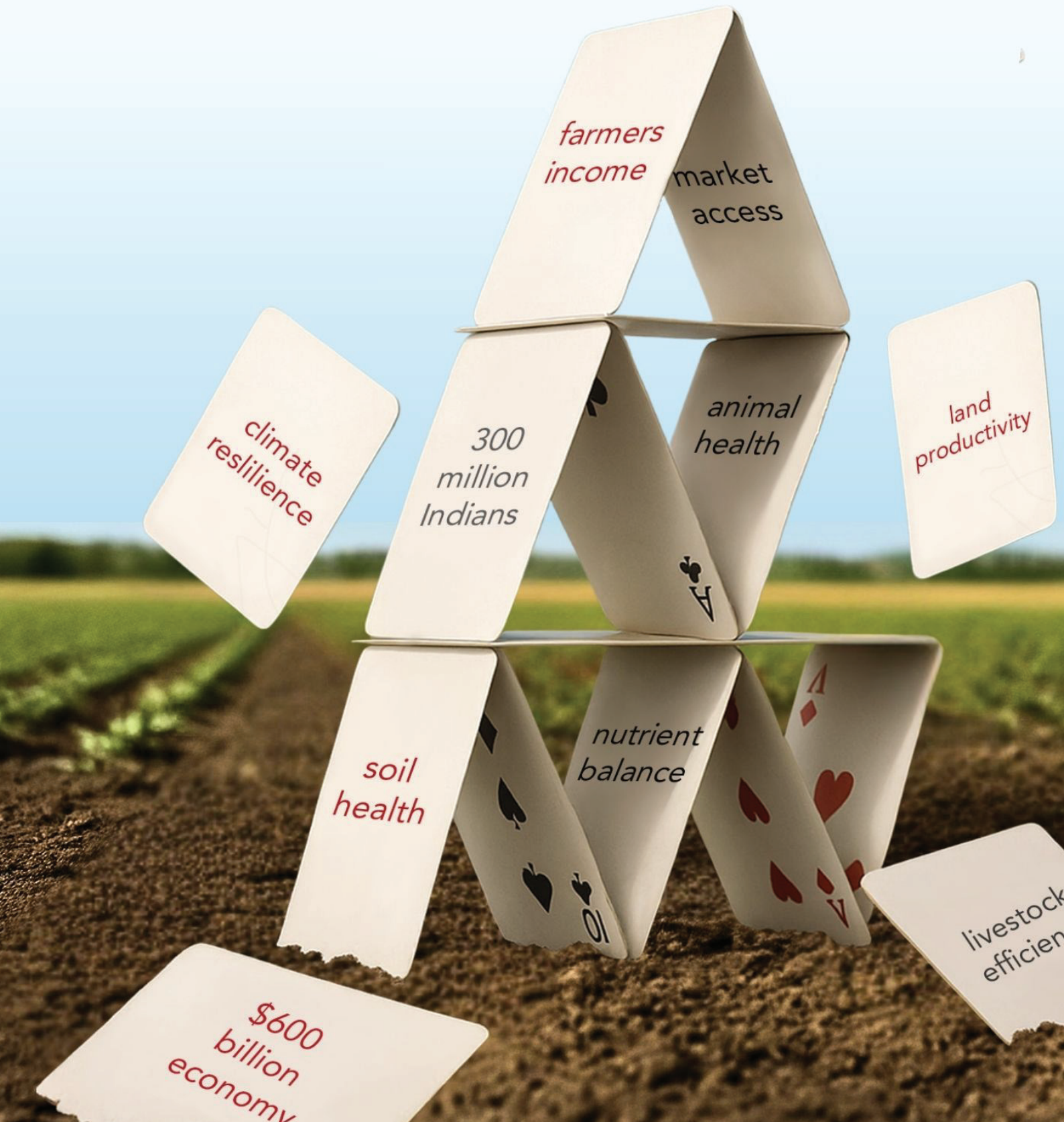
one crisis away

A distillation of India's food systems landscape

Imperatives and market opportunities: 2025



More than 300 million Indians now live one bad season away from poverty — equal to the population of the entire United States - depending on a single monsoon's mercy.

