KVK must necessarily have the post of agricultural engineer to liaise with the local stakeholders in promoting regionally differentiated agricultural mechanization.
- An independent and dedicated scheme at both central and state levels should be launched, focusing on mechanization of field operations, on-farm post-harvest operations, primary processing, and value addition, including dairy and fishery mechanization, as recommended by the Parliamentary Committee.
- Subsidies on imported agricultural machinery must be curtailed in order to promote local manufacturing – Make in India and Atma Nirbhar Bharat. Subsidies on "Services" rather than "Purchase of Equipment" to be considered, as it will strengthen 'custom hiring' and 'Rent to hire' models to improve service and upgradation of equipment. The local manufacturers shall be provided assistance in testing fees to promote standardization. Credit facilities for local manufacturing have to be enhanced. Production linked Incentive (PLI) scheme should be launched for manufacturing agricultural machinery in areas such as Northeastern states, Eastern states, etc. where minimal or no manufactures are locally available.
- Scheme of custom hiring centres for farm machinery and post-harvest machinery for primary processing should be promoted more vigorously
- Each state should establish at least one Farm Machinery and Post-Harvest Machinery Testing Centre at the district level to ensure quality standards and performance validation
- Farm machinery repair and maintenance centres, at least one in each Panchayat, should be opened in PPP mode to enhance machinery longevity and operational efficiency.
- Awareness programs should be organized to educate farmers on the benefits of proper machinery utilization.

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