Improving the Well-being of Small and Marginal Farmers through Regenerative Agriculture

MITRA Strategy (2026-30)

Scaling resilient, low-emission farming systems to secure rural incomes and restore natural ecosystems

1. Context

Dr. Reddy's Foundation (DRF) is a not-for-profit organization focused on enhancing the dignity and well-being of socially and economically vulnerable people. Set up in 1996 by Dr. K. Anji Reddy, DRF has directly affected more than 1.6 million lives in the past 27 years (indirect impact 8 million) in the areas of – Education, Livelihoods, Health, and Climate Action. Dr. Reddy's Foundation, through its major flagship program, MITRA (Making Integrated Transformation through Regenerative Agriculture) addresses food security and climate change through the promotion of regenerative agriculture under the livelihoods theme. In MITRA, we promote climate-resilient agricultural practices to achieve food security and sustainably increase farm income while reducing negative environmental impacts. The program improves farmers' income and overall well-being by promoting regenerative agriculture practices through community based service delivery of strong farmer-farmer extension system (Lead Farmers Platform) backed by public/ private extension system, with a major focus on soil health, alongside complementary on-farm and off-farm activities, and results in co-benefits in the form of environmental and economic resilience for the farmers.

Our Story of Change and Impact

Veerendra Kachi, from the village of Mohari in the Jabalpur district, was once caught in a cycle of poor economic conditions common to small and marginal farmers. He faced the compounding difficulties of high cultivation costs, low yields, and degraded soil quality. His situation was further complicated by erratic monsoon rainfall, decreasing groundwater levels, and long dry spells in the region. Like many in his position, he lacked the training to think and act like an agripreneur and struggled with a lack of market access and an inability to secure the right price for his produce due to his small landholding.

Recognizing Veerendra's eagerness to learn and willingness to support his peers, DRF's MITRA program identified him as a Lead Farmer. The Lead Farmer methodology leverages the trust and social closeness between fellow farmers to facilitate wider dissemination and sustained adoption of regenerative agriculture practices. Veerendra was trained in a new regenerative agricultural system that focuses on restoring soil health, capturing carbon, and improving the water cycle rather than just "sustaining" the status quo. Instead of depleting the land, these systems treat the farm as a living ecosystem. To achieve this, a farmer needs to adopt conservation land preparation techniques, like Zero Tillage (ZT) for wheat cultivation, Dry

Direct Seeded Rice (DSR) for paddy crops, and introducing Cover Crop in summer season. Additionally, soil test based nutrient application will further improve the soil health. He was also trained on how to demonstrate these techniques to others, becoming a messenger for the program and helping to bridge the gap between scientific knowledge and field interventions.

The impact of these interventions on Veerendra's life has been transformative. Over the past four years, he has evolved from a struggling smallholder into a successful agripreneur. Originally managing only 5 acres of owned land, his transition to regenerative farming gave him the confidence to take an additional 15 acres on lease, bringing his total cultivated area to 20 acres.

For wheat cultivation, he previously used the broadcasting method, which required land preparation with a cultivator and rotovator at a cost of ₹3,800 per acre. He transitioned to Zero Tillage (ZT) using a Happy Seeder for direct sowing across all 20 acres, which reduced his sowing cost to ₹1,800 per acre. This change resulted in a saving of ₹2,000 per acre per season on sowing costs for wheat. For the paddy crop, he moved from transplanting (which cost ₹9,500 per acre) to Direct Seeded Rice (DSR) on 7 acres. This shift reduced his land preparation and sowing costs to ₹2,800 per acre per season, creating a saving of ₹6,700 per acre for paddy. The economic growth resulting from increased production and lower inputs allowed him to invest in a Happy Seeder and a Combined Harvester, turning his farming into a viable enterprise.

Veerendra's approach to nutrient management also changed significantly after adopting Zero Tillage and utilizing the recommendations from the soil sample testing report at DRF's Soil Testing Resource Centre (SRTC) lab. Because Zero Tillage reduces soil disturbance, conserves moisture, and enhances soil health, he has been able to save significantly on fertilizer application. In his wheat fields, over the years, he has saved almost 15–20% on fertilizer application. The introduction of a summer cover crop further helped improve the soil biodiversity and water moisture while reducing soil erosion during the dry summer. The Zero Tillage method additionally helped improve soil structure. Since the paddy crop is cultivated immediately after the cover crop, soil sample test reports confirmed that the micronutrients were better in the field, and he now saves almost 25–30% annually on fertilizer application in the paddy field. The economic impact due to the reduction in input and labor costs alone helped Veerendra save approximately INR 1,31,775 in 2025 for his 20-acre land. His additional income due to higher yields as a result of all the interventions almost reached INR 16,000–INR 18,000 per acre.

Beyond his own success, Veerendra has acted as a catalyst for adoption in his village, providing technical support to close to 50 Fellow Farmers and proving that the Lead Farmer Platform can effectively scale sustainable agriculture at the village level. Veerendra's story illustrates the transformative potential of a consolidated regenerative agricultural system—integrating DSR, ZT, and cover crops—as demonstrated by the transition of a marginal farmer into a successful agripreneur. By treating the farm as a living ecosystem, this holistic approach addresses the critical nexus of soil health, water conservation, and climate resilience. The implementation of ZT and DSR significantly reduces soil disturbance and methane emissions while enhancing carbon sequestration and moisture retention. The

inclusion of summer cover crops further bolsters soil biodiversity and prevents erosion during dry spells, creating a natural nutrient cycle that has reduced the need for synthetic fertilizers. These interventions collectively mitigate the impacts of erratic monsoons and declining groundwater, serving as a scalable blueprint for resilient, sustainable, and income-secure food systems, while integrating a co-benefit approach into the interventions.

Therefore, for the regenerative agriculture strategy, similar cases from different project locations demonstrate how a carefully designed, off-farm yet land-linked enterprise can simultaneously:

- Create new income streams for marginal and landless households using agricultural residues.
- Increase women's economic participation and decision-making space within the household through home-based production and controlled marketing.
- Improve household nutrition via higher protein intake and diversified diets.

Agriculture is at the heart of India's economic stability, ensuring food security, creating jobs, and fostering ecological resilience. The sector is a vital pillar of the economy, employing nearly 44% of the workforce, contributing approximately 18% to the national Gross Value Added (GVA), and sustaining the livelihoods of more than 100 million small and marginal farming households (86% of holdings with an average size of about 1.1 ha). Indian agriculture is currently grappling with increasing structural and systemic challenges. These pressures stem from climate change, water scarcity, land degradation (affecting ~30% of land or 97.85 million ha), escalating input costs, labour shortages, and a decline in factor productivity. The challenges at hand pose a significant risk to the realization of our national development goals, such as enhancing farmers' incomes, fulfilling climate commitments outlined in India's Nationally Determined Contributions (NDCs), and advancing towards the Sustainable Development Goals (SDGs).

India stands out as one of the most climate-vulnerable nations in the world (9th in the Climate Risk Index for 1995–2024). Also, agriculture and related sectors account for about 13.72% of the nation's greenhouse gas emissions, primarily stemming from rice farming, livestock production, fertilizer application, and changes in land use. At the same time, almost 52% of India's cultivated land relies solely on rainfall, while more than 60% of irrigation comes from groundwater extraction, creating significant pressure on water resources (irrigation efficiency remains low at 30–65%). Government estimates reveal that more than 97.85 million hectares, accounting for ~30% of the total land area, are impacted by land degradation. This leads to a decline in soil organic carbon (less than 5% of soils have adequate nitrogen; only about 20% have sufficient organic carbon), decreased nutrient-use efficiency, and diminished resilience to climate shocks.

2. Current Challenges

2.1. Predominance of Small and Marginal Landholdings

Indian agriculture is dominated by small and marginal farmers, who constitute nearly 86% of all operational holdings, with an average farm size of about 1.1 ha. Such fragmentation severely limits economies of scale, reduces bargaining power in input and output markets, and constrains the adoption of mechanisation, precision agriculture, and modern irrigation systems. Small landholdings also increase

transaction costs for aggregation, insurance, and credit delivery, making farmers more vulnerable to climate shocks and market volatility. Based on recent Garrett Ranking studies (2025-2026) among Indian smallholders, it is evident that information, financial, structural, and institutional gaps are predominant constraints restricting small and marginal farmers from adopting climate-smart technologies.

Table 1. Key Constraints Restricting Adoption of Climate-Smart Technologies Among Indian Smallholders (Garrett Ranking Studies, 2025-2026)

Rank	Constraint Category	Specific Primary Issue
I	Information	Lack of timely, hyper-local weather & technical advisories.
II	Financial	High cost of inputs and lack of affordable, timely credit.
III	Structural	Small, fragmented landholdings prevent mechanization.
IV	Institutional	Inadequate training and lack of access to "Smart Seeds."

2.2. Heavy Dependence on Non-Renewable Input Sources

Over the last three and a half decades, global commercial energy consumption has surged by more than 75%, reflecting accelerating demand across all production sectors. According to the International Energy Agency (IEA), the industrial sector's share of total energy use has declined by about 9% since 1980–81, while agriculture's share has gradually risen—making it one of the fastest-growing energy-consuming sectors worldwide. In India, agricultural energy consumption increased at an annual average growth rate of 4.4% between 2014–15 and 2023–24, driven by expanding irrigation, mechanization, and input-intensive practices. This trend underscores agriculture's growing vulnerability to global fuel price fluctuations and supply disruptions.

The sector's heavy dependence on non-renewable, fossil-fuel-based inputs—including synthetic fertilizers, pesticides, and diesel-powered equipment—poses serious sustainability challenges. India, the world's second-largest consumer of chemical fertilizers, applies roughly 60 million tonnes annually, yet nutrient use efficiency remains as low as 30–50%. Such inefficiency not only inflates production costs but also contributes to soil degradation, groundwater contamination, and elevated greenhouse gas emissions, undermining long-term soil fertility and environmental health. Presently, agriculture accounts for nearly 5–7% of India's total primary energy consumption, mainly from groundwater pumping, machinery operation, and post-harvest processing. If current trends continue, the sector's energy requirement is projected to rise from 1.8–2.0 kW/ha today to nearly 2.5 kW/ha over the next two decades.

This growing energy intensity in agriculture exacerbates climate impacts through fossil fuel combustion and rising emissions of carbon dioxide, nitrous oxide, and methane. Transitioning from non-renewable to renewable and circular energy systems has therefore become a strategic necessity. India's abundant renewable energy resources—particularly solar, wind, and biomass—present viable alternatives. Currently, renewable power sources constitute nearly half (about 254 GW of 510 GW) of India's total installed electricity capacity, with initiatives like the National Solar Mission catalyzing renewable integration in rural and agricultural sectors.

Harnessing renewables to power agriculture, alongside improved nutrient and water-use efficiency, can dramatically reduce fossil fuel dependence. Such a shift not only mitigates emissions but also strengthens the economic resilience of small and marginal farmers by lowering input costs and stabilizing production under climate stress. Embedding these transitions within regenerative agriculture and energy-smart farming frameworks ensures that productivity gains are coupled with ecosystem restoration, energy security, and farmer wellbeing.