executive summary

India's food systems are under unprecedented climatic strain. In 2023, 86% of days recorded extreme weather, leading to the loss of nearly 2 million hectares of crops, 92,000 livestock, and over 80,000 homes. Rising heat, erratic monsoons, and shifting seasons now shape the lives and incomes of over 300 million people dependent on farming, livestock, fisheries, and forestry. Crop yields are falling, pests are proliferating, and natural buffers—soils, forests, and water bodies—are thinning under pressure. Each season now compounds livelihood volatility, deepening rural distress and threatening national food security.

The breadth of impact spans India's entire production landscape. Eighty per cent of small and marginal farmers have faced losses due to droughts or floods; poultry and dairy producers are seeing heat-linked declines in output and animal health; fishers are losing productive days to storms and warming seas; and forest-dependent communities are confronting declining non-timber produce and rising fire risks. Together, these sectors account for nearly half of India's workforce—people whose livelihoods are most vulnerable to climatic shocks and least supported by adaptive infrastructure.

India's food economy stands at the intersection of climate vulnerability and opportunity.

Soil degradation affects nearly 96 million hectares

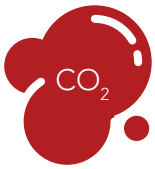
1/3rd of arable land

Yields could fall

6–10% by 2050

Livestock losses exceed

₹2,600 crore annually



85% of soils lack organic carbon

97% lack nitrogen

Fisheries productivity has declined by ***10–15%*** in some coastal regions due to rising sea temperatures.

Yet, this same sector holds transformative potential. Food, agriculture, and allied sectors together represent a $600 billion economy, projected to double by 2035. Investments in soil health, resilient seeds, digital irrigation, cold chains, and climate data systems could protect and grow this base. Technologies like AI-driven climate forecasting, satellite farm analytics, precision irrigation, portable cold storage, and genomic breeding are already redefining resilience. Emerging bio-economy models—bio-CNG clusters, residue-to-fibre conversion, regenerative agri-enterprises—are turning waste into value. Digital platforms linking farmers, cooperatives, and agri-tech innovators are shortening value chains, improving traceability, and embedding climate intelligence into production decisions.

India's next food transition will be defined not by the scale of production, but by the quality of adaptation. The fusion of data, science, and enterprise offers a pathway to make every acre, animal, and kilogram of produce more resilient. The opportunity is clear: to turn India's climate-exposed food systems into a living network of innovation—one that feeds the country, powers its rural economy, and strengthens its future against a warming planet.

India's food systems sit at the frontlines of climate change—exposed, underinvested, yet full of adaptive potential. Closing even a 30-point resilience gap could unlock ₹4–5 lakh crore in productivity and 10–12 million stable green livelihoods by 2040. With precision data, regenerative practices, and circular

innovation, India can transform its food economy from one crisis away—to one opportunity ahead.

Subsector	India's Current Status	Climate Vulnerability	Potential if Adaptation Scales
Agriculture & Crops 	Employs 55% of workforce, 96 million of whom have degraded land, with a projected yield loss of 6–10%	Droughts, heatwaves, erratic rainfall reducing yields and soil fertility	Soil carbon restoration & regenerative farming could lift yields by 15–25%, safeguard ₹1 lakh crore in annual farm losses
Livestock & Dairy 	70% rural households; ₹2,600 crores losses/yr; 35% feed deficit	Heat stress, disease spread, declining fodder quality	Heat-resilient breeds, feed innovation, and cold chains could stabilise incomes and protect 50 million smallholder livelihoods
Fisheries (Marine & Inland) 	28 million employed; 10–15% yield decline	Warming seas, salinity shifts, storm surges	Climate-smart aquaculture, solar cold chains, and mangrove restoration could recover ₹25,000 crores in value
Forestry & NTFP 	350 million dependents; 41% forest cover degraded	Forest fires, erratic rainfall, declining NTFP yields	Agroforestry & carbon-linked community enterprises could generate ₹50,000 crores and restore 2 million hectares of degraded forest land

