CGIAR Initiative Report

Integrating Multidimensional Sustainability Assessment into Decisions and Policies for Promoting Sustainable Farming in India

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CGIAR Sustainable Intensification of Mixed Farming Systems

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Summary:

The study explores integrating a multidimensional sustainability framework to promote sustainable farming practices in India, focusing on the diverse agroecological zones of Latur and Solapur in Maharashtra. These two districts, chosen for their differing climatic and socio-economic conditions, showcase unique agricultural practices and resource use. Latur leans toward traditional farming with cash crops like soybean and sugarcane, while Solapur embraces a more diverse cropping pattern that includes horticulture and floriculture, with crops like guava, grapes, and chrysanthemums. The study's careful approach, including stratified sampling and household categorization into farm household typologies, highlights its commitment to capturing the complexity of regional diversity and socio-economic challenges. The study identifies two distinct farm types in each district, differentiated by socio-economic factors such as land ownership, income, and access to irrigation. Farm Type 2 households, with larger landholdings and better resource access, tend to fare better in sustainability. In contrast, Farm Type 1 households, constrained by limited resources and lower education levels, struggle with weaker performance. This disparity underscores systemic inequities that demand targeted interventions to support the most vulnerable. Using the Multidimensional Sustainability Assessment Tool (MSAT), the study evaluates sustainability across five key areas: economic, environmental, social, human well-being, and productivity. Both districts perform reasonably well in water management and health but show major weaknesses in economic resilience and biodiversity conservation. Household-level analysis reveals more profound disparities often masked by aggregate scores, with many households falling short in income, education, and gender equity. This emphasizes the need for disaggregate level analysis and inclusive policies addressing systemic and localized issues. The study offers clear recommendations for improving the sustainability of mixed-farming systems. Localized solutions should address unique challenges in each district, such as providing better access to modern tools in Solapur and enhancing access to institutional credit in both regions. Encouraging biodiversity-friendly farming and improving gender equity can tackle systemic gaps while replicating successful practices from better-performing farm types can help uplift others. Targeted financial and educational support for marginalized households is also crucial for fostering equitable development.

In conclusion, the study highlights the interconnected challenges of resource distribution, technological advancement, and socio-economic equity in Maharashtra's farming systems. While some progress has been made, systemic vulnerabilities persist, requiring a comprehensive and multidimensional approach. The MSAT framework provides valuable insights to develop tailored strategies consisting of bundled solutions, paving the way for resilient, inclusive, and sustainable agricultural practices in India.

1. Introduction:

Agriculture forms the critical foundation of India's rural economy, providing livelihoods for a substantial portion of the population while simultaneously confronting persistent challenges that impede sustainable growth and rural development. The sector faces complex, interconnected obstacles including climate variability, land constraints, low productivity, and systemic market barriers and risk that fundamentally challenge its potential to alleviate rural poverty and promote equitable economic transformation (World Bank, 2022). India's agricultural transformation remains uneven, marked by significant regional disparities in productivity and resilience. States like Maharashtra, which is our present study location and project site represent diverse agro-ecological regions, exemplify the challenges posed by climate variability, particularly in rainfed areas (Swami & Parthasarathy, 2021). Despite policy efforts to expand irrigation and improve infrastructure, fluctuating productivity trends and persistent rural income disparities highlight the need for more integrated approaches (Daundkar & Pokharkar, 2020; Kumar et al., 2015).

In this context, mixed-farming systems—which strategically integrate crops, livestock, and diversified agricultural enterprises—emerge as a promising pathway to enhance agricultural productivity, resilience, and sustainability. The realization of this potential necessitates a comprehensive approach to policy and decision-making, one that incorporates multidimensional perspective addressing social, economic, and environmental dimensions in a holistic and integrated manner. Also, studies have shown that integrated mixed farming systems—combining crops and livestock—can significantly enhance productivity and profitability under both rainfed and irrigated systems and (Meena et al., 2022). Similarly, the rise of small multi-enterprise farms in India reflects structural shifts toward models resembling those in East and Southeast Asia, driven by the need for resilience and resource efficiency (Djurfeldt & Sircar, 2016).

Therefore, the farming systems analysis considering multidimensional sustainability is critical for tailoring policies to the diverse needs of India's farming communities. These assessments analyze the economic, social, and environmental impacts of farming practices and interventions, enabling policymakers to design context-specific solutions that address regional disparities across semi-arid, sub-humid, and humid regions (Lee, 2005). For instance, mixed methods research combining agricultural household surveys and qualitative techniques can provide nuanced insights into the challenges and opportunities specific to these diverse agro-ecological zones. Policy innovations must recognize the multidimensional nature of sustainability to ensure inclusive and equitable agricultural growth. Measures such as promoting crop diversification toward high-value crops can enhance farmer welfare by generating higher returns and creating employment opportunities (Singh, 2012; Anuja et al., 2020). However, equitable access to resources and markets remains critical, as the emergence of a class of wealthy farmers has deepened rural inequalities (Mohanty, 2001). Integrating multidimensional sustainability assessments into agricultural policies is critical for advancing sustainable mixed-farming systems globally, including India. By addressing regional disparities, promoting diversification, and empowering smallholder farmers through targeted interventions, India can foster a resilient and equitable agricultural transformation that aligns with long-term environmental and socio-economic goals, contributing to sustainable development and rural well-being (Ansari et al., 2023; Paul et al., 2023).

Against this background, this study employs a multidimensional framework integrating technology adoption, market access, food security, and environmental sustainability to assess agricultural transformation opportunities for India, specifically for Maharashtra's farming households. By analyzing these interconnected dimensions, the study aims to identify tailored strategies and bundled solutions that promote sustainable mixed-farming systems, address regional disparities, and enhance the resilience and productivity of smallholder farmers. Integrating multidimensional sustainability assessments into agricultural policies and decisions can help in advancing sustainable mixed-farming systems in India. Such an approach ensures that interventions are context-specific, inclusive, and aligned with long-term environmental and socio-economic goals.