2.3. Energy-Inefficient Agriculture Practices

Agricultural operations such as land preparation, irrigation pumping, fertilizer manufacture and use, and post-harvest handling are among the most energy-intensive activities in food production. Studies show that energy-related inputs can account for up to 80% of total production costs in some cereal systems, making farmers highly vulnerable to fuel price fluctuations. For India's smallholders, this energy dependence not only drives higher emissions but also undermines profitability, resilience, and long-term sustainability.

The rice–wheat rotation in the Indo-Gangetic Plains (IGP), covering around 10.5 million hectares and serving as India's primary food and livelihood base, exemplifies this challenge. Intensive tillage, manual rice transplantation, and excessive irrigation collectively consume vast amounts of diesel and electricity. For instance, puddled transplanted rice (PTR) alone uses up to 25–30% of total irrigation water, while maintaining flooded fields through frequent pumping significantly escalates energy demand. In the upper and middle IGP, electricity powers most irrigation, while in the lower regions diesel pumps dominate—both contributing heavily to production costs and emissions. Fertilizer use, groundwater depletion, and heavy pesticide application further intensify energy use, with about 84% of wheat cultivation costs traceable to these high-energy inputs.

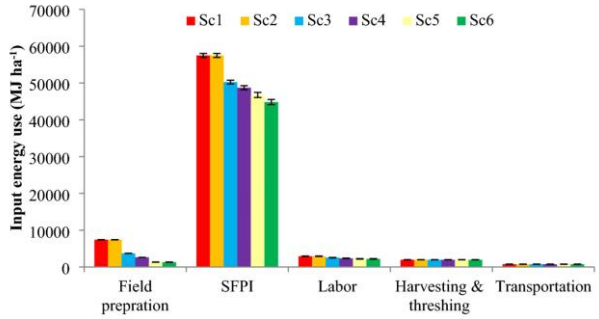
This over-reliance on energy-intensive practices has led to escalating costs, soil degradation, nutrient imbalances, and declining productivity—posing a growing threat to smallholder viability and national food security. Research across South Asia indicates that intensive tillage alone can account for over 20–25% of total production costs in rice–wheat systems, highlighting the urgent need for energy efficiency in agricultural operations.

Transitioning to energy-smart agriculture (ESA) practices—such as laser land leveling, zero tillage (ZT), direct-seeded rice (DSR), site-specific nutrient management (SSNM), and precision irrigation—offers significant energy and cost savings. ESA-based zero-tillage systems can save up to 36 liters of diesel per hectare, equivalent to 2,027 MJ of energy, while reducing machinery wear and labor time. Moreover, such practices substantially cut greenhouse gas emissions. With agriculture contributing roughly 24% of global anthropogenic emissions (FAO, 2023), improving energy efficiency is critical for both climate mitigation and farm profitability.

In the illustrated figure (adopted from Kakraliya et al., 2022), energy-use efficiency improves steadily from conventional to advanced climate-smart management (Sc1–Sc6). The data reveal sharp declines in energy use for seed, fertilizer, pesticide, and irrigation (SFPI) inputs, as well as for field preparation—two of the most energy-intensive components. These trends underscore the potential for smallholders to optimize energy use, reduce costs, and enhance resilience by adopting

energy-smart, conservation-oriented, and regenerative production systems.

Figure 1. Operation-wise input energy-use (%) of rice system under different management practices.



Ref to Fig 1. SFPI refers to seed, fertilizer, pesticides, and irrigation. Sc1, business as usual-conventional tillage (CT) without residue; Sc2, CT with residue; Sc3, reduced tillage (RT) with residue + recommended dose of fertilizer (RDF); Sc4, RT/Zero tillage (ZT) with residue + RDF; Sc5, ZT with residue + RDF + GreenSeeker + Tensiometer; Sc6, Sc5 + Nutrient expert. Vertical bars indicate ± S.E. of the mean of the observed values (adopted from Kakraliya et al., 2022).

2.4. Stagnant and Sub-Optimal Crop Yields

Despite technological advancements, yield growth in several major crops like rice and wheat has plateaued in many regions of India, with annual growth rates slowing to 1.4% CAGR from 2011-2023 compared to 3.7% in the 1980s. Yield gaps persist, due to degraded soils affecting 96.4 million ha (ICAR 2025), inefficient water and nutrient management with nutrient use efficiency at 30-50% (MoAFW 2024), limited access to quality seeds, and inadequate extension services covering only 10-15% of farmers (IFPRI 2024). Climate stress further exacerbates yield variability, with projections of 10-40% declines in crop yields by 2050 under high-emission scenarios (NITI Aayog 2023), resulting in unstable production outcomes and undermining national food security objectives.

2.5. Excessive and Imbalanced Use of Fertilisers and Agro-Inputs

India's fertilizer use remains heavily skewed toward nitrogen (with an N:P:K ratio of 8.4:2.3:1 in 2023-24, per MoAFW data), often at the expense of phosphorus, potassium, and micronutrients, leading to widespread imbalances. Recent assessments under the Soil Health Card scheme (analysed by CSE in 2025) reveal that 64% of tested soil samples are low in nitrogen and 48.5% are low in organic carbon, despite high overall consumption of around 60 million tonnes annually. An ICAR study published in November 2025 in Land Degradation & Development highlights that such imbalances, combined with climate change, accelerate organic carbon degradation, with regional hotspots like Punjab and Haryana showing declines due to excessive urea and phosphorus application. This reduces nutrient use efficiency to 30-50% (FAO 2023; ICAR 2024), degrades soil biology, raises input costs (fertilizer subsidies reached ₹2.25 lakh crore in FY24, per Union Budget), and contributes to declining crop response ratios, dropping from 12 kg grain per kg N in the 1960s to about 5 kg today (World Bank 2023 report on Indian agriculture).

2.6. Inefficient Use of Irrigation Water

Agriculture accounts for 80-90% of freshwater withdrawals in India, with estimates around 84-89% usage in the sector, far exceeding the global average of 70% per FAO (2024). However, irrigation efficiency remains low at 30-50% for surface systems and 65-75% for groundwater. Flood irrigation continues to dominate over 60% of the irrigated area, leading to high conveyance losses (up to 50-60%), waterlogging, and salinity. Micro-

irrigation systems like drip and sprinkler despite which achieve 40-70% water savings and 80-95% efficiency, cover only about 10-15 million ha out of a potential 69 million ha (less than 20-22%), achieving proven water savings of 30–50%, cover less than 20% of the potential area. This limited adoption restricts water productivity and intensifies groundwater depletion, with India extracting 25% of global groundwater (primarily for agriculture at 87-89%), leading to annual losses of ~450 km³ in north India from 2002-2021 and projected tripling of depletion rates by 2080 under climate scenarios (CGWB 2025; Stanford-led study in Science Advances 2023; Earth's Future 2024)

2.7. Limited Adoption of Farm Mechanisation

India's farm power sources have shifted significantly: animal and human contributions declined from 83% in 1960 to about 12% by 2018-19, while tractors and tillers rose from 2.54% to over 49% in the same period (MoAFW 2024). Despite this progress, overall farm mechanization in India remains limited at 45-47% as of 2024-25 (MoAFW SMAM data;), far below developed countries (>90%) and peers like China (60%) and Brazil (75%). Operation-wise, levels vary: 70% for seed-bed preparation, 40% for sowing/planting/transplanting, 33% for weeding/inter-culture, and 34% for harvesting/threshing. However, Small and marginal farmers, comprising 86% of holdings with average size ~1.1 ha, face major barriers like limited credit access—only 5% used bank loans for machinery under SMAM (PRS 2023)—hindering adoption and stalling sector growth.

Mechanization also varies regionally: higher in Punjab and Haryana (60-70%), but lower in Jharkhand and northeastern states (<30%). Numerous government and institutional initiatives are in progress to address these challenges and promote the comprehensive development of the sector.

India leads global tractor production with ~900,000 units/year, becoming a net exporter (NITI Aayog 2025), yet fragmented landholdings remain a key obstacle. Threshers rank second in sales after tractors for harvesting utility, while rotavator adoption grows for efficient land preparation. Large farms are more mechanized, but only ~44% of small/marginal producers use machinery. To boost adoption, there's a pressing need for developing and promoting small, affordable implements like mini-tractors, solar-powered pumps, automated seed drills, and versatile tools suited to small holdings. These can bridge labor gaps, enhance efficiency, and support women farmers, aligning with targets of 75% mechanization by 2047 (Standing Committee 2023) and farm power to 4 kW/ha by 2030 (MoAFW 2025).

2.8. The Need for Small Hand/Powered Implements

In India, small and marginal farmers dominate the agricultural landscape, accounting for about 86% of all operational holdings with an average land size of just 1.1 hectares. These farmers often rely on manual labour and traditional tools, leading to high drudgery, labour shortages exacerbated by rural-urban migration (70% of farmers face worker unavailability, PwC 2024 report), and low productivity. Labour costs have risen due to wage inflation, with seasonal shortages increasing operational expenses by 20-30% in many regions. Fragmented landholdings make large machinery impractical and unaffordable, resulting in inefficiencies that hinder income growth and sustainability. Absence of women-friendly tools increases physical strain, affecting gender participation in a negative way in a sector where women perform 60-80% of farm work (FAO 2024).

Small hand implements (e.g., manual weeders, seed drills, and sickles) and powered implements suited for small-holdings are essential to address these challenges. They cut manual labour by up to 60% in tasks like tilling, weeding, and harvesting, minimize the input waste and environmental impact.

2.9. Inadequate Crop Residue and Agro-Waste Management

Crop residue and agro waste mismanagement—particularly stubble burning—remains one of the most persistent environmental and public health challenges in India and across South Asia. Stubble burning refers to the deliberate burning of crop residues left in the field after harvest, most commonly following rice and wheat crops. Globally, crop residue burning (CRB) accounts for nearly 25% of total biomass burning (IPCC; FAO 2024), while Asia, dominated by rice production systems, contributes disproportionately. Within the region, India exhibits residue burning levels 93% higher than Pakistan and 30% higher than China (Figure 2).

Estimates of the quantity of crop residues burned in India vary widely—from about 6.6% to 43% of total residues across studies. The Ministry of Agriculture and Farmers Welfare (2024) reports that India generates roughly 754 million tonnes (Mt) of agricultural residues annually, of which about 500 Mt are recycled or reused in livestock feed, rural fuel, or industrial applications. However, an estimated 178 Mt remain unutilized, with approximately 87 Mt burned annually (Datta et al., 2020). Although burning incidents have slightly declined since their peak in 2021–2023, recent remote-sensing evidence suggests shifts in burning times to evade satellite detection (NASA, 2025).