Food System Subsector Summary

The/Nudge Institute & the^delta prize are committed to helping India solve challenges that the bottom 30% of the population face, and doing so at scale. the^delta prize does so through its Grand Challenge model, the first of its kind in India, by:

- Guiding markets to solve for the underserved by using competition to direct talent and capital into areas typically neglected by private investment.
- Providing catalytic inducements aligned with seed-to-series funding needs of innovators, ensuring ideas are not only socially impactful but investable and scalable.
- Mobilising ecosystems—corporates, government, academia, and funders—to create systemic momentum and long-term adoption of proven solutions.
- Generating credible evidence through rigorous M&E processes (baseline, midline, endline) that validate both impact and investability

Prize prioritises technology-led breakthroughs that achieve time-bound, quantifiable impact, can unlock 10–30× downstream capital multipliers, and will lead to sustained market or policy adoption.

At the^delta prize, our focus doesn't stop at understanding complex problems and systems, but goes further to induce market models & tech-first solutions that could unlock these complex systems. Through evidence, incentives, and ecosystem orchestration, each challenge hopes to transform a complex social issue into an investable innovation frontier.

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1 introduction

It is a truth (now) universally acknowledged, that climate change impacts the poorer populations disproportionately. Their health and living environments are severely impacted, while their already precarious livelihoods are thrown into further instability - causing in turn, a deeper slide into vulnerability. These effects can't be fixed overnight as the problems themselves are global in nature, even when the impact is most felt by a farmer on their one acre of land.

While scientific and policy communities look to tackle climate change at a global scale, this report explores where markets can play a role in mitigating the impacts of climate change, and simultaneously supporting vulnerable populations in climate-proofing their livelihoods. Markets are able to mobilise resources and achieve results (albeit short term) on a faster timeline than policy is able to, and therefore plays a critical role in how we can work to sustain communities until larger term systemic change kicks into effect. We explore where the ecosystem can induce innovation and competition to rapidly solve some of India's most pressing climatic concerns, and provide the bottom 30% with the agency to shore up their defenses against climate change.

1.1 wherein lies the problem?

India, the world's most populous country, is at extreme risk of climate change and its impacts. In India, climate change and global warming is associated with extreme weather events and their impacts,[1] with a majority of Indians expressing concern about the impact of global warming and extreme weather events.[2] At a geographic level, 57% of Indian districts, home to 76% of the country's population, are at high to very high risk from extreme heat.[3] The World Bank estimates that up to 75% of India's workforce depends on heat-exposed labour, which in turn contributes to approximately 50% of the GDP.[4] SELCO, in a 2023 study, found that extreme weather events most affect livelihoods by reducing productivity, a loss of assets (livestock and agricultural produce), and early retirement for health reasons - all compounding to lesser income, and for fewer productive working years.

1.2 approach

India's population. The study delved into the impact of climate on manufacturing, waste, food, hospitality and care, transportation, and informal livelihoods.

The sectors which show the most promise for circular economy strategies to reduce emissions are buildings and other construction, transport and the food system, where they can reduce emissions from production, use (in terms of energy used for heating, cooling and fuelling) and disposal (when they are sent to the incinerator or the landfill). Instead of recycling at the end of materials' life cycle, upstream strategies that include shifting consumption patterns and designing products that use materials more efficiently have the highest potential to reduce emissions.

A detailed analysis of the impact of climate on each sector was undertaken, with an eye on where markets could be prompted to play a role, and work with individuals affected by adverse climatic conditions to secure their livelihoods. Industries like mining and manufacturing have significant impacts on people's livelihoods, exacerbated by climate change, but these require systemic overhaul at an industry scale with significant policy oversight. Miners have very little control over any aspect of their employment, and markets can play little role in mitigating the impacts of climate change, or bolstering their income.