2. Study location and study methodology:

2.1. Location and sample selection:

The study was conducted in two demographically and geographically diverse districts of Maharashtra, India—Latur and Solapur—selected through a rigorous process involving secondary data analysis, consultations with key stakeholders, and preliminary site visits (figure 1). Stratified sampling was employed to select specific villages within these districts, ensuring the representation of distinct agricultural practices and rural characteristics. Matephal village in the Latur block of Latur district was chosen for its unique attributes, while Bhend village in the Madha block of Solapur district was selected to represent an arid region. A total of 145 households across the two selected villages were surveyed. This sampling approach was designed to capture regional diversity while facilitating an in-depth understanding of Maharashtra's complex agricultural systems and rural livelihoods. The careful selection of study sites ensured that the surveyed villages reflected the essence of their respective regions, enabling a detailed and comprehensive analysis of the agricultural landscape and rural life in the study areas.

2.1. Construction of farm typology and detailed description:

Constructing farm typologies is helpful in understanding the heterogeneity within farming systems and for tailoring interventions to specific needs and contexts. By categorizing farms into relatively homogeneous groups based on key livelihood covariates (not fixed and may vary from region to region), it becomes possible to analyze the diverse strategies farmers can employ to sustain their livelihoods. This classification enables researchers and policymakers to identify common challenges, opportunities, and resource constraints faced by different farm types. These typologies provide a foundation for designing targeted policies and interventions better aligned with the unique characteristics and needs of distinct farming communities, ultimately contributing to improved agricultural productivity and rural development outcomes.

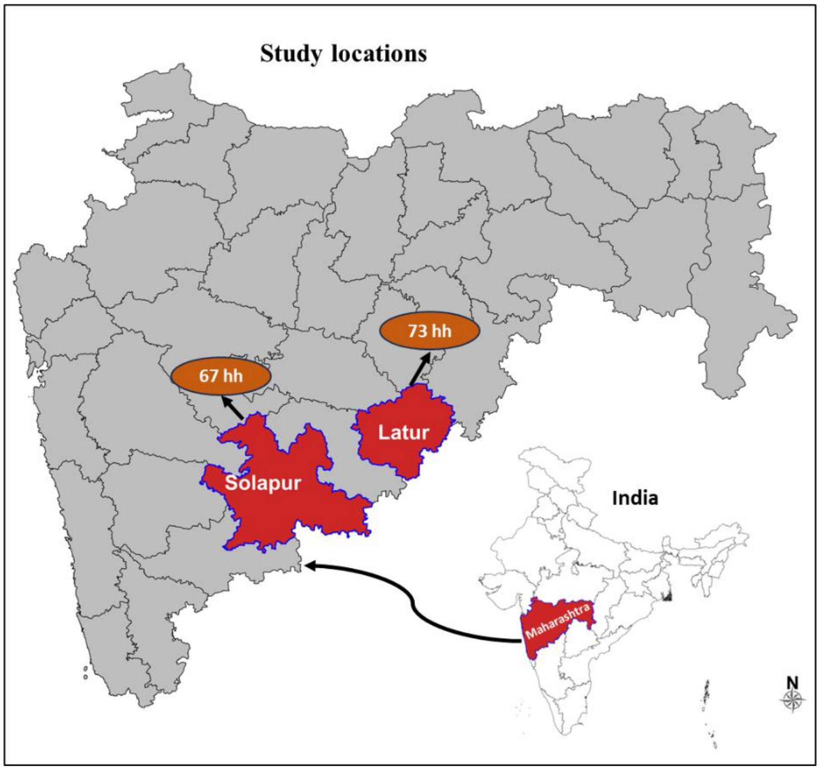

Figure 1: Study location

In this context, ten key livelihood covariates were considered to develop relatively homogeneous farm household typologies in this study. These included family size, the age and education level of the household head, land ownership, the proportion of irrigated land, household income, savings, access to credit, and livestock ownership. Principal Component Analysis (PCA) was employed to reduce the dimensionality of the data and identify the most influential variables. This was followed by the k-means clustering[1] method systematically classified households into two relatively homogeneous farm types for each study location. This robust approach provided a foundation for understanding the socio-economic and agricultural dynamics within the study areas, offering insights into farmers' livelihood patterns and resource access.

The analysis revealed significant variations in livelihood patterns across the two farm types in the Latur and Solapur districts, particularly regarding land ownership, income levels, and asset holdings (table 1). Farm type 2 households in both districts demonstrated better access to resources and stronger economic indicators than those in farm type 1. For instance, farm type 2 households owned larger landholdings and a more significant proportion of irrigated land, which allowed them to achieve higher annual incomes and accumulate greater savings. Additionally, these households exhibited better access to credit and a higher number of livestock, particularly cattle, reflecting their more substantial asset base and improved livelihood opportunities. On the other hand, farm type 1 households, although more numerous in both districts, faced significant constraints regarding land and

[1] The k-means clustering method is a way to group similar items together into a set number of categories based on their shared characteristics.

asset ownership and limited access to irrigation. These limitations were reflected in their lower incomes and reduced savings, indicating weaker financial stability. The educational attainment of the household heads was also notably lower among farm type 1 households compared to farm type 2, particularly in Latur. This educational disparity may influence the ability of farm type 1 households to access and effectively utilize available resources. Also, interestingly, while family size remained relatively consistent across farm types and regions, Solapur's farm type 2 households stood out for their significantly larger landholdings and higher financial capacity compared to all other groups. This distinction underscores the resource advantage farm type 2 households enjoy in Solapur, contributing to their better livelihood outcomes.