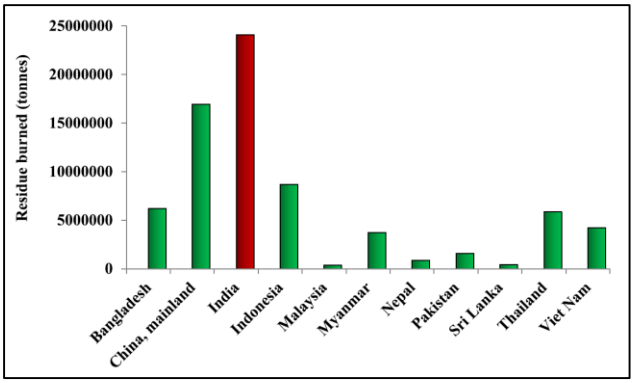
This continued reliance on open-field burning releases massive quantities of particulate matter (PM2.5, PM10) and greenhouse gases (CO_2, CH_4, N_2O), degrading air quality, reducing soil organic matter, and impairing human health. The environmental cost is expected to escalate further as population growth and food demand drive higher residue generation. UN projections (2024 Revision) indicate that India's agricultural output could rise by nearly 45% by 2050—from ~619 Mt in 2017 to ~899 Mt—creating substantial additional residue streams unless effective management systems are scaled up.

Despite immense potential, agricultural residues remain underutilized in industrial bioenergy production. Out of the 754 Mt generated each year, only a small share—equivalent to about 5 Mt installed capacity—is used for biofuels or biomass

energy. While initiatives such as the Sustainable Alternative Towards Affordable Transportation (SATAT) programme aim to establish 5,000 compressed biogas plants (targeting 15 Mt production by 2030), fewer than 100 plants are operational as of 2025 (MoPNG). Similarly, second generation (2G) ethanol refineries, such as IOCL's Panipat unit, mark important progress but remain limited in scale: India's total biomass power capacity stands at ~10 GW against an estimated potential of 25 GW (MNRE 2024; IEA 2024). Key barriers include high logistics costs, weak supply chains, technological complexity, and insufficient price incentives—factors that leave India's biomass energy potential largely untapped. To address these gaps, scaling mechanized and decentralized residue management solutions is critical. Technological implements such as Happy Seeders,
Super Straw Management Systems (SMS) for combines, baler–shredder units, and tractor mounted choppers enable either in situ residue incorporation or ex situ collection for energy and industrial use—eliminating the need for burning. Under the Central Sector Scheme on Crop Residue Mana gement (CRM), nearly 2.95 lakh machines have been deployed with ₹3,623 crore support (2018–2023), creating over 40,000 Custom Hiring Centres (CHCs) to enhance smallholder access. In Punjab alone, the distribution of 31,000 subsidized machines in 2025 contributed to a 26% decline in burning incidents compared with 2022–2023 (LSE 2025).

Residue management mechanization can cut labor demands by up to 50%, costs by 20–30%, and emissions substantially—while generating feedstock for renewable energy and organic amendments. Yet adoption among smallholders remains uneven due to high capital costs, limited awareness, and fragmented markets. Integrating residue management into broader regenerative agriculture and circular bioeconomy strategies—through village level biomass aggregation, carbon market mechanisms, and strengthened farmer cooperatives—can unlock long term value, reduce pollution, and align with India's climate and energy transition goals.

Figure 2. Amount of residue burned in South Asian countries



2.10. Declining Soil Health and Land Degradation

India's agriculture sector, which supports over 100 million small farmers is grappling with escalating soil health decline and land degradation affecting 97.85 million ha (~30% of total land), up from 94.53 million ha in 2003-05—a rise of 1.45 million ha every 7-8 years (ISRO SAC 2025)—potentially exceeding 100 million ha by 2030 at a 0.2-0.3% annual rate. Key degradation types include water/wind erosion (36.2 million ha, 11.01%; ICAR-IISS 2025); salinity/sodicity (3.64 million ha, 1.11%); nutrient depletion/low organic carbon (only 20% soils with sufficient SOC, <5% N-adequate; 64% low in N, 48.5% low in SOC, CSE 2025 Soil Health Card analysis); and vegetation degradation (30.07 million ha, 9.15%). Hotspots primarily encompass the

Indo-Gangetic Plains, Punjab, Haryana, Rajasthan, and Maharashtra, where 43% of high-risk districts exhibit poor SOC levels (CSE 2025). Globally, UNEP (2024) reports 70% of Earth's land altered and one-third degraded (UNU-INWEH 2025).

Major causes, amplified by climate change, involve intensive farming and fertilizer imbalance (N:P:K ratio 8.4:2.3:1, MoAFW 2024), leading to 38% microbial diversity loss (ICAR 2025); erosion and unsustainable practices like monocropping, excessive tillage, and residue burning, causing nutrient loss of 5.37-8.4 million tonnes/year (ICAR-IISS 2025); climate factors such as projected 1-4°C temperature rise by 2080 and erratic rainfall exacerbating erosion/SOC loss (IPCC AR6 2022); and deforestation, overgrazing, and urbanization, with erosion as the main process (MoEFCC NAP 2023).

Impacts include 10-20% yield losses (FAO 2025; RGICS 2025 notes 15-20% annual in key crops); 20-30% reduced water retention (NITI Aayog 2023); further 20-30% SOC loss (CSE/Bio-Inputs 2025); nutrition threats for a 14% undernourished population (FAO 2024); annual economic losses of ₹1.5-2 lakh crore (ICAR 2025); and livelihood risks for the 47% workforce (MoSPI 2025).

2.11. Limited Non-Farm and Off-Farm Livelihood Options

Off-farm and non-farm income has emerged as a crucial economic strategy for Indian farmers amid numerous agricultural challenges. Agriculture's GDP share has dropped from 75% decades ago to 14-15% in 2024-25 (OECD 2025), while employing 46.1% of the workforce (up from 44.1% in 2017-18, Economic Survey 2025), the need for diversification in income sources has become imperative. Income instability from price volatility and climate risks adds financial strain, pushing alternative avenues. Off-farm income provides stability, empowers farmers, and boosts rural growth, with ~96% of households engaging in 2023 (Sage Journals 2025).This shift is exacerbated by the prevalence of small and fragmented land holdings making them less productive and financially viable. However, the reliance on off-farm income is not without its controversies. Critics argue that it may distract farmers from investing in agricultural improvements, perpetuating a cycle of dependency on non-farm income sources rather than enhancing agricultural productivity. Inadequate development of non-farm enterprises, agro-processing, and service sectors constrains income diversification, making households highly vulnerable to agricultural shocks.

As rural demographics shift and urbanization increases, the discourse surrounding off-farm income continues to evolve, underscoring its role in shaping the future of Indian agriculture. Rural livelihoods remain overly dependent on agriculture.

2.12. Lack of interest in interconnecting soil health and one health

Modern definitions portray soil as a dynamic, living ecosystem—not just a plant growth medium but a provider of essential services, including water filtration, carbon sequestration (storing up to 2,500 gigatons globally, per IPCC AR6 2022), and climate regulation. The interplay of various soil organisms and their relationships with plants and the abiotic environment underscores the necessity of maintaining soil vitality to support both agricultural productivity and broader ecological health.

Despite these advances, soil health remains underrepresented in broader health

frameworks, such as the One Health approach, which integrates human, animal, and environmental well-being. The One Health Joint Plan of Action (2022–2026) emphasizes ecosystem protection but addresses soil mainly through pollution lenses, overlooking its direct ties to zoonoses, antimicrobial resistance (AMR), and nutrition. Degraded soils facilitate pathogen spillover, antibiotic persistence from agricultural runoff, and contaminated food chains, heightening zoonotic risks like brucellosis. Poor soil management contributes to malnutrition via nutrient-deficient crops, antimicrobial resistance (AMR) via manure-amended fields, and respiratory issues from erosion or residue burning. For smallholder farmers, this cycle undermines productivity, incomes, and health security amid climate stress. Regenerative practices—site-specific nutrient management, reduced tillage, and organic amendments—restore soil vitality while aligning with One Health principles. Scaling soil health cards and farmer training can prevent blanket inputs, fostering resilient, low-emission systems that enhance human, animal, and environmental wellbeing.

2.13. Persistent Socio-Economic Vulnerabilities

Smallholder farm households in India face persistently low and unstable incomes, with average monthly earnings at ₹11,438 in 2023-24 (MoSPI 2025), limited savings, and high exposure to production risks (e.g., climate shocks) and market volatility (e.g., price fluctuations). Dependence on informal credit—utilized by 36% of farmers due to barriers in formal access (Farmonaut 2026)—fuels rising indebtedness, with average outstanding loans per household at ₹74,121. Limited insurance coverage, despite schemes like PMFBY (allocated ₹12,242 crore in 2025-26 budget), exacerbates vulnerability, as only 25-30% of smallholders are insured (World Bank 2023 estimates). These socio-economic constraints hinder investments in improved technologies and adaptive practices, perpetuating a cycle of poverty—28.1% of rural populations remain poor at the $3.65/day line (World Bank 2025). To cope, 96% of households engage in off-farm activities for diversification.

2.14. Gender Inequities in Agriculture

In India, women play a pivotal role in agriculture, constituting 60-80% of the agricultural labor force and performing 75-80% of farm operations such as sowing, transplanting, weeding, harvesting, and post-harvest activities, according to (FAO's 2024 State of Food and Agriculture Report). Despite their substantial contributions—driving 30-40% of rural household income through allied activities like dairy and poultry (MoAFW 2024)—women face deep-rooted systemic barriers that perpetuate inequities. Only 13.96% of operational landholdings are owned by women as of the 2015-16 Agriculture Census (with marginal increases to ~15% by 2024 per MoRD estimates), limiting their access to credit, subsidies, and decision-making (World Bank Gender Data Portal 2025). Women receive just 8-10% of institutional agricultural credit (RBI 2025 Agricultural Credit Review), often relying on high-interest informal sources, which exacerbates indebtedness amid rising input costs. Training and extension services reach only 20-25% of women farmers, hampered by mobility constraints, cultural norms, and male-dominated programs (ICAR 2024 Gender Mainstreaming Report). Mechanization adoption is low among women due to non-ergonomic, heavy equipment; only 10-15% of smallholder women use tools like power weeders or mini-tillers, increasing physical drudgery (NABARD 2025 Rural Pulse).

Decision-making remains male-centric, with women holding <5% of leadership roles in farmer producer organizations (FPOs) (MoAFW 2024).

These gender gaps reduce overall farm productivity by 20-30%, as per World Bank (2023) estimates, and limit the effectiveness of extension and innovation systems, stifling adoption of climate-smart practices. Climate stress—projected to intensify with 1-2°C temperature rises and more erratic monsoons by 2030 (IPCC AR6 2022)—often doubles women's workload through additional tasks like water fetching and livestock care, heightening their vulnerability to health risks and economic shocks (UN Women 2024 Asia-Pacific Report).

Over the next five years (2026-2030), closing these gaps is critical as urbanization and male migration could increase women's farm responsibilities to 85% in rural areas (ILO 2025 Projections), while climate impacts may reduce yields by 10-20% in female-managed farms without adaptive support (IFPRI 2025).