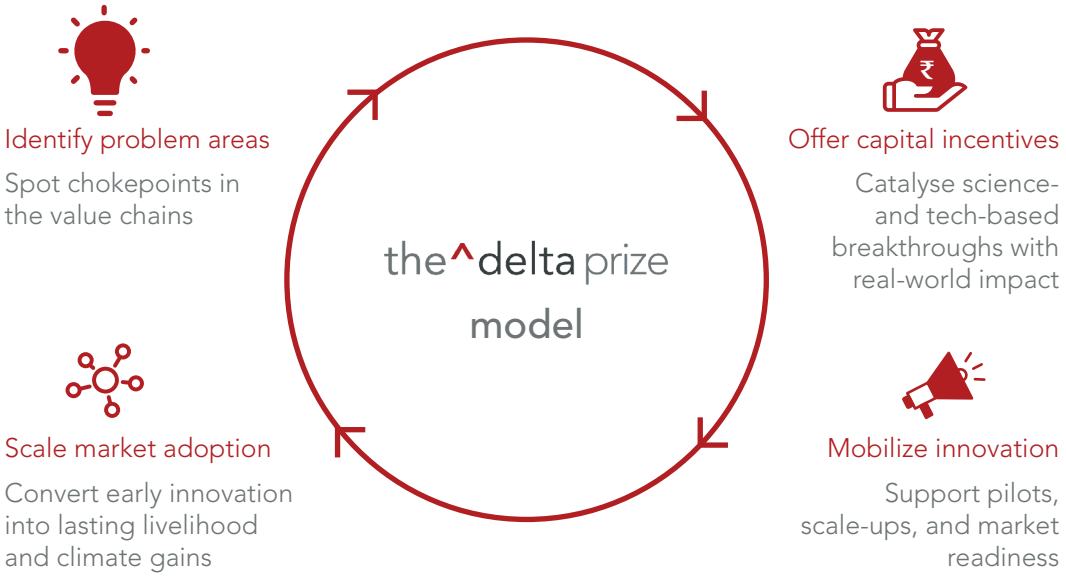
Sectors such as food systems and waste management however, due to the fragmented nature of these systems, show greater promise for market based interventions. This report presents a cumulative view of value chains in the waste sector, to highlight the economic losses and opportunities in these chains, with an eye on enhancing livelihoods for the bottom 30% and contributing to net economic growth.

1.3 incentive based plays

At the^delta, prize runs an incentive-based grand challenge model to drive innovations at scale and improve livelihoods for the bottom 30%. We identify technological choke points that are holding back

scale and adoption across different food value streams. the^delta prize guides markets to solve for the underserved through grand innovation challenges. We offer incentives that meet the seed / series capital aspirations of the brightest problem solvers, demonstrate investability, and mobilize sustained attention and momentum for specific problem areas through our interventions. To that end, this report identifies problem areas with great potential for effective market interventions, and lays the groundwork for more targeted interventions where we see opportunity for science based tech enabled solutions that improve livelihoods and support in climate proofing our economy.

How Incentive-Based Innovation Unlocks Climate-Resilient Livelihoods



Innovation at scale

- Tackles market inefficiencies
- Accelerates breakthrough solutions for vulnerable communities

Tech-based solutions

- Drives sustainable tech uptake
- Improves adaptive tech uptake

Livelihood resilience

- Supports bottom 30%
- Strengthens income stability

> **Incentives can turn climate challenges into innovation opportunities -driving scalable, market-ready solutions for India's most vulnerable.**

2
A story of India's 300 million people under climate stress

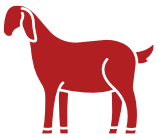
India is one the world's largest and fastest growing agriculture economies. Over 300 million people are dependent on agriculture and allied activities, including livestock rearing, fisheries, and forestry. Together, these livelihoods form the backbone of the Indian economy and contribute a GDP of approximately 16%, remaining a crucial pillar for India's food security.