Table 1: Livelihood Patterns of Farmers in Latur and Solapur by Farm Type

	Latur (N=73)		**Solapur (N=67)**	
Particulars	**Farm type 1**	**Farm type 2**	**Farm type 1**	**Farm type 2**
Proportion of households (%)	67	33	80	20
Age of the household head (years)	52	39	48	39
Education level of the household head (years)	6	12	7	11
Family size (No)	5	4	4	5
Land ownership (Ha)	1.17	1.81	1.18	3.41
Proportion irrigated area (%)	25	54	77	84
Households' yearly income (INR)	89320	150440	199696	571429
Household's savings (INR)	19640	70520	58804	167500
Credit access (INR)	0	6000	7857	128571
Ownership of cattle (No)	0.22	1.00	0.77	1.57
Ownership of small ruminants (No)	0.02	0.00	0.05	0.00

3. Basic information about the study locations:

3.1. Infrastructure, institution and farm implements:

The comparative analysis of basic infrastructure and institutional accessibility between Latur and Solapur highlights notable differences and similarities in their developmental landscapes (table 2). Both regions demonstrate commendable availability of essential institutions like educational centers, health facilities, and cooperative societies, ensuring fundamental support to the rural populace. However, the accessibility within these categories varies subtly, with Solapur often having these facilities closer to the villagers than Latur. For instance, while both villages have schools and village information centers nearby, Solapur generally benefits from shorter distances, potentially fostering greater ease of access for the community. A significant divergence is evident in banking facilities. The commercial banks are not available in the village but are located at a distance of 8 km from Latur village and 5 km from Solapur village. Cooperative societies, critical for collective farming and resource pooling, are available in both regions, but Solapur enjoys a logistical advantage with closer proximity.

When evaluating the accessibility of farm implements, a pronounced disparity between the two regions becomes apparent (table 3). Latur showcases better availability of traditional and modern implements, such as the animal-drawn plow, broad bed and furrow (BBF) maker, and grading machine, which are crucial for efficient farming practices. Conversely, Solapur demonstrates limited access to such machines and tools. However, it offsets this gap with the availability of newer technologies like the Happy Seeder and power-operated weeders, indicating a shift towards mechanization. Both regions, however, share common ground regarding access to vital implements like tractors, threshers, and seed drills, which form the backbone of contemporary agriculture. The absence of specific tools, such as fruit-picking machines, in both areas underlines a broader need for advancements in niche agricultural equipment to cater to diverse farming needs.

Overall, Latur appears relatively well-equipped with traditional farming implements and institutional infrastructure, though accessibility remains challenging due to distances. While lacking in some conventional tools and a local banking facility, Solapur compensates through improved proximity to essential services and selective mechanization. This analysis underscores the importance of tailored interventions in both regions to enhance accessibility and technological adoption, fostering balanced rural development.

Table 2: Availability and accessibility of basic infrastructure and institutions

Particulars	**Status**	**Latur**	**Solapur**
Educational institute	Available	Yes	Yes
	Distance (Km)	0.25	0.10
Village information center	Available	Yes	Yes
	Distance (Km)	0.25	0.00
Primary health center	Available	Yes	Yes
	Distance (Km)	0.25	0.50
Seed/ fertilizer dealer	Available	Yes	Yes
	Distance (Km)	0.25	0.40
Bank	Available	Yes	Yes
	Distance (Km)	8.00	5.00
Cooperative society	Available	Yes	Yes
	Distance (Km)	1.00	0.50

Table 3: Level of accessibility of various farm implements

Farm implements	**Ease of access**	
	Latur	**Solapur**
Animal drawn plough	Yes	No
BBF maker	Yes	No
Fruit picking machine	No	No
Grading machine	Yes	No
Happy seeder	No	Yes

Harvester	Yes	Yes
Power operated weeder	No	Yes
Seed drill/ planter	Yes	Yes
Thresher	Yes	Yes
Tractor	Yes	Yes

3.2. Cropping pattern and major and minor crops:

The cropping pattern in the two study locations, Latur and Solapur, reveals both shared trends and notable regional variations in cultivating field crops, vegetables, fruits, and flowers (table 4 & figure 2). Regarding field crops, both regions exhibit diversity but differ in the prominence of specific crops. Latur primarily relies on cash crops, focusing on sugarcane and soybean as major crops, reflecting a production system geared towards high-value, market-oriented agriculture. In contrast, Solapur demonstrates a broader mix of major crops, including sugarcane, maize, and pulses like black gram, indicating a relatively diversified approach to field cropping that accommodates food and cash crops.

The minor field crops in both regions suggest some similarities but with subtle differences in their crop baskets. Sorghum and chickpea emerge as common minor crops in both locations, showcasing their importance as subsistence or secondary crops. However, Solapur adds wheat to its list of minor crops, possibly due to its adaptation to local climatic and soil conditions. In contrast, Latur focuses on pigeon peas, reflecting the region's emphasis on pulse cultivation.

The two regions also highlight distinctive patterns when comparing vegetable, fruit, and flower cultivation. Onion is a significant vegetable crop in both locations, underscoring its economic value and widespread acceptance among farmers. Solapur further diversifies its crop portfolio with guava and grapes as major fruit crops, illustrating a stronger inclination toward horticulture. This focus may be linked to market demand and the availability of agro-climatic conditions that favor fruit production. Regarding minor crops, Solapur stands out by cultivating custard apples, bananas, and chrysanthemums, reflecting its greater engagement in perennial fruit production and floriculture. Latur, in contrast, lacks significant minor crops in this category, pointing to a narrower crop diversification strategy.

Overall, while Latur prioritizes field crops with a focus on cash crops, Solapur demonstrates a more balanced approach by integrating horticulture and floriculture alongside its field crops. This contrast highlights how local agroecological conditions, market opportunities, and cropping strategies shape the agricultural landscape in each region.