2.15. Dominance of Monocropping Systems

The continued dominance of monocropping systems—particularly cereals like rice and wheat across large areas of the Indo-Gangetic Plains and other regions—will remain a major challenge for Indian agriculture, exacerbating resource strain and vulnerability. Monocropping has significantly reduced agro-biodiversity and made farming systems more susceptible to pests, diseases, and climate shocks, including projected temperature rises of 1–2°C and more frequent extreme events by 2030 (IMD 2025). It accelerates soil nutrient depletion, with continuous cereal cultivation causing 20–30% greater loss of organic carbon and essential nutrients compared to diversified systems (CSE 2025), while driving excessive dependence on synthetic fertilizers combined with low nutrient use efficiency (FAO 2023; ICAR 2024). This inefficiency, combined with high water demands in rice-wheat systems consuming up to 3,000-5,000 liters per kg of rice, and groundwater depletion at ~450 km^3 annually in northern India; CGWB 2025; NITI Aayog 2023), undermines ecological resilience, weakens soil structure, and increases reliance on chemical inputs, further degrading land health. Limited crop diversification also restricts income opportunities—farmers remain exposed to price volatility and market risks—and limits dietary diversity, contributing to persistent malnutrition (14% undernourished population, FAO 2024). Without a shift toward diversified, climate-resilient cropping patterns, monocropping will intensify yield stagnation (projected 10-20% declines by 2030; FAO 2025), income insecurity, excessive water usage (potentially tripling depletion rates by 2080 under climate scenarios; Earth's Future 2024), low nutrient efficiency, and environmental stress, threatening smallholder livelihoods and national food security goals

2.16. Weak Market Linkages and Value Chains

Many farmers—especially smallholders—lack access to efficient markets, storage, processing, and price discovery mechanisms, leading to significant inefficiencies in the agricultural supply chain. High post-harvest losses, estimated at Rs. 1.53 trillion (USD 18.5 billion) annually and ranging from 3.89-5.92% for cereals to 6.02-15.05% for fruits (NABCONS 2022), stem from inadequate infrastructure like cold storage (shortfall of over 25% against required 30 million tonnes) and poor handling, resulting in distress sales at low prices due to insufficient market connectivity and extended travel times. Limited integration into value chains—exacerbated by fragmented supply

systems and knowledge gaps—reduces farm profitability by 20-30% in operational costs and discourages diversification into high-value crops like fruits and horticulture, where losses reach 25-30% across the chain (Research Gate 2025),

2.17. Shortage of Green Fodder for Livestock

Livestock productivity is constrained by the insufficient availability of quality green fodder. Insufficient quality green fodder, with projected deficits of 11–63% for green fodder and 23–25% for dry fodder (NDDB 2022;), amid rising demand from a growing herd (over 535 million animals, 2023 Livestock Census) and population. Dependence on low-quality crop residues and feeds reduces digestibility, leading to lower milk yields (e.g., average 4-5 kg/day vs. potential 8-10 kg/day, ICAR 2024), poorer animal health, and diminished income potential for smallholders, who rely on livestock as a key risk-buffering asset contributing 30% to agricultural GVA (MoAFW 2024).

From a GHG emissions lens, this shortage exacerbates environmental impacts, as large ruminants (cattle and buffalo, ~80% of India's livestock) produce high methane through enteric fermentation—accounting for 50-60% of agricultural emissions and ~10-12% of national GHGs (512 Mt CO2e in 2022, MoEFCC Report 2024;). Low-digestibility feeds (e.g., residues with <50% digestibility) prolong fermentation, increasing methane output by 20-30% compared to high-quality forages (IPCC AR6 2022). Without interventions, emissions could rise 15-25% by 2030 due to herd growth and climate-stressed fodder availability (World Bank Livestock Report 2023).

Better digestibility interventions are urgently needed for large ruminants, such as enzyme additives, silage production, and high-nutrient forages like hybrid Napier grass, which can improve feed efficiency by 20-40%, cut methane by 10-30% (ICAR-NIANP 2025), and boost milk production by 15-25% (NDDB 2025). Schemes like the National Livestock Mission (₹2,800 crore allocation FY25) aim to promote these, but scaling requires integrated extension and subsidies to reduce smallholders' costs and emissions.

2.18. Weak Agricultural Extension Systems

India's agricultural extension systems continue to face persistent challenges in delivering effective support to farmers, particularly smallholders, amid escalating climate risks and productivity demands. Public extension services, with a low officer-to-farmer ratio of 1:1,100 (versus the recommended 1:750, NITI Aayog 2025), suffer from capacity constraints, limited farmers' reach, and insufficient integration of digital tools, resulting in low adoption of improved practices. A key challenge is the inadequacy of climate advisories, where services often provide generic or outdated information on risks like erratic rainfall and extreme weather, reaching only 20-30% of farmers effectively (FAO 2025). This stems from poor incorporation of real-time data and climate-smart agriculture (CSA) tools, limiting adaptation and contributing to 10-20% annual yield losses (ScienceDirect 2025). Extension agents also lack sufficient CSA training, leading to low awareness—63% of smallholders cite climate as their top concern (Rockefeller Foundation 2023).

Farmer-to-farmer models, promising for peer learning through SHGs, FPOs, lead farmers, and local cadres, struggle with trust deficits, knowledge gaps, and uneven implementation, hindering scalability across diverse regions

(ICAR 2024). Digital extension, expanding via apps and AI platforms like VISTAAR and Kisan Call Centres, is hampered by the digital divide—limited smartphone/internet access (only 40-50% rural penetration, TRAI 2025), poor connectivity, low digital literacy, and fragmented data systems—resulting in ineffective outreach and slow adoption of climate-smart innovations (NITI Aayog Reimagining Agriculture 2025). Without addressing these issues, extension systems will fail to meet growing needs, exacerbating yield gaps and vulnerability for 86% of smallholders (MoAFW 2024)

2.19. Gaps in Agri-Skill Development Infrastructure

India's agri-skill development infrastructure face widening gaps, limiting the capacity to train farmers, rural youth, women and service providers in regenerative agriculture, climate-smart technologies, mechanization, and data-driven decision-making amid escalating demands for sustainable farming. With only ~1,000 dedicated agri-skill centers operational (e.g., under Skill India and ATMA schemes, MoAFW 2024), coverage remains inadequate for 100+ million smallholders, training just 10-15% annually (NITI Aayog Reimagining Agriculture 2025). This shortage stems from limited funding (agri-skilling allocation at ₹1,500 crore in FY25, insufficient for projected needs, Union Budget 2025) and uneven distribution, with rural youth (18-35 age group, 55% of workforce) accessing only 20-25% of programs due to infrastructure deficits like poor training facilities and digital divides (World Bank Skills for Agriculture 2024). As a result, human capital formation stagnates—only 5-10% of farmers adopt CSA or mechanization (FAO India 2025)—slowing technology diffusion and exacerbating yield gaps of 20-50% in key crops (ICAR 2025). Without scaling centers to 5,000+ and integrating AI/digital platforms (targeting 50% coverage by 2030, NITI Aayog 2025), this will hinder adaptation to climate risks and sustainable growth for 86% smallholders.

2.20. Fragmented Policy and Institutional Frameworks

India's agricultural policies continue to operate in silos across sectors like agriculture, climate, energy, water, and rural development, hindering coordinated responses to escalating challenges such as climate change and resource scarcity. Limited integration between domestic schemes (e.g., PM-KUSUM for energy, PMKSY for water, and NAPCC for climate) and global commitments like NDCs and SDGs restricts investment in sustainable practices, e.g., sustainable agriculture finance at USD 2.1 billion annually, skewed toward credit (85%) (CPI 2025). This fragmentation, leads to inefficient resource use, such as misaligned subsidies promoting water-intensive crops amid 87% agricultural water demand by 2030 (NABARD 2025), and slows scaling of innovations. Without unified frameworks—e.g., integrating IWRM for climate adaptation (CEEW 2025)—policy gaps will exacerbate productivity losses (10-20% from climate shocks, NABARD 2025) and limit resilience for smallholders.

3. Opportunities

3.1. Regenerative Agriculture as a National Climate and Development Priority

Regenerative agriculture presents a proven approach to meet various policy goals through effective land management. This method enhances soil health, boosts water productivity, fosters biodiversity, and supports livelihoods, all while lowering emissions intensity. This strategy emphasizes scalable regenerative

practices like site specific nutrient management (SSNM), Direct Seeded Rice (DSR), Zero Tillage (ZT), and crop diversification. These methods are already acknowledged by national and state governments as climate-smart practices through various schemes and pilot programs.

SSNM operationalise regenerative agriculture by shifting fertilizer use from blanket doses to context-specific, soil-informed decisions that rebuild soil as a living system rather than depleting it. Regular soil testing diagnoses nutrient status and organic carbon trends, enabling SSNM to match nutrient supply with crop demand, which improves nutrient use efficiency, reduces losses and greenhouse gas emissions, and supports soil carbon sequestration—core aims of climate-smart and regenerative agriculture. In India, soil-test based recommendations through schemes like the Soil Health Card and the National Mission for Sustainable Agriculture embed this approach into national climate and development priorities by linking balanced, site-specific nutrient management with land degradation neutrality, soil health restoration, and resilient food security.

DSR has the potential to cut irrigation water usage by 15–25 percent, decrease methane emissions by as much as 30 percent, and significantly lower labor costs. Zero Tillage enhances soil organic carbon, cuts fuel consumption by 50–70 percent, reduces cultivation expenses, and boosts overall productivity, especially in the rice–wheat systems of the Indo-Gangetic Plains.

By diversifying rice-wheat systems with pulses or oilseeds, farmers can achieve a remarkable 10–25% increase in overall system productivity. This enhancement is attributed to improved nutrient cycling and a decrease in pest pressure. Incorporating legumes/ cover crops boosts soil nitrogen levels, leading to a 5–15% increase in yields of following cereal crops, all while keeping fertilizer use in check. Swapping out just one season of irrigated rice for pulses, oilseeds, or millets can lead to a remarkable reduction in irrigation water use by 30–60%. Shifting towards pulses, oilseeds, horticulture, and fodder can boost net farm income by 20–50% when compared to traditional cereal mono-cropping.

Promoting these practices on a large scale directly supports climate mitigation (SDG 13), enhances water-use efficiency (SDG 6), achieves land degradation neutrality (SDG 15), and boosts income for smallholders (SDG 2 and SDG 8).

3.2. Water Stewardship and Climate Resilience

Water security is becoming one of India's most pressing development challenges. Agriculture is responsible for almost 80 percent of freshwater withdrawals, yet irrigation efficiency lingers at a low range of 30–65 percent across various systems. This strategy prioritizes water-saving technologies, precision water management, and community-driven governance, seamlessly aligning with national initiatives such as PMKSY (Per Drop More Crop), Atal Bhujal Yojana, and state groundwater management frameworks.

Enhanced water productivity, quantified as crop yield per unit of water utilized (kg/m^3), will act as a fundamental performance metric within this strategy. By combining regenerative practices with micro-irrigation, crop planning, crop water budgeting and soil moisture management, we enhance both adaptation and mitigation results, establishing agriculture as a key player in India's climate strategy. Furthermore, contamination of fresh water

aquifers with the excess of fertilizers runoffs make it imperative to have modified managed aquifer recharge systems. Artificial recharge is one of many techniques used to manage water resources and is being promoted as a significant solution to water scarcity in project areas. Aquifers (Groundwater) can be recharged in two basic ways - naturally and artificially. In natural recharge, the rainwater or surface water gets percolates into shallow and deep aquifers by itself through uncovered soil surfaces and fissures in the rock mass. Artificial recharge to the aquifer is the process of draining rainwater or surface water into the aquifer by constructing simple biochar lined civil structures. This concept of channelizing surface rainwater into lined bore wells/dug wells and recharge (soak) pits is possibly to revitalize the wells which are dried up or have reduced water level considerably compared to the past.