These livelihoods include some of the most vulnerable population segments in India today.

Over 85%
of the farmers are marginal and small today

~95%
of India's milk producers have herd sizes of up to 5 animals

~30 million
farmers raise backyard chickens[5]



~83.4%
of goats in India belong to landless small-scale farmers[6]

They are also the segments who have historically suffered productivity losses due to the unorganised nature of several of these livelihoods and lack of access to good quality inputs and newer technology innovation.

While these losses persist, weather stress and erratic weather events due to climate change have multiplied the losses, often leading to loss of income and complete loss of livelihoods for these people. India experienced extreme weather events on 86% of days in 2023, with close to 3000 people losing their lives, over 80,000 houses being destroyed, close to 2 million hectares of crop area being lost, and more than 92,000 livestock perished. According to a study published in the Indian Journal of Occupational & Environmental Medicine, the social and economic costs of climate change today in India, including the impact on household consumption, livelihoods, and migration, are a growing concern. A report published in December 2020 by ActionAid and Climate Action Network South Asia showed that across India, about 37.5 million people will be displaced by 2030, and an estimated 62.9 million by 2050, majority of them being the most vulnerable of these livelihoods.

Agriculture is suffering an outsized impact from climate change. Frequent and severe weather events, such as floods, droughts, and cyclones, negatively impact crop yields, soil fertility, and water availability, putting millions of farmers' livelihoods and food security at risk. Smallholder farmers, who often lack access to advanced technology, financial resources, and quality inputs, are particularly vulnerable. According to a survey, conducted by the Forum of Enterprises for Equitable Development (FEED) in collaboration with the Development Intelligence Unit (DIU), at least 80% of marginal farmers in India have suffered crop losses due to adverse climatic events over the past years; the primary causes being drought (41%), irregular rainfall (32%), and early withdrawal or late arrival of the monsoons (24%).

Climate change is also a major concern for current livestock systems worldwide. With India having the largest livestock population in the world (520.6 million), the risk is huge. Climate change affects feed and water resources as well as animal health and overall physiology. It also has implications for the processing, storage, transport, retailing and consumption of livestock products.

The fisheries sector is navigating its own challenges in the face of climate change, even though the sector is considered to be the "sunrise sector" with India ranking second in global production. Increasing cyclones, erratic monsoon rains and rising temperatures are affecting the lives of people dependent on fisheries as their source of livelihood.

Livelihoods in the forestry sector are not left unaffected either. In 2023, 6.37 million hectares of forest land was lost worldwide. As per World Bank, close to 275 million people are believed to be earning a bulk of their livelihoods from forests, however, more than 40% of the forest land is already degraded, or on the verge of degradation.

Together, these livelihoods are at the core of food security for close to 150 crore individuals across India, and livelihood security for the most vulnerable population in India. However, as climate change intensifies, these livelihoods stand at the brink of complete disruption. Every agricultural and livestock farmer is one crisis away from destitution, and by extension, our food security stands on a teetering edge. It is of utmost importance to build resilience at the forefront of these livelihoods, ensuring that the losses experienced by these communities today are reduced, their adaptive capacities strengthened, and their pathways to sustainable growth secured for the future. This report builds a grounded and closer view of how climate change is reshaping these livelihoods, while identifying key areas where innovation can drive resilience and long-term sustainability of our food systems, and those that feed us.

> "Every agricultural and livestock farmer is one crisis away from destitution, and by extension, our food security stands on a teetering edge.

3
Farming: the backbone of India's economy; the core of its food system

Around the world, about 4.8 billion hectares (4800 million) of land is under agricultural use.[9] Of this, India alone has 180.11 million hectares of agricultural land.[10] The sector provides livelihoods for nearly 150–160 million people, with ~55% of the population depending on agriculture as their primary source of income, contributing ~18% to national GDP. Agriculture was once dominated by farmers holding large and medium sized lands, however today, over 85% of the holdings are small or marginal, with 1-2 hectares average land size.