Table 4: Cropping pattern in the study locations: major and minor crops

Crop type	Category	Latur	Solapur
Field crops	Major	Soybean, Sugarcane	Sugarcane, Maize, Black gram
	Minor	Sorghum, Chickpea, Pigeonpea	Sorghum, Wheat, Chickpea
	Major	Onion	Onion, Guava, Grapes

Vegetables, fruits and flowers	Minor	---	Custard apple, Banana, Chrysanthemum

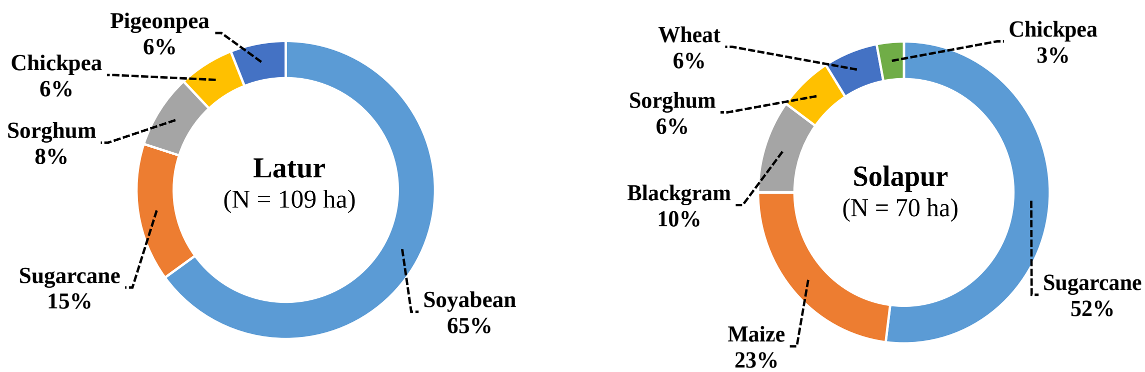

Figure 2: Cropping pattern in the study locations: area covered by different crops

4. Multi-dimensional sustainability assessment of smallholder farming systems:

4.1. About the Multi-Dimensional Sustainability Assessment Tool (MSAT):

The Multi-Dimensional Sustainability Assessment Tool for smallholder farming systems (MSAT), developed by ICRISAT, represents a significant advancement in evaluating the sustainability of smallholder farming systems. Rooted in the Sustainable Intensification Assessment Framework (SIAF), the MSAT builds upon its predecessors by incorporating a broader, more detailed set of indicators. It organizes sustainability into five key domains: environmental, economic, productivity, social, and human well-being (figure 3). This framework, characterized by its adaptability and ease of use, offers a more holistic understanding of farming systems using 124 measurable indicators. These indicators have been refined through extensive consultations with farmers, researchers, and development practitioners, ensuring relevance and contextual accuracy.

One of MSAT's strengths lies in its flexibility. It allows stakeholders to assign weights to indicators, reflecting localized priorities. This participatory approach enhances its applicability across diverse agricultural contexts. Moreover, the aggregated index, with a maximum value of 100, provides a precise and comparative measure of sustainability and resilience at different scales (Figure 4). This quantitative output simplifies complex assessments, making them accessible to a broad audience while maintaining analytical rigor.

The MSAT offers a more detailed and actionable framework compared to other predecessor frameworks. Its domain-specific focus enables stakeholders to identify precise entry points for co-designing strategies that enhance sustainability and resilience. The user-centric design further underscores its utility, bridging the gap between academic frameworks and practical implementation. While both frameworks aim to guide sustainable agricultural practices, MSAT's comprehensive structure and stakeholder-driven methodology position it as a transformative tool for addressing the multi-dimensional challenges smallholder farmers face globally.