Similarly, there is need to promote farm/community ponds to reduce dependence on ground water for irrigation during dry spells. Such ponds further increase irrigation coverage leading to higher agricultural outputs with enhanced water security for the farming community. Studies in semi-arid regions, have shown that groundwater recharge through farm ponds can enhance the water table by 10% to 30%, benefitting the community. Furthermore, rainwater harvesting in farm ponds can store monsoon water, which becomes available for irrigation during the Rabi season. This can increase the number of irrigation cycles to 3-4 irrigation for water-demanding crops like wheat and mustard. This increase can lead to a 50% to 100% rise in irrigation availability compared to normal conditions.

3.3. Emerging trends in Farm Mechanisation

Although farm mechanization in India has achieved significant progress over the years, it has not yet realized its full potential. Therefore, in order to attain the ambitious goal of enhancing farm power availability to 4 kW/ha by 2030, it is essential to develop a comprehensive strategy involving multiple stakeholders that guarantees steady progress in the appropriate direction. We have offered several recommendations for strategic interventions to promote the comprehensive development of the agricultural mechanization ecosystem.

3.3.1. Designing compatible implements for small-scale farms

As highlighted in the challenges section, the predominance of tractor-based mechanisation in Indian agriculture has left smaller, affordable tools underdeveloped, particularly for small- and medium-sized farms where fragmented landholdings limit efficiency. With average annual tractor utilisation ranging from 500 to 600 hours—well below the optimal 1,000 hours needed for cost-effectiveness (MoAFW 2024)—the lack of suitable implements for small plots exacerbates this issue. While power tillers showed initial promise, their low adoption due to poor maneuverability in tough terrains and operational complexities underscores the urgent need for tailored solutions. To address these gaps and enhance productivity for smallholders over the next five years, we must prioritise the development and dissemination of compatible machinery suited to small landholding systems, such as compact mini-tillers, solar-powered pumps, power weeders, seed drill and planter, lightweight harvesters, and versatile multi-crop tools designed for plots under 1 hectare (NITI Aayog Reimagining Agriculture 2025). These implements can reduce labor drudgery by 40-60%, cut operational costs by 20-30%, and improve efficiency for women farmers, aligning with national goals to raise farm power

availability to 4 kW/ha by 2030 and achieve 75% mechanization by 2047 (MoAFW 2025; Standing Committee 2023).

3.3.2. Equipment on farms designed to be accessible and suitable for women

As previously noted, the migration of male family members is markedly high in eastern Indian states, particularly Bihar and Jharkhand. Therefore, it is essential to develop women-friendly agricultural machinery to mitigate the challenge of intensive physical labor resulting from the absence of masculine members in farming households. The monotony associated with agricultural operations should be alleviated through the development of compact and efficient machinery. Policymakers have already made considerable progress in this regard. The Indian Council of Agricultural Research (ICAR) has compiled a compendium of agricultural equipment appropriate for utilization by women farmers. Other policies in favour of gender-inclusiveness overcoming barriers are boosting women's land rights via joint titling (targeting 30% by 2030 under NRLM, MoRD 2025), enhancing credit access through schemes like Mahila Kisan Sashaktikaran Pariyojana (aiming for 50% female coverage by 2030), promoting women-friendly mechanization (e.g., subsidies for lightweight tools under SMAM, MoAFW 2025), and expanding training via digital platforms to reach 40 million women (NITI Aayog Digital Agriculture Mission 2025). Such measures could lift productivity by 15-25% and reduce vulnerability, aligning with SDGs 5 (Gender Equality) and 2 (Zero Hunger) (FAO 2025).

3.3.3. Facilitating the advancement of mechanization in horticulture

India ranks as the world's second-largest producer of fruits and vegetables, with a total horticultural agricultural area of approximately 272 lakh hectares. Despite the extensive area, mechanisation has been predominantly implemented in cereal crops such as wheat and rice (60%), whereas it remains considerably limited in horticulture-related crops. The development of small hand tools appropriate for horticultural crops can therefore be beneficial for producers engaged in horticulture.

3.3.4. Sustainable mechanized solution of crop residue management

As outlined in the challenges section, inadequate crop residue management leads to widespread stubble burning—contributing to 87 Mt of unused residues being burned annually (MoA&FW 2024; Datta et al., 2020)—causing pollution, health risks, and projected increases with 45% growth in agricultural output by 2050 (UN 2024; FAO 2025). To counter this, we see significant opportunities in sustainable, mechanized approaches that transform residues into valuable resources, reducing emissions and enhancing soil health.

In-situ methods like mechanical incorporation into soil improve fertility and preserve organic matter (Ravindra et al., 2018; ICAR 2024), while composting produces nutrient-rich material (N 2%, P 1.5%, K 1.4-1.6%) that boosts soil productivity and crop yields by 4-9% (Romasanta et al., 2017; NDDB 2025). However, adoption remains low (<1% of farmers) due to 30-40 day timelines and labor costs, highlighting the need for mechanized alternatives.

Ex-situ industrial solutions offer scalable potential: mechanized collection during harvest enables conversion into biogas via anaerobic digestion (hydrolysis, acidogenesis, acetogenesis, methanogenesis), biochar

through pyrolysis, or energy via combustion, gasification, or methanation (Bioenergy International 2025). Direct combustion or co-firing produces power/heat, with byproducts like bottom/fly ash usable in manufacturing for cement, bricks, and road construction—despite drawbacks like emissions, which can be mitigated with advanced filters (CEEW 2025). Densification into pellets or briquettes enhances efficiency, creating portable fuels for industrial/residential use, as adopted in Thailand, India, and African nations to address firewood scarcity (IRENA 2024).

By promoting mechanized tools like balers, shredders, and Happy/smart seeders, we can reduce burning by 20-30% in hotspots, while fostering manufacturing linkages to utilize residues in bioenergy and materials, aligning with net-zero goals and creating rural jobs

3.4. Diversified Livelihoods: Farm, Non-Farm, and Livestock Systems

As outlined in the challenges section, smallholder farmers face income instability from climate risks, high post-harvest losses, and limited market linkages, making sole reliance on crop farming unsustainable. To address this, adopting a household-level livelihood approach, integrating crop production with livestock-based and non-farm opportunities to reduce vulnerability, smooth cash flows, and enhance resilience.

Livestock systems, play a critical role in income diversification, nutrient cycling, and household nutrition. When managed responsibly, integrated crop-livestock models—such as using climate-smart forages like Super Napier—tackle fodder shortages, boost dairy productivity, improve soil health as cover crops, and generate biomass for bio-gas, reducing methane emissions by 10-20% through better digestibility. This aligns with the National Livestock Mission's priorities for sustainable husbandry and supports SDGs on nutrition (SDG 2), income security (SDG 8), and resilience (SDG 13).

Non-farm options further buffer risks, with examples like mushroom cultivation offering low-risk, high-return opportunities for women and landless households. Requiring minimal land (indoor setups on shelves or bags), it recycles agricultural waste (e.g., paddy straw, spent grains) and yields quick harvests (3-4 months, 10-15 kg/m²) with net profits of ₹3000 - 5000 cycle for small units. With low water needs (20-30% less than field crops) and climate resilience (controlled environments mitigate heat/drought), it addresses gender inequities by empowering women and socio-economic vulnerabilities, potentially adding 20-30% to household income while reducing dependency on mono-cropping. Scaling through training and market linkages could tap India's growing mushroom demand, fostering circular economies and inclusive growth.

3.5. Soil Health, One Health, and Environmental Integrity

Over the next 10 years (2026–2035), bridging soil health and One Health is imperative for global sustainability. With land degradation affecting 1.7 billion people and projected to worsen by 20–30% due to climate extremes (UNCCD 2024), integrated approaches could restore 26 million hectares in India alone (MoEFCC NAP 2023) and enhance food security for 1.45 billion by 2030 (UN 2024). Prioritizing research, policy inclusion (e.g., expanding India's Soil Health Card Scheme to microbial metrics), and education will foster resilient practices, reducing emissions by 10–20% through better carbon storage (FAO 2025) and ensuring healthier ecosystems for future generations.

Healthy soils are the cornerstone of regenerative farming practices. India is experiencing a consistent drop in soil organic carbon and micronutrient balance, a consequence of intensive farming practices and the overuse of chemical inputs. This approach fosters the restoration of soil health by focusing on balanced nutrient management, enhancing organic matter, minimizing tillage, and incorporating biological inputs—all in harmony with the Soil Health Card Scheme and national soil conservation objectives.

The opportunity lies in integrating the One Health framework, acknowledging the interconnectedness of human health, animal health, and ecosystem health. This approach enhances public health and food safety by minimizing chemical residues, advocating for responsible livestock management, and elevating environmental quality. These outcomes are becoming essential focal points in both national and global policy discussions, reflecting a growing commitment to ecosystem resilience.

3.6. Enabling Climate Finance and MRV Readiness

As highlighted in the challenges section—where climate vulnerability, soil degradation, and fragmented policies limit sustainable practices—leveraging digital technologies in regenerative agriculture presents a sunrise opportunity to boost farmers' incomes and environmental outcomes over the next decade. To capitalize on this, we must prepare regenerative agriculture for investment by aligning interventions with robust Measurement, Reporting, and Verification (MRV) frameworks, essential for accessing climate finance and carbon markets (e.g., India's voluntary carbon market under the Carbon Credit Trading Scheme 2023, projected to reach USD 190 billion by 2030 per NITI Aayog 2025).

Regenerative practices deliver clear, quantifiable results, such as reduced GHG emissions (e.g., 20-30% methane cuts via better livestock feed, ICAR 2025), increased soil organic carbon stocks (up to 20% via biochar, FAO 2024), improved water-use efficiency (30-50% savings with micro-irrigation, MoAFW 2024), and enhanced productivity/income per unit of land (10-25% yield gains in diversified systems, World Bank 2023).

These align with latest standards, including outcome-focused CSA metrics under India's NDCs and results-driven mechanisms like green bonds (RBI 2025). Opportunities lies in advancing the digital MRV systems using remote sensing (e.g., ISRO satellite data), farm-level IoT sensors, and community monitoring to ensure transparency, scalability, and policy credibility, unlocking USD 5-10 billion in annual climate finance for smallholders by 2030 (CEEW 2025).

3.7. Agri-Skill Academy: Institutional Capacity for Transformation

As detailed in the challenges section, gaps in agri-skill infrastructure and weak extension systems—marked by limited centers, low reach (only 20-30% of farmers), inadequate climate advisories, and digital divides—hinder training in regenerative practices and slow technology adoption among smallholders. Building on the identified gaps in agri-skill infrastructure and extension systems—characterized by limited training centers, low coverage (reaching only 20–30% of farmers), inadequate climate advisories, and persistent digital divides—the Agri-Skill Academy can emerge as a catalytic institution to drive systemic transformation in the agriculture sector. Anchored within

national frameworks such as Skill India, the National Skill Qualification Framework (NSQF), and state skill missions, the Academy can function as an integrated platform for capacity building at both national and sub-national levels. Its mandate would encompass developing future-ready skills in regenerative agriculture, water stewardship, sustainable livestock systems, agri-entrepreneurship, digital agriculture, and climate-smart decision-making. By targeting farmers, rural youth, women, frontline extension personnel, and agri-service providers, the Agri-Skill Academy would enhance human capital, institutionalize peer-to-peer learning, and strengthen adaptive resilience—laying the foundation for large-scale regenerative and carbon finance-based transitions.