Being one the world's largest and fastest growing agriculture economies, India's agriculture market is valued at $580 billion to $650 billion today. If India's agriculture matches its full potential, it is set to become a $1.4 trillion market by 2035 and $3.1 trillion market by 2047.[11] But alongside this lies the fragility of agriculture - the land is strained, the soils tired, and farmers' livelihoods increasingly uncertain. It is estimated that about 37.5 million people will be displaced by 2030 due to climate change - the majority of them depending primarily on agriculture for their income.[12]

As per weather records, India experienced extreme weather events on 86% of days in 2023.[13] The percentage changed to 93% in just the first nine months of 2024.[14] Extreme weather is no longer an exception but the norm, disrupting agriculture - the most practised livelihood in India and making climate change a lived reality for those at the margins. According to a survey, conducted by the Forum of Enterprises for Equitable Development (FEED) in collaboration with the Development Intelligence Unit (DIU), 80% of the marginal farmers in India have suffered crop losses due to adverse climatic events in recent years. Between 2015–16 and 2021–22, around 69 million hectares of cropped land were lost, 33.9 million ha to floods and heavy rainfall, and 35 million ha to droughts.[15] In 2021 alone, 5 million ha of crop area were lost to floods, storms, and landslides, resulting in an estimated ₹30,000 crore loss in farmer incomes.[16]

Rising temperatures, erratic monsoons, extended dry spells, and unseasonal rains are lowering crop yields, degrading the soil quality and negatively impacting crop health. Crops such as wheat, rice, and maize are particularly vulnerable. According to projections, a 2.5 to 4.9°C increase in temperature across the country could decrease the wheat yield by 41–52% and rice yield by 32–40%.

3.1 Soil is responsible for producing 95% of the food we eat, but more soil has been degraded than we can recover back

Soil is the "operating system" beneath agriculture, responsible for water retention, nutrient cycling, carbon storage, and supporting 95% of food production. The top 30 cm of soil globally store 680–700 gigatonnes of carbon, more than twice the carbon in the atmosphere. However, a soccer pitch of soil is eroded every five seconds, and it is estimated that by 2050 around 90% of the Earth's soils could be degraded.[17] It takes up to 1000 years to produce 1 inch of soil, making the replenishment of soil a distant reality.

> "a soccer pitch of soil is eroded every five seconds

The soil on which close to 160 million Indians rely for their livelihood is suffering. According to the latest land use data by MoAFW from 2021, India's total land area is 328 million hectares. ISRO's recent estimates state that about 96 million hectares is already classified as 'degraded land'. The soil in India is degrading at an annual rate of about 15 tonnes per hectare, higher than the sustainable rates of 5 to 12 tonnes per hectare.[18]

The intensity at which agriculture production has grown in the recent decades, including increase in pesticide use, and almost 700% increase in inorganic fertilisers, has been identified as the major cause in the degradation of soils, resulting in increasing soil erosion, soil compaction and greenhouse gas emissions. Climate change accelerated the degradation further as alterations in temperature, precipitation patterns, and the frequency of extreme weather events affect soil processes, accelerate microbial activity, moisture levels, and disrupt soil structure, leading to the erosion of organic matter.

As plants absorb nutrients from soil, changes in moisture and temperature affect the nutrients in the soil, directly impacting the quality of nutrients that reach crops. According to a study between 2015-16 and 2018-19 of more than five crore soil samples from across India, about 85% of the samples were deficient in organic carbon; 97% samples were deficient in available nitrogen; 83% samples were deficient in phosphorus; and 71% samples were deficient in potassium.[19]

Soil Organic Carbon (SOC), which is the fraction of carbon in decomposed organic matter within soils has also been degraded in Indian soils, reaching an extremely low percentage of less than 0.5%, compared to the ideal 1–1.5% for healthy soils, as per a report by ICAR. It underpins soil fertility, structure, and biological activity - literally making soils "alive," helping improve nutrient cycling, water retention, and binding soil aggregates, reducing erosion and helping crops thrive. Practices such as fertiliser overuse, residue burning, frequent tilling, and declining crop diversity are together depleting SOC levels, eroding soil health, and accelerating CO_2 emissions. In India's main agricultural soils, SOC depletion erodes productivity and resilience, increasing input costs and vulnerability to droughts and extreme weather events.