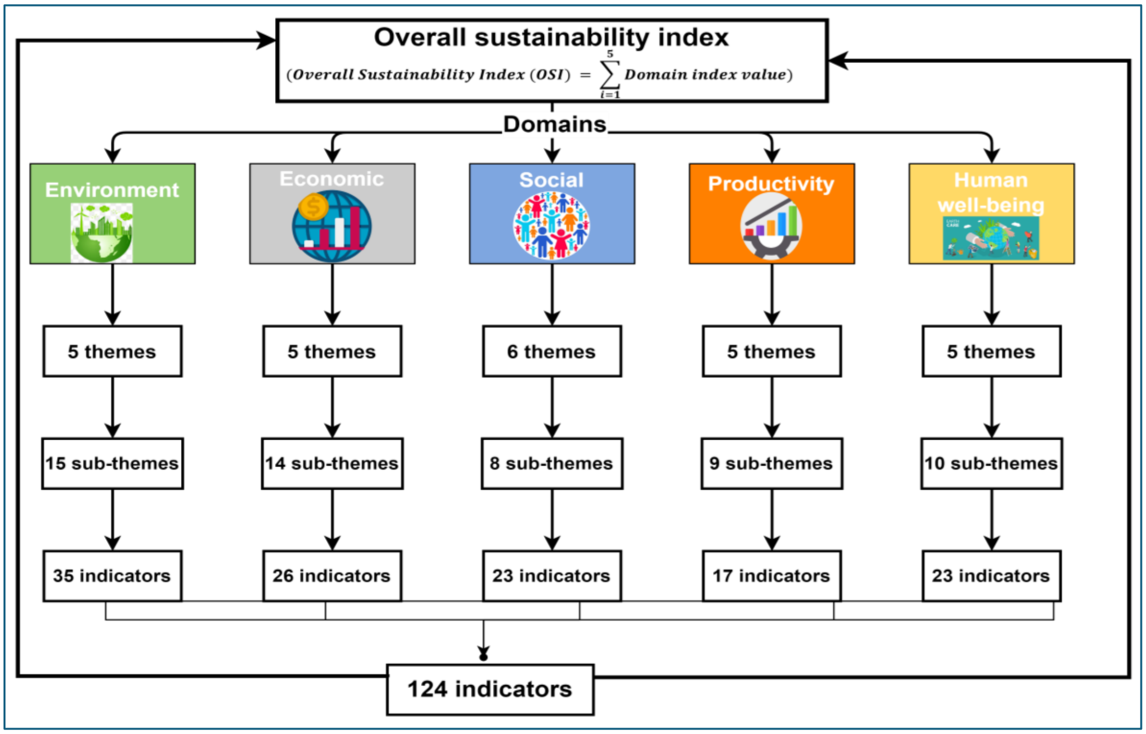

Figure 3: Flow-chart of MSAT: Journey from domains to indicators

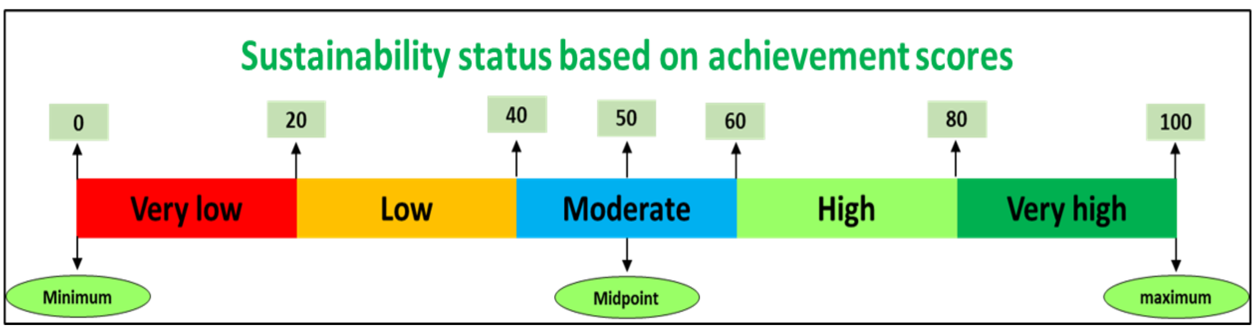

Figure 4: Sustainability status based on achievement scores

5. Exploring multidimensional sustainability in farming systems - leveraging MSAT to identify key intervention points:

Agricultural sustainability is a critical priority in the face of mounting global challenges, including climate change, food insecurity, and resource depletion. Smallholder farming systems are inherently complex, encompassing ecological, economic, and social dimensions that interact dynamically over time. Assessing these systems' sustainability requires comprehensive tools that capture this multidimensionality and identify actionable leverage points for improvement. The Multidimensional Sustainability Assessment Tool (MSAT) offers a robust framework for evaluating farming systems holistically, enabling stakeholders to pinpoint areas of vulnerability and opportunity. This study leverages MSAT to understand the sustainability of diverse farming systems, providing insights to guide interventions and foster resilient agricultural practices.

5.1. Overall sustainability status at the aggregate level and household level:

The overall sustainability score, described in Equation 1, is a comprehensive representation derived from the combined scores across five domains. This assessment offers insights into the sustainability status at district and household levels, as illustrated in Figure 3.

$$\boldsymbol{Overall\ Sustainability\ Index\ (OSI)} = \sum_{i=1}^{5} \boldsymbol{Domain\ index\ value} \qquad (1)$$

The sustainability assessment incorporates district and household-level scores, offering a comparative understanding of sustainability status.

Figure 5 compares overall sustainability achievement scores for different farm types in two districts alongside household-wise sustainability achievement score distributions within each district. A critical review of this analysis reveals distinct patterns that underline disparities in performance and areas requiring targeted intervention. For both districts, there are variations in sustainability achievement scores between farm types. One type consistently demonstrates better sustainability outcomes, indicating potential differences in resource management, practices, or external support. However, neither farm type in either district reaches a satisfactory benchmark of half the possible achievement score, suggesting systemic challenges that limit progress.

The household-wise distribution of sustainability scores further emphasize the critical issues, with a significant proportion of households in both districts falling within the area of concern. This reflects widespread vulnerabilities across farming households, irrespective of location. While there are subtle differences between districts, with one exhibiting slightly higher household scores on average, the overall picture points to a shared struggle to overcome the identified barriers to sustainability.

The consistent underperformance, particularly in households scoring within the concern range, signals an urgent need for tailored policy and programmatic responses. Interventions should focus on empowering the most vulnerable households by addressing gaps in resources, technology, and knowledge. Simultaneously, the relative success of one farm type across both districts could offer insights into practices or systems that might be adapted for broader implementation.

In summary, the findings reveal persistent gaps in sustainability achievements across farming systems in both districts. Addressing these gaps requires a dual approach: empowering underperforming households to move out of the concern zone and scaling successful practices from relatively better-performing farm types. Such efforts are essential to fostering equitable and sustainable agricultural development.