4. The Role of Regenerative Agriculture to Improve Well-being of Small and Marginal Farmers

Regenerative agriculture, first articulated by Robert Rodale (1983), is "one that, at increasing levels of productivity, increases our land and soil biological production base... produces foodstuffs free from biocides with minimal reliance on non-renewable resources." At its core, regenerative agriculture views soil health as the entry point for restoring ecological balance, optimizing natural resource use, and strengthening the social and economic fabric of rural livelihoods. Unlike conventional or organic systems that largely focus on input-based regulation, regenerative agriculture emphasizes the ongoing renewal of natural, social, and economic capital—ensuring that productivity improvements are sustained through ecosystem health and farmer wellbeing. For India's small and marginal farmers, whose livelihoods are increasingly at risk from climate variability, degraded soils, water scarcity, and declining biodiversity, regenerative agriculture offers a pathway to stability and prosperity. By rebuilding soil organic matter, improving moisture retention, and enhancing nutrient cycling, it reduces input costs, safeguards yields under stress, and restores the productive capacity of small farms. The approach supports diversification of crops, livestock, and allied activities, lowering income risk and enabling farmers to adapt to changing weather patterns while maintaining food security and ecological balance. Focusing on regenerative agriculture thus aligns directly with the wellbeing of small farmers—it builds resilience against climate shocks, reduces dependency on external inputs, and enhances long-term profitability through healthier soils and ecosystems. Integrating regenerative practices within broader rural development efforts—through One Health approaches, capacity building under Agri-Skill Academies, and climate finance mechanisms—can enable a systemic transition toward resilient, low-emission, and income-secure farming systems. Such a farmer-centered shift not only supports India's climate and development goals but also ensures that agricultural transformation is inclusive, equitable, and sustainable for those most vulnerable to environmental and economic shocks.

5. DRF's Regenerative Agriculture (RA) Strategy

"No race can prosper till it learns there is as much dignity in tilling a field as in writing a poem" – ***Booker T. Washington***

This strategy to improve and ensure the well-being of small and marginal farmers comprises an Integrated Climate-Resilient Farming System for Enhanced Productivity, Resource Restoration, Income Stability, and Long-Term Adaptive Capacity. Indian agriculture stands at

a critical crossroads, shaped by escalating climate variability, mounting pressure on natural resources, and enduring livelihood vulnerabilities for small and marginal farmers. The rising frequency of droughts, heat stress, erratic rainfall, and groundwater depletion is eroding farm productivity, while soaring input costs and market volatility further constrain incomes. These issues call for a climate-resilient strategy that transcends mere productivity gains to encompass ecological sustainability, economic resilience, and human capital development.

The well-being of small and marginal farmers is central to India's progress, as agriculture employs nearly half the population and supports 80% of the extremely poor in rural areas. All 17 UN Sustainable Development Goals (SDGs) connect directly or indirectly to farming, making farmer inclusion essential for their achievement—particularly SDG 2: "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture."

In response to these challenges and opportunities, DRF has crafted its regenerative agriculture strategy, centered on small farmers through a co-benefit model. This approach aims to boost returns from agriculture and allied activities while curbing emissions via regenerative practices. It will guide future initiatives, refine current programs, adapt to emerging needs, and better align with stakeholder priorities and the broader ecosystem. The strategy accounts for small farmers' realities, including literacy levels, bargaining power, risk tolerance, exposure to innovations, decision-making processes, and community influences. Anchored in climate-resilient regenerative agriculture as a systems-level transformation, it positions regenerative approaches as the ecological core. These enhance soil organic matter, water-use efficiency, and GHG reductions, bolstering farming systems against shocks. Yet, widespread adoption demands enabling economic, technological, and institutional supports to mitigate transition risks and short-term livelihood pressures for farming households. Therefore, built on seven strategic principles, it directs priorities and operations around key components. In essence, the strategy seeks to improve the well-being of small and marginal farmers by promoting regenerative agriculture, connecting them to ecosystems, and empowering informed decisions.

6. Strategic Principles

6.1. Farmer-Centred Approach

To effectively promote interventions aimed at improving farmers' income and overall well-being, it is essential to place farmers at the heart of the process, ensuring that they are active participants at every stage. At DRF, our approach will prioritize farmer-centered solutions, where every intervention is designed with the needs and insights of farmers as the guiding force. This means that farmer participation will not only inform but also validate the solutions we introduce, ensuring they are contextually relevant and practical for the community.

From the initial stages of identifying challenges to the design and implementation of solutions, farmers will be directly involved in the process. Their input, feedback, and experiences will be integral at every step, making them active stakeholders in the entire journey. By adopting a participatory approach, we aim to co-create solutions that resonate with farmers, empowering them to take ownership of the changes and drive their own path toward greater income and well-being. Ultimately, this inclusive and collaborative approach will

ensure that interventions are sustainable, effective, and tailored to the real-world needs of farmers.

6.2. Focus on Soil Health

Soil health is positioned as one of the foundational strategic principle shaping productivity, climate resilience, and rural livelihoods over the next decade. Healthy soil is treated not only as a production input but as a living system that underpins food security, water security, and climate resilience for small and marginal farmers. Declining soil organic carbon, nutrient imbalances, and microbiome loss are framed as national scale risks that directly threaten Viksit Bharat 2047 and rural prosperity, making soil restoration a non-negotiable pillar of the strategy rather than a standalone project.

The strategy anchors soil health within a One Health approach, recognising the interdependence of human, animal, and ecosystem health. By reducing chemical residues, rebuilding soil biology, and promoting responsible livestock and land management, regenerative practices are positioned as pathways to safer food, healthier communities, and more resilient local ecologies.

Soil health drives the choice of on farm practices: balanced nutrient management, enhanced organic matter, reduced tillage, and the use of biological inputs aligned with national programmes like the Soil Health Card Scheme. Regenerative methods such as direct seeded rice, zero tillage, cover cropping, and integrated farming systems are emphasised for their potential to rebuild soil organic carbon, cut fertilizer use and emissions, and stabilise yields for smallholders facing climate extremes.

As a strategic principle, soil health also shapes the system architecture envisaging state-of-art soil testing labs, portable diagnostics, and digital advisory platforms that turn soil data into actionable intelligence for farmers. A "soil first" digital mission integrating AI, satellites, and Soil Health Card data is proposed to provide local language advisories, early warnings on degradation, and precision recommendations for inputs, water, and cropping decisions.

The strategy treats soil health as a lever for policy alignment and farmer incentives, linking improvements in soil organic carbon and adoption of bio inputs to schemes like PM KISAN, insurance, credit, and emerging carbon markets. Public–private–community partnerships are envisaged to co-develop microbial solutions, smart testing kits, and inclusive skilling programmes for women and youth, so that "soil first" becomes a broad based movement rather than a technical guideline.

6.3. Complementing Existing Agri- extension Systems

DRF will work on solutions that complement existing systems (government, or private) to improve their reach and effectiveness. DRF believes in making farmers influential and responsible clients rather than passive beneficiaries to ensure sustainability.

Participatory methods like farmer-to-farmer extension will increase farmer ownership of the technologies that are effective. To ensure sustained and improved impact of the local extension machinery by the government / private players, co-creation and co-ownership will be crucial.

Since government extension workers are few in number, we will prioritize on encouraging local

communities to proactively participate by selecting a "lead farmer" to stand-in as the "local extension agent" from the community; which for the sake of clarity, needs to be emphasized is not a parallel extension system, but one that supplements/complements the existing system in order to improve the effectiveness of all stakeholders and encourage farmers to "own" the last-mile changes. In short, DRF endeavours to build a bridge between the community and the extension machinery through its efforts.

6.4. Adoption of Feasible and Scalable Technologies

The adoption of technologies in agriculture must be based on their ease of implementation, economic viability, local relevance, and the availability of a strong support system. At DRF, we focus on identifying and promoting technologies that meet these criteria, ensuring that they can be effectively integrated into existing farming systems. The priority is given to technologies that are easy for farmers to adopt with minimal disruption to their current practices. Furthermore, these technologies must be economically viable, delivering tangible benefits such as cost reduction, increased productivity, and long-term sustainability. DRF also emphasizes scalability, selecting solutions that can be expanded across regions and have a positive net impact on farmers' livelihoods. By prioritizing such technologies, we aim to foster large-scale adoption that empowers farmers and strengthens the resilience of agricultural systems.

6.5. Strengthening Community - Private Sector Linkage

DRF will work with private sector partners, including start- ups, or established companies if they add value either in one of the key focus areas or extend end-to-end support in the value chain for the farmers. Companies will be on-boarded to participate and be stakeholders in the community platforms nurtured by our efforts.

Such collaborations will help the community to leverage the value offered by the organization while simultaneously helping the organization to expand their business/ outreach Community/ individual ownership of franchisees, distributorships etc. our programs will ensure a continued symbiotic relationship between the community and private sector and focus on strengthening the farmers' skills to achieve self-reliance by opting to endorse Community organisations/ farmers' collectives so that they can gain from these linkages.

Further, the focal role of our work will be to create a fall back option for farmers in case of any set-backs during the transition phase and enable farmers to independently steer a way forward in the ecosystem.

6.6. Leveraging Existing Resources

Since no one group or organisation can address the complex and multi-disciplinary issues of agriculture sector, DRF supports collective problem inquiry and strategic collaborations to avoid reinventing the wheel and save time and valuable resources. We will partner with organizations/ resource agencies recognized for their expertise and further leverage their expertise/skill, under a "knowledge partnership" agreement to save time and resources.

Our programs will aim to be the platform to bring communities and stakeholders together to multiply impact. Our priority areas include Agriculture & Water, Farm Mechanisation, Bio-energy through crop residue management,

Agriculture Skill Academy and Non-Farm Livelihoods.

6.7. Design Thinking and Minimum Viable Product (MVP) Approach

At DRF, we embrace a culture of innovation and experimentation, always open to exploring new opportunities to address complex challenges. However, all new interventions and pilot projects will follow a structured approach grounded in Design Thinking and the Minimum Viable Product (MVP) model. The Design Thinking process encourages a deep understanding of the problems faced by farmers and other stakeholders through collective inquiry and empathic problem-solving. This approach allows us to develop innovative solutions that are directly aligned with user needs. The MVP approach ensures that these solutions are tested and refined with minimal resources and time, allowing for quick feedback and iterations. By pressure-testing new ideas, we can identify effective, scalable solutions while reducing risks and ensuring that interventions are both practical and impactful. This promotes continuous learning, adaptability, and user-centred design.