Different kinds of soil and the crops grown in them are differently impacted by climate change.

Soil type	Land share and key crops	Climate impact
Alluvial soil[20]	~45% land share: Indo-Gangetic Plains – Punjab, Uttar Pradesh, Bihar, West Bengal Key crops: wheat, rice (paddy), and sugarcane	SOC depletion (15-25% over 2-3 decades) affecting paddy-wheat cycles, accelerated due to high temperature Micronutrient deficiencies under flooding conditions
Black soil[21]	~16% land share: Maharashtra, Madhya Pradesh, Gujarat, Telangana, Tamil Nadu Key crops: cotton, soybean, sorghum, and wheat	10-18% SOC loss due to high temperatures Micro-nutrient imbalance during drought and dry periods
Red soil/clayey soil[22] I	~10% I Karnataka, Chhattisgarh, Odisha, Eastern Ghats, and middle Ganga belt Key crops: rice, cotton, pulses, and groundnut	20-30% SOC loss in erosion-prone slopes Oxidation due to high temperature
Sandy desert/yellow soil[23]	~4% land share: Rajasthan, Gujarat, southern Punjab Key crops: millets, barley, and pulses	Very low SOC in general, vulnerable to absolute decline due to changing weather patterns Severe micronutrient deficiencies

Table: Soil type and impact on SOC

3.1.1 With climate change here to stay, farmers' produce is at risk today

Soil remains at the core of a farmer's produce, rightly defining its quality and nutrient level. With climate change affecting both soil and crops, the overall quality and yield are getting affected as well. According to a report by ICAR, climate change is projected to adversely affect crop yields in India by 6-10% by 2050. Between 2015 and 2021, India has already lost 33.9 million hectares of crops due to excess rains and an additional 35 million hectares due to drought. Several Indian sectors including agriculture suffered $159 billion in economic losses in 2021 due to lost working hours from extreme climate impacts.

> By 2030, India is projected to see a substantial 5.8% decline in working hours — equivalent to 34 million full-time jobs — due to heat stress.[24]

Challenges in Soil Health	
Topsoil Erosion	Intense monsoon downpours cause severe soil erosion on small farms, stripping away fertile topsoil and nutrients. Approximately 30% of India's soil is already degraded, and climate-driven runoff exacerbates this loss of productive land.
Organic Matter Decline	Over 94% of soil nutrients come from inorganic fertilizers and only ~6% from organic sources. Crop residues are often burned or removed, leaving soils devoid of carbon. This loss of organic matter has hurt soil structure – soils become hard or powdery and less able to hold water.
Nutrient Leaching & Volatilization	Extreme heat and erratic heavy rains cause nutrients (especially nitrogen) to escape the soil – either volatilized as ammonia in heat or leached out by downpours. This leads to nutrient-deficient soils and forces farmers to apply more fertilizer (raising input costs) to achieve the same yields.
Waterlogging Damage	Flood events leave fields waterlogged, which depletes soil oxygen and washes away soluble nutrients. The resulting soil structure damage and nutrient loss degrade fertility and can stunt crops in subsequent seasons. Marginal farmers often can't afford remedial measures like soil aeration or re-fertilization after such episodes.
Soil Salinity (Coastal)	Intrusion of saltwater from rising sea levels and storm surges is turning coastal farmlands saline. In parts of Odisha and West Bengal, fields have become too salt-laden for traditional crops, pushing some small farmers to abandon their land.
Soil Salinity (Inland)	Unsustainable irrigation and fertilizer practices are also increasing soil salinity in inland areas. Roughly 7 million hectares of land in India are affected by salt build-up, and climate change (with less frequent rains to flush soils) is worsening this. These salts impede crop growth and render land barren.
Nutrient Imbalances	Decades of intensive monocropping and heavy chemical fertilizer use have depleted micronutrients and soil organic carbon.
Pesticide Damage to Soil	Excessive pesticide usage has harmed soil biodiversity, destroying soil biota such as earthworms and microbes that naturally regenerate soil fertility. This "silent" degradation makes soils less resilient to pests and diseases, ironically creating a vicious cycle of more pesticide dependence.
High Restoration Costs	Once soil is degraded, restoring its health (through organic manure, gypsum for salinity, etc.) is expensive and slow. Marginal farmers often cannot afford the needed amendments, so problems like nutrient deficiency or salinity remain unaddressed
Low Soil Testing & Knowledge	Although programs like the Soil Health Card exist, most small farmers are unaware or haven't used them. Lacking soil testing and guidance, farmers do not realize their soil's nutrient deficiencies or pH imbalance, leading to improper fertilizer use and further soil damage.