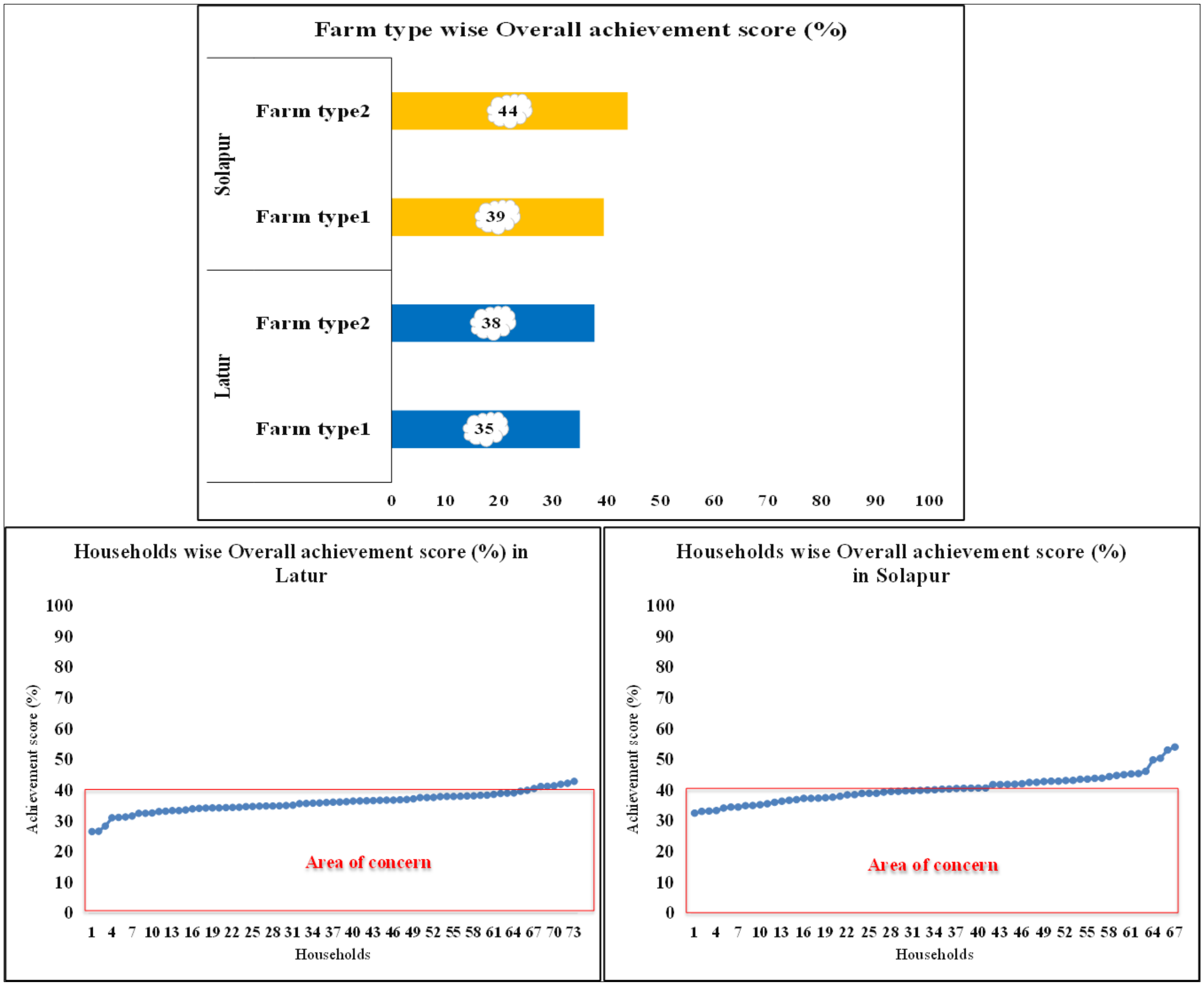

Figure 5: Comparative analysis of farm type and household-wise overall sustainability achievement scores across study locations

5.2. Domain-wise achievement status at the aggregate level and household level across locations:

Figures 6 & 7 represent domain-wise sustainability achievement scores across locations at aggregate and household levels, with detailed comparative data across farm types and domains. While the figures provide valuable insights, a few critical observations emerge that must be discussed.

The analysis illustrates a mixed performance across domains and household levels. Aggregate achievement scores reveal notable disparities, indicating uneven progress among different domains. While some domains demonstrate above-average achievements, others fall well below the midpoint, signaling potential challenges. Domains consistently below the 40% threshold emerge as critical areas requiring targeted interventions. Such trends underscore the need for nuanced strategies to address underperformance in these domains. At the household level, variations between them add another layer of complexity. Certain households exhibit strong achievements in specific domains, suggesting that localized practices or conditions might influence success rates. Conversely, other households struggle to meet even baseline expectations in multiple domains. This heterogeneity implies that a one-size-fits-all approach may not address these disparities. Additionally, the comparison across locations highlights geographic variations in achievement scores. Locations with higher overall scores benefit from enabling factors that could be replicated in lower-performing areas. However, the persistence of domains below the concern threshold across multiple locations suggests systemic issues that transcend local conditions, warranting a broader policy-level response.

Also, the comparison between aggregate and household-level achievements highlights another essential concern. While aggregate scores may appear satisfactory, they can mask significant disparities at the household level, particularly among less advantaged farm types. This points to the need for an inclusive approach that ensures all households and domains benefit equitably from development efforts.

Finally, the findings emphasize a dual focus on systemic and localized strategies to enhance domain-wise achievements. Tailored interventions, informed by farm-type and location-specific challenges, alongside broader reforms addressing systemic gaps, could drive progress. The persistent underperformance in certain domains highlights the urgency for targeted action to ensure no domain or household lags.