6.8. Data Driven M&E for Transparency and Traceability

DRF will use result-based management for effective execution and monitoring of our programs. The team will rigorously measure and evaluate program outcomes and practice data-based decision making; in addition to using a combination of result monitoring, process or activities monitoring, beneficiary monitoring as part of the monitoring framework.

While this is already integrated, we will strengthen it further by leveraging new technologies like GIS based crop growth mapping, Integration of MRV system etc. DRF's strategy is built on the belief that smallholder agriculture thrives through comprehensive systems transformation, rather than through standalone technological or agronomic solutions.

DRF is set to play a pivotal role in enhancing the national and global knowledge landscape by meticulously documenting evidence and insights from its field interventions, transforming them into top-tier knowledge products. This initiative will encompass the creation of practice-based case stories that highlight scalable models and contextual insights. It will also involve publishing book chapters and research papers in peer-reviewed international journals to enhance scientific knowledge of climate-resilient and regenerative agricultural systems from a practitioner perspective i.e., small and marginal farmers. Additionally, it will feature the sharing of evidence-informed viewpoints through opinion articles in prominent newspapers. With this comprehensive strategy for sharing knowledge, DRF will enhance policy discussions, provide valuable insights to practitioners and researchers, and establish itself as a trusted authority in regenerative agriculture, climate resilience, and sustainable rural livelihoods.

7. Strategic Priorities (2026-2030)

Our goal is to develop and expand integrated regenerative agriculture and livelihood systems that restore soil health, boost water productivity, and improve farm-efficiency and results in overall wellbeing of the farmers. We aim to mitigate climate risks for smallholder households, with a focus on empowering women and youth. This will be achieved

through the establishment of diverse income pathways both on and off the farm, ensuring stable incomes and fostering the long-term adoption of regenerative practices.

7.1. Strategic Priority 1*: Community Platform to promote Regenerative Agriculture practices at scale*

A key priority will be to nurture a platform of community volunteers for the promotion of regenerative agriculture practices, which results in co-benefits of well-being of farmers and ecology. The delivery of last-mile extension services through Lead farmers, acting as force multipliers for the public/ private/ digital extension system. Passionate farmers with a will to bring change to their community will be identified and nurtured by using a participatory method. They will bridge the last-mile extension gap and help the promotion of regenerative practices at scale

7.2. Strategic Priority 2: *Execution backed by Action Research to bridge the lab to land process of agriculture transformation.*

Strengthen action research and co-development of innovative solutions in agriculture and allied sectors to refine lab-scale technologies—developed under controlled conditions—for real-world farm applicability. This will accelerate the adoption of regenerative practices, enhance scalability, and address on-ground challenges like climate variability and soil variability, targeting a 20-30% improvement in technology transfer efficiency by 2030. It involves action research integration, co-development and refinement of the promising ideas/ solutions with collaborators followed by promotion of them among the farmers with integrated robust monitoring and evaluation

7.3. Strategic Priority 3: *Mainstreaming Women farmers in Indian Agriculture*

Mainstreaming women farmers is not a standalone gender program—it is a fundamental imperative for scaling regenerative agriculture, enhancing climate resilience, and building the resilient, equitable rural livelihoods. Embedding women's empowerment across all strategic components—regenerative agriculture, bioenergy, mechanization, skill development, diversified livelihoods, and livestock management—ensures that women benefit equitably from transitions and emerge as active agents of change in their communities.

Women have been the backbone of Indian agriculture since long back, constituting 60–80% of the agricultural labor force and performing 75–80% of critical farm operations—sowing, transplanting, weeding, harvesting, and post-harvest activities. Despite this substantial contribution, women farmers remain systematically marginalized, facing entrenched barriers that severely constrain their productivity, agency, and well-being. Training and extension services reach only 20–25% of women farmers, hampered by mobility constraints, cultural norms, and male-dominated program design. Women also bear a disproportionate labor burden; mechanization adoption remains low at 10–15% among women smallholders due to non-ergonomic, heavy equipment that increases physical drudgery and health risks.

These systemic inequities directly undermine farm productivity, reduce adoption of climate-smart and regenerative practices, and perpetuate cycles of poverty and food insecurity. World Bank estimates suggest that closing gender gaps could boost farm productivity by 20–30%, with cascading

benefits for household nutrition, resilience, and rural economies. Climate stress further exacerbates women's vulnerability; projected temperature rises of 1–2°C and erratic monsoons by 2030 are likely to increase women's workload through additional tasks like water fetching and livestock care, intensifying health risks and economic shocks. Without deliberate, inclusive intervention, urbanization and male migration could increase women's farm responsibilities to 85% in rural areas by 2030, compounding vulnerability in the absence of support systems.

7.4. Strategic Priority 4: *Policy Advocacy and Institutional Collaboration for Regenerative Scaling.*

Advocate for integrated policies and foster collaborations to scale regenerative agriculture, addressing fragmented frameworks and enabling systemic support for smallholders. Aim to influence national and state policies, for alignment of schemes with regenerative practices by 2030, enhancing funding flows and adoption rates. As noted in the challenges section, fragmented policies across agriculture, climate, energy, water, and rural development operate in silos, restricting coordinated investments and scaling sustainable practices amid rising climate vulnerability and resource depletion. This priority is crucial to bridge these gaps, integrating schemes like PMKSY, NLM, and NAPCC for holistic support. Benefits include streamlined subsidies for regenerative tools (e.g., soil health assessment, biochar and micro-irrigation), improved extension reach, reduced GHG emissions by 15-20% through policy-driven adoption, and empowered institutions for resilient livelihoods, aligning with NDCs and SDGs to boost well-being of smallholders.

8. Strategic Components

The Regenerative Agriculture strategy includes the following strategic components, which have been outlined, based on the present challenges faced by the small and marginal farmers in adoption of regenerative agriculture practices and newer opportunities to support their wellbeing.

8.1. Strategic Component 1 (SC01): *Agriculture and Water Practices*

Regenerative practices form the ecological backbone of the strategy. It focuses on restoring soil health through minimizing the disturbances to intrinsic ecological balances in soil while keeping an eye on the changes through episodic soil testing, site-specific-nutrient management (SSNM), improving water retention and use-efficiency, enhancing biodiversity and ground-water recharge, recycling and reusing excess storm water through in-situ and ex-situ conservation techniques and reducing greenhouse gas emissions, while sustaining farm productivity.

Core activities include:

- Adoption of climate-smart agronomic practices such as direct seeded rice (DSR), alternate wetting and drying (AWD), zero and reduced tillage, residue retention, crop diversification, and site specific nutrient management.
- SSNM focussing on generating high-quality soil test reports that allow site specific fertilizer recommendations, providing crop specific advisory based on soil test data, customized nutrient schedules instead of generic dose sheets, along with supporting CSR and climate action objectives by promoting higher input-use efficiency, and reduced environmental impacts across a large farmer base.

- To promote contour bunds, mulching, and cover crops increasing infiltration and soil moisture, while downstream farm ponds with associated modified aquifer recharge system and check dams to capture surplus runoff.

- To design a tertiary treatment system that can reduce remaining nutrients (N, P), suspended solids, pathogens, heavy metals, and organics using constructed wetlands with biochar integration.

- Transition from extractive input use to biologically driven soil systems, emphasizing organic carbon enhancement, microbial activity, and balanced nutrient cycles.

- Promotion of water-efficient cropping systems to address increasing water scarcity and climate variability.

Regenerative practices designed for agriculture and water improve climate resilience by increasing yield stability under stress conditions, reducing dependence on external inputs, and lowering exposure to droughts and floods. Furthermore, in-situ and ex-situ water interventions, planned at both farm and watershed levels for supplemental irrigation and aquifer recharge significantly reduce climate risk to the farming communities. Nevertheless, adoption requires risk-bearing capacity and supportive enabling conditions, which are addressed through the other strategic components.

8.2. Strategic Component 2 (SC02): *Surplus Biomass utilization as a Strategic Lever for Regenerative Transformation*

This strategic component establishes biomass management as a fundamental driver of regenerative and climate-resilient agriculture, turning crop residues from an environmental burden into valuable economic and ecological resources. Transforming agricultural waste into biogas, biochar, pellets, and briquettes, DRF is set to champion circular value chains that minimize residue burning, decrease greenhouse gas emissions, and enhance soil health. Decentralized circular biomass systems will seamlessly integrate into farming communities, boosting soil health, local energy security and creating new income opportunities. This component seamlessly combines climate mitigation, soil regeneration, and livelihood diversification, guaranteeing that environmental advantages are closely tied to real economic benefits for farmers. This strategy is in perfect harmony with the nation's renewable energy goals and the global commitments to combat climate change.

Core activities include:

- Pilot and demonstrate decentralized bioenergy processing units, including biogas, biochar, pellet, and briquette facilities, in targeted agro-climatic zones using community-based or farmer-producer models.

- Establish streamlined systems for aggregating and supplying crop residue by collaborating with farmer groups and local entrepreneurs to guarantee a reliable feedstock supply.

- Encourage the use of biochar on farms and within communities as a soil enhancer, seamlessly blending it with regenerative agriculture methods.

- Empower rural youth and farmers by enhancing their technical and entrepreneurial skills for the effective operation, maintenance, and management of bioenergy systems through comprehensive training and ongoing support.

The effective execution of this component will greatly diminish open-field residue burning, resulting in enhanced air quality and decreased climate and health risks in rural areas. Farmers

will unlock fresh and dependable income opportunities through residue-based bioenergy value chains, boosting their income stability and resilience against climate challenges. Utilizing biochar enhances soil organic matter, boosts nutrient retention, and increases water-holding capacity, all of which lead to lasting productivity improvements. Harnessing clean, locally sourced energy will diminish reliance on fossil fuels and cut down on household energy expenses. This component will enhance climate resilience at the farm level, while promoting inclusive rural enterprises and achieving energy self-sufficiency.

8.3. Strategic Component 3 (SC03): *Farm Mechanisation focusing on Small Farm Implements relevant for Small Land Holdings and Major Implements*

Enhancing precision, timeliness, and resource-use efficiency through suitable mechanization minimizes labor reliance and mitigates operational risks associated with methods such as DSR, ZT, AWD, and diversified cropping systems. Advanced technologies, such as AI, IoT, sensors, and automation, elevate decision-making and optimize inputs to new heights. Promoting affordable, small-scale, and women-friendly tools is crucial. These innovations aim to alleviate physical labor and ensure that regenerative practices are accessible to smallholder farmers across diverse agro-ecologies.

Core activities include:

- Introduce and implement innovative climate-smart machinery solutions for DSR, ZT, AWD, and diverse cropping systems. This includes cutting-edge precision seed drills, advanced laser land levellers, efficient no-till seeders, effective residue management tools, and versatile modular multi-crop planters.
- Combine cutting-edge digital and sensor technologies—like soil moisture sensors, automated irrigation systems, and AI-driven advisory tools—to enhance the management of water, energy, and resources.
- Create local access points such as tailored hiring centers, agricultural service enterprises, and community-based tool banks to enhance the affordability and availability of mechanization for small and marginal farmers.
- Elevate and expand the reach of women-friendly small farm tools designed for essential tasks like sowing, weeding, and harvesting, paired with specialized training to minimize labor and boost women's involvement.
- Enhance technical expertise with practical demonstrations, comprehensive operator training, and robust after-sales support systems to guarantee effective use, maintenance, and long-term adoption of mechanization technologies.

Implementing this component effectively will significantly alleviate labor burdens, reduce production costs, and minimize operational delays, particularly benefiting smallholder farmers and women. Enhanced precision and optimized resource utilization will lead to increased water productivity, improved soil health, and reduced greenhouse gas emissions, thereby bolstering climate resilience on the farm. Improved access to mechanization will reduce obstacles for adopting regenerative practices, allowing farmers to make the transition with greater confidence and sustainability. Farmers will see enhanced productivity, minimized climate risks, and increased economic stability. Meanwhile, rural youth and women will gain access to new skill-based jobs and entrepreneurial opportunities in agri-service ecosystems.

8.4. Strategic Component 4 (SC04): *Non-Farm Livelihoods for Improving Climate Resilience*

Understanding the inherent challenges faced by smallholder agriculture, DRF focuses on off-farm and non-farm income diversification as a key approach to strengthen livelihood resilience. Diversified income systems minimize household vulnerability to climate-related crop losses, ensure steady cash flow during challenging seasons, and empower farmers to manage short-term risks linked to the shift towards regenerative practices. Integrated crop–livestock systems provide a range of synergistic advantages, enhancing nutrient recycling, boosting overall farm productivity, and minimizing environmental impacts. This component tackles essential challenges like the shortage of climate-smart fodder and limitations on land. It champions scalable livelihood models, including improved forage cultivation and mushroom production, that are inclusive, low-risk, and environmentally sustainable, with a particular emphasis on empowering women and supporting land-constrained households.

Core activities include:

- Empower smallholder farmers to embrace mixed crop–livestock systems that improve nutrient cycling, maximize resource efficiency, and secure stable incomes through a variety of outputs.
- Implement and broaden the use of advanced planted forages like Super Napier to tackle fodder shortages, boost dairy productivity, serve as cover crops for enhancing soil health, and generate biomass for bio-gas production.
- Create decentralized, affordable mushroom production units aimed at empowering women farmers and landless households, enhanced by training, starter kits, and connections to the market.
- Provide organized training in livestock management, fodder cultivation, mushroom production, value addition, and essential enterprise skills via the Agri Skill Academy and peer learning platforms.
- Enhance access to input suppliers, aggregation systems, local buyers, dairy cooperatives, and bioenergy projects to guarantee economic sustainability and ongoing income generation.

By successfully implementing this component, we will greatly diminish income volatility for smallholder households, fostering diverse and complementary income streams that extend beyond just primary crop production. Enhanced fodder availability and integrated crop-livestock systems will boost dairy productivity, lower feed costs, and improve soil health through effective nutrient recycling and ground cover. Women and landless households will access dependable, low-risk income streams through mushroom production, enhancing financial inclusion and strengthening household resilience. In summary, a variety of livelihoods will enhance farmers' ability to endure climate challenges, promote the ongoing use of regenerative practices, and foster rural economies that are more stable, resilient, and environmentally sustainable.

8.5. Strategic Component 5 (SC05): *Livestock Management*

The objective of this component is to primarily integrate climate-resilient livestock practices into regenerative farming to boost productivity, animal welfare, and ecosystem health, targeting smallholder farmers with herds under 10 animals. Aim to cover 100,000+ farmers by

2030, increasing livestock-derived income by 25-40% while reducing methane emissions by 15-20% through better management.

Core Activities include:

- Sustainable Feeding and Nutrition: Develop balanced rations from farm residues (e.g., Napier, Super Napier, crop stover, silage) and introduce nutrient dense fodder systems to cut water use by 50% and feed costs by 30%.

- Mechanisation Integration: Tie into Component 3 by promoting small-scale tools like chaff cutters, and manure spreaders tailored for small holdings, reducing labor by 40% and enabling women-led operations.

- Market and Value Chain Development: Build cooperatives for milk, meat, and wool processing, with cold chain linkages to urban markets. Explore non-farm extensions (Component 4) like biogas from dung for household energy, creating additional revenue streams and reducing fossil fuel dependency.

- Climate Resilience Focus: Address risks like fodder shortages during droughts through insurance schemes and emergency feed banks. Use data analytics for predictive health monitoring, aligning with DRF's science-based approaches from our climate strategy discussions.

8.6. Strategic Component 6 (SC06): *Agriculture Skill Academy*

Introducing an Agri-Skill Academy to address the upcoming risk of younger generation avoiding farming as profession, to bridge the gap of data centred, technology driven precision agriculture with skilled work force aiming to reduce the migration and providing opportunities for women and youth within the rural areas

The Agri-Skill Academy will serve as DRF's primary hub for cultivating the knowledge, skills, and capacities essential for advancing regenerative and climate-resilient agriculture. Experience timely, practical, and locally relevant training on regenerative practices and climate-smart mechanization through an innovative blend of digital and community-based learning. Through the use of relatable, adaptable, and purpose-driven content, the academy will guarantee that smallholder farmers, women, and rural youth can easily access the resources they need. A robust peer-to-peer learning ecosystem will enhance digital delivery, cultivating trust, contextual learning, and accelerating adoption. The academy will unite to showcase agriculture as a contemporary, skilled, and technology-driven profession.

Core activities include:

- Create and implement flexible, locally relevant training programs focused on regenerative agriculture, climate-smart mechanization, and bioenergy systems using WhatsApp, bulk SMS, YouTube, and the Skillfy platform.

- Create Lead Farmer Platforms that facilitate peer-to-peer learning, showcase local demonstrations, and promote community-driven knowledge sharing.

- Empower rural youth and women by training and certifying them as agri-service providers in machinery operation, maintenance, repair, and digital advisory services.

- Incorporate cutting-edge digital decision-support tools and expert advisory services, such as mechanization guidance and crop and water management tips, into your training programs.

- Forge strategic alliances with machinery manufacturers, service providers, and educational institutions to ensure that skills training is perfectly aligned with market demand and employment opportunities.

The successful launch of the Agri Skill Academy will significantly enhance farmers' technical capabilities to adopt regenerative and mechanized practices, leading to improved productivity, enhanced resource-use efficiency, and increased climate resilience. Gaining access to reliable, locally pertinent information will mitigate adoption risks and enhance decision-making on the farm. New skill-based employment and entrepreneurship opportunities will empower women and rural youth, enhancing household income stability and fostering social inclusion. Community-driven learning platforms will enhance local innovation ecosystems and foster collaborative problem-solving. This initiative aims to strengthen rural economies, making them more resilient, skilled, and better equipped for the future.

9. Contribution to Overall Ecosystem

Equally significant is DRF's contribution to enhancing the knowledge ecosystem. Through comprehensive documentation, meticulous analysis, and strategic dissemination of field evidence, DRF will provide practice-based insights to the global scientific community, influence policy discussions, and support practitioners. Case studies, peer-reviewed publications, book chapters, and opinion articles will guarantee that insights from smallholder contexts inform research priorities and climate policy deliberations, establishing DRF as a reputable strategic contributor in regenerative agriculture and climate-resilient rural development.

Digital soil health reports generated under the strategic pillar of regenerative Agriculture and water strengthen the agrarian ecosystem by improving resource use efficiency, rebuilding soil and water systems, and enhancing climate resilience at both farm and watershed scales. By promoting input-use efficiency and regenerative soil practices (organic carbon enhancement, microbial activity, balanced nutrient cycles), farmers gradually shift from extractive input dependence to biologically driven fertility, lowering costs and environmental externalities across a large farmer base. Constructed wetlands with biochar-based tertiary treatment add a critical water-quality dimension by stripping residual nutrients, solids, pathogens, heavy metals and organics from return flows, reducing downstream pollution risks for communities and ecosystems. Coupled with water-efficient cropping systems (e.g., DSR, zero tillage, moisture-conserving cover crops), these interventions stabilize yields under stress, expand access to reliable supplemental irrigation, and lower climate risk for small and marginal farmers, while other strategic pillars focus on enabling adoption through knowledge, incentives and institutional support.

Livestock management provides diversified income streams and risk mitigation against crop failures, while non-farm livelihood options enhance household resilience through alternate employability, breaking cycles of poverty and dependency on rain-fed agriculture. Farm mechanization reduces labor costs, boosts productivity via timely operations, and bridges extension gaps through community-led models like MITRA, enabling yield increases translating to higher incomes per acre. Crop residue management promotes sustainable soil health, curbs stubble burning pollution, and supports climate resilience aligned with UN

SDGs 2, 8, and 13, fostering scalable, peer-to-peer knowledge sharing for long-term ecosystem vitality .

10. Partnerships

The DRF strategy overcomes the fragmentation in agricultural interventions—such as siloed policies across climate, energy, water, and rural development—by creating a collaborative, systems-oriented platform. This integrates financial resources from donors and CSR partners with technical expertise and community trust, emphasizing principles of additionality and inclusivity to scale regenerative agriculture strategy for smallholders, women, and rural youth. As a strategic integrator, DRF converges innovations from research institutions and startups with government policies and local farmer platform, ensuring long-term sustainability through shared risk-taking and evidence-based approaches. This model empowers donors to fund high-impact, measurable outcomes in the water-energy-climate nexus, converting vulnerable landscapes into resilient ecosystems. We believe this strategy will enable us to:

- Strengthen collaborations with existing partners while forging new ones;
- Enhance engagement with state and national governments to influence policies, plans, and schemes benefiting small and marginal farmers;
- Partner with international and multilateral organizations to advance innovations that improve farmer outcomes and ecological balance;
- Build alliances with expert agencies to leverage their technical support and solutions;
- Collaborate with private players and start-ups in the ecosystem to facilitate farmers' access to inputs and markets for their produce.

11. Conclusion

This strategy underscores DRF's commitment to transforming smallholder agriculture via a holistic, climate-resilient, and livelihood-centered model. By transcending isolated efforts, it integrates regenerative practices, climate-smart mechanization, circular bioenergy, skill building, diversified livelihoods, and soil health under a One Health framework. This foundation, bolstered by economic, technological, and institutional enablers, directly addresses smallholders' core vulnerabilities, including climate exposure, labor shortages, resource scarcity, and income instability.

The six strategic components form a unified pathway to amplify adaptation, mitigation, and rural prosperity: regenerative agronomy boosts soil carbon, water efficiency, and yield stability; mechanization enables precise, inclusive operations; bioenergy converts residues into resources while curbing emissions; the Agri Skill Academy equips stakeholders for innovation; diversified livelihoods, including crop-livestock integration and non-farm ventures like mushroom cultivation, provide risk buffers; livestock management enhances productivity and circularity; and action research bridges lab-to-land gaps for scalable solutions.

Central to this is soil health as the One Health cornerstone, linking regeneration to ecosystem vitality, nutrition quality, animal and human well-being, and climate outcomes—delivering co-benefits in sustainability, public health, and risk reduction across interventions.

Overall, the strategy offers a scalable, evidence-based blueprint aligned with national

climate pledges, state plans, and SDGs, blending ecological restoration with economic and human development to reframe agriculture as a resilient, equitable livelihood amid accelerating climate change.

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