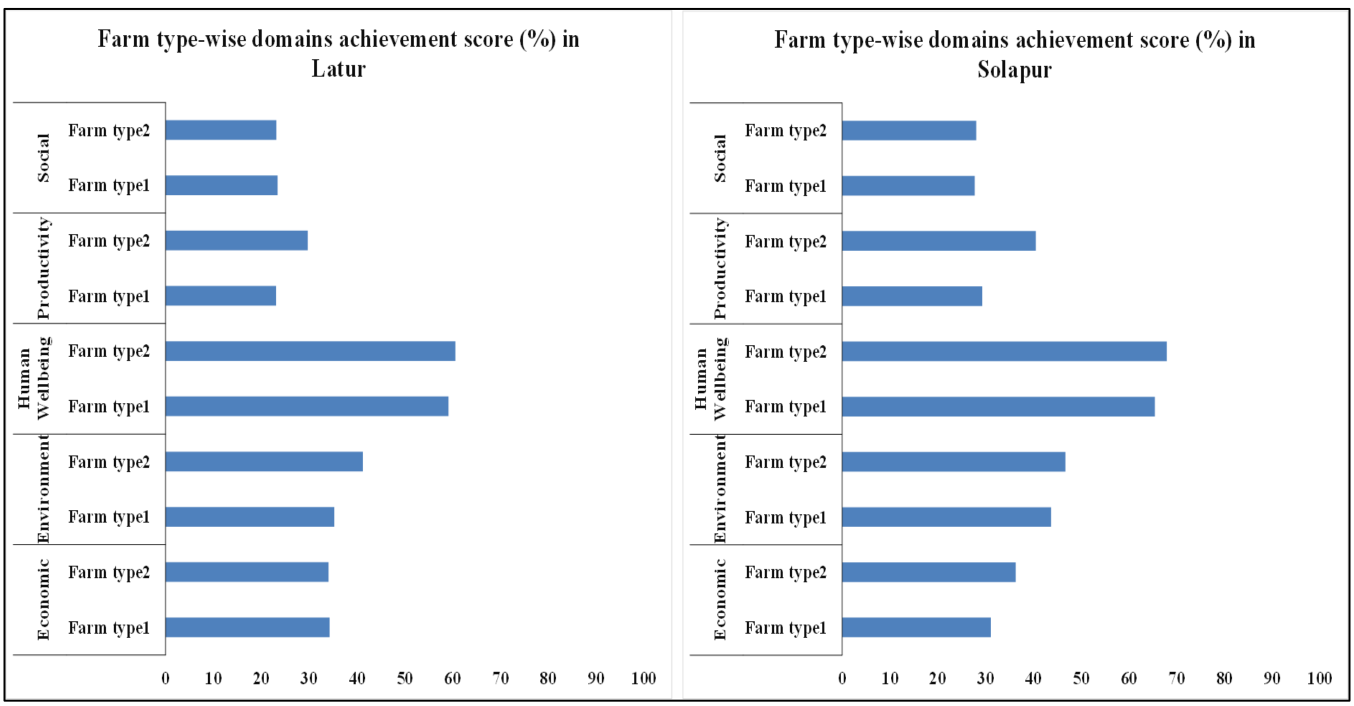

Figure 6: Domain-wise and farm-type-wise overall achievement scores across locations

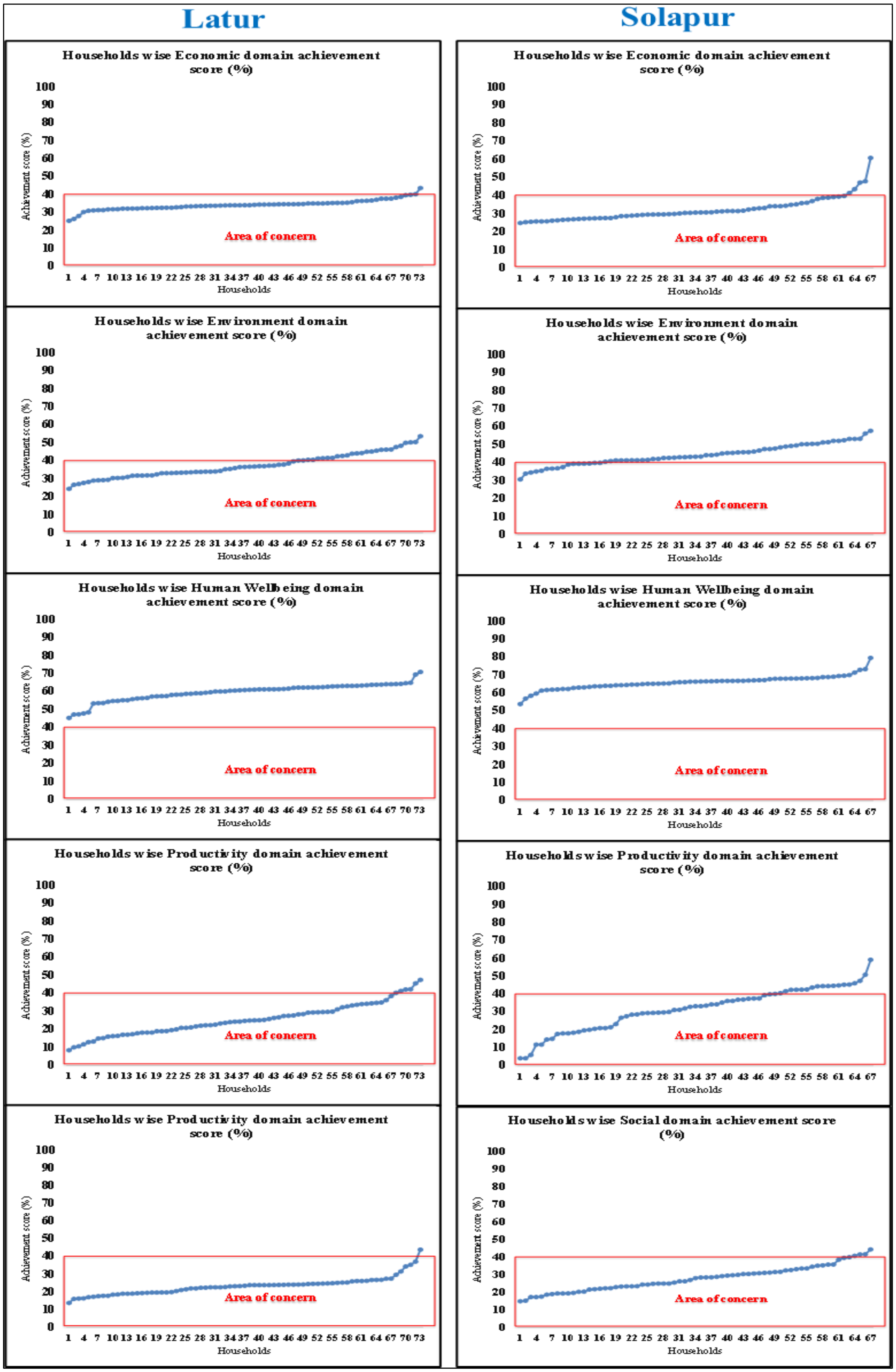

Figure 7: Comparative analysis of domain-wise and household-wise overall achievement scores

5.3. Theme-wise achievement status at the aggregate level across locations:

The table below (table 5) provides a comparative overview of theme-level sustainability achievement scores across two farming types in Latur and Solapur. A critical review reveals several areas of concern, strengths, and disparities. The comparative analysis of achievement scores across themes and locations highlights key strengths and challenges. While some domains, such as health, living conditions, and cost optimization, exhibit commendable performance, several critical areas of concern persist. Economic vulnerabilities are evident in low income and expenditure scores and inadequate resources and infrastructure, particularly in Solapur's farm type 1. Environmental sustainability remains uneven, with significant biodiversity and soil management issues, though water management and energy utilization show promise. Human well-being is relatively strong, though education and nutrition require improvement. Productivity scores are concerning, particularly for cropping systems and livestock management. Social dimensions reveal systemic inequities, with low access to subsidies, poor gender equity, and limited information access. These findings imply a need for targeted interventions to address economic fragility, environmental degradation, and social inequities, alongside leveraging existing strengths in health and resource efficiency to foster holistic development.

Table 5: Theme-wise achievement status at the aggregate level across locations

Domain	Theme	Latur		Solapur	
		Farm type1	Farm type2	Farm type1	Farm type2
Economic	Farming orientation	46	48	40	47
	Income and expenditure	6	7	9	17
	Optimized cost of production	89	82	86	79
	Resources and Infrastructure	41	39	28	32
	Risk management	21	23	20	29
Environment	Biodiversity	4	17	17	30
	Climate, Air and Energy Utilization	62	62	66	66
	Land	27	32	38	36
	Soil and waste management	37	40	33	33
	Water	42	52	55	65
Human Wellbeing	Education	44	52	43	50
	Health	77	78	79	81
	Living conditions	75	71	82	83
	Nutrition and Food Security	48	50	55	57
	Work-life balance	62	62	82	81
Productivity	Cropping System	6	14	0	0
	Factor Productivity	16	16	15	27
	Livestock production and management	28	42	42	56
	Technical inputs	29	27	30	51
	Yield	29	39	43	49
Social	Access to subsidies and government services	17	19	28	23
	Financial and non-financial inclusion	39	36	39	41
	Gender equity and empowerment	17	20	17	18
	Information access	6	0	16	18
	Labor Rights and working conditions	34	35	48	46
	Poverty levels, Employment opportunities and Remuneration	20	20	18	20

5.4. Implication for co-designing sustainable farming system

The findings on the multidimensional sustainability assessment of farming systems highlight critical insights for co-designing sustainable agricultural practices. Leveraging the Multidimensional Sustainability Assessment Tool (MSAT), the analysis underscores systemic challenges and localized disparities across farm types, districts, and sustainability domains. Comparative data reveal that no farm type consistently achieves satisfactory benchmarks, reflecting structural vulnerabilities in resource management, technology adoption, and external support systems. Notably, certain farm types exhibit relatively higher scores, suggesting the potential of replicating their practices for broader impact. A significant concern emerges from the disparity between aggregate and household-level performance. While aggregate scores may suggest progress, they often mask substantial inequities at the household level, particularly among marginalized groups. The domain-wise analysis further reveals that critical dimensions, such as economic resilience, biodiversity conservation, and gender equity, consistently underperform. These persistent deficits highlight the need for targeted and nuanced interventions. Geographic variability in scores reinforces the importance of localized strategies, as higher-performing regions exhibit enabling factors that can inform practices in underperforming areas. Additionally, the thematic analysis reveals systemic fragilities, particularly in economic and environmental dimensions, alongside modest progress in health and resource efficiency. Interventions should focus on enhancing income, education, and infrastructure while promoting sustainable biodiversity and soil management practices. Addressing these gaps requires a dual approach—empowering vulnerable households through targeted policies and scaling successful practices from better-performing farm types. By integrating localized insights with systemic reforms, stakeholders can co-design inclusive and resilient farming systems that foster long-term sustainability.

A vast diversity of sustainability score achievement across households, with a few households scoring very high and a large proportion of farmers underperforming, underscores the need for an integrated approach from farming systems to landscape scale harnessing the value of natural resources and value chains. Targeted financial and institutional support for smallholder farmers will also be crucial to overcoming systemic vulnerabilities. Education, skill development, and rural infrastructure investments can empower smallholders to diversify their livelihoods and adopt sustainable practices. Moreover, leveraging digital technologies for precision agriculture, market intelligence, and supply chain integration can enhance farmers' resilience to climate and market shocks (Paul Jr et al., 2024).

6. Conclusions and policy implications:

The study highlights critical insights into the sustainability of farming systems, emphasizing systemic and localized challenges at both aggregate and household levels. Despite some progress in domains such as health, living conditions, and water management, the overall sustainability scores for farm types across districts remain below acceptable benchmarks, with significant disparities. Variations between farm types and geographic locations underline the uneven distribution of resources, technological adoption, and external support. Notably, while one farm type exhibits relatively better sustainability outcomes, no group achieves the halfway mark of the potential score, pointing to widespread problems that need urgent attention.

The domain-wise analysis reveals that while some areas perform above average, key dimensions such as economic resilience, biodiversity conservation, and gender equity consistently underperform, signaling systemic gaps that require urgent attention. Household-level data further emphasize the disparity, as aggregate scores often mask the vulnerabilities of marginalized households. Many households across locations fall within the area of concern, struggling with inadequate income, poor infrastructure, and limited access to critical resources. These findings underscore the need for a dual strategy—addressing household-specific challenges while implementing broader systemic reforms to tackle root causes of inequity and underperformance.

The thematic analysis adds depth by identifying strengths, such as progress in health and resource efficiency, that can serve as building blocks for broader improvements. However, systemic issues persist across all regions, particularly in economic and environmental dimensions. Localized enabling factors in higher-performing areas provide valuable insights for replication in underperforming locations. The study concludes that promoting sustainability in farming systems, specifically mixed-farming systems, necessitates an integrated, multidimensional approach. This requires a combination of localized interventions to leverage existing strengths and broader policy reforms aimed at equitable resource distribution, enhanced technological adoption, and capacity building. By aligning systemic and household-level strategies, it is possible to create farming systems that are more sustainable, fair, and resilient.

Finally, the present study is recommended:

- Very high heterogeneity in cost of production, yields (gaps), and net returns across farm households provides nuanced insights and a way forward to design and promote more equitable, resilient, and profitable farming systems.
- Low scores for productivity, and social and economic sustainability for the majority of households is a major concern and would help in identifying effective integrated strategies
- Implement farm-type and location-specific interventions to address unique challenges and leverage local strengths.
- Achievement of high sustainability scores by certain households suggests an opportunity to incentivize farmers-to-farmers knowledge sharing and extension
- Address structural issues, including gender equity and biodiversity conservation, through targeted policy changes.
- Prioritize vulnerable households with programs improving income, infrastructure, and knowledge access.
- Ensure aggregate-level progress translates into equitable benefits across all households and domains.

- We suggest that such analysis is needed for all the major farming systems and agro-ecologies to better inform relevant policies.

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