Table: Challenges in soil health

Challenges in Soil Health	
Deforestation & Erosion	Loss of tree cover around farms (due to deforestation or firewood needs) leaves soil more exposed. Without windbreaks or forest cover, heavy rains wash away soil more easily and dry spells bake the soil.
Crop Residue Removal	Smallholders, especially in Punjab and Haryana often burn crop residues (stubble burning). This deprives the soil of organic matter that would have come from residue decomposition. Over time, continuous residue removal has contributed to declining soil organic carbon in many regions (most Indian soils have <0.5% carbon, far below ideal levels).
Secondary Soil Contamination	Floods can deposit sand or silt on fields, and polluted runoff can introduce heavy metals or pollutants to soils.
Desertification Risks	In arid and semi-arid zones, repeated droughts and over-extraction of groundwater are driving desertification. For example, parts of Rajasthan and southern Haryana see creeping expansion of barren lands; India's National Bureau of Soil Survey estimates 37% of land faces degradation/desertification
Acidifying and alkalinity issues	Overuse of chemical fertilizers has altered soil pH in many regions. Over 70% of tested soils are now either too acidic or too alkaline for optimal crop growth
Soil Structure Degradation	The physical health of soil is deteriorating under unsustainable practices. Excessive tillage with heavy machinery and continuous cropping have broken down soil structure and compacted layers
Monoculture impacts	The Green Revolution's legacy of rice–wheat monoculture and heavy chemical inputs has stripped soils of micronutrients and organic matter. This continuous soil exhaustion is especially problematic for marginal farmers who cannot easily restore soil fertility through fallows or crop rotation.

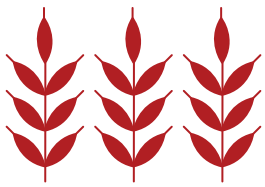
Table: Challenges in soil health

Data suggests that major crops grown by marginal and small farmers (wheat and paddy) are severely affected by climate change. Rainfall variability and delayed monsoon onset have led to up to 40% drop in paddy cultivation in the country. Erratic rainfall and high temperatures have increased the frequency of crop losses due to both drought and waterlogging.[25] It is projected that a 2°C rise in temperature can decrease rice yield by about 0.75 tons per hectare in high-yield areas.[26] Warming winters are affecting the sowing pattern for wheat. The yield is estimated to reduce by 6–25% by 2100, with an 8–27% chance of crop failure due to heat stress.

projected impacts of climate change on crops

a 2°C rise in temperature can decrease rice yield by about

0.75 tons per hectare



Warming winters are affecting the sowing pattern for wheat. The yield is estimated to reduce by

6–25% by 2100

While climate impact is across farming, marginal and smallholder farmers are at the centre of it. The decline in yields and fertility of available land can trap them in an endless cycle of poverty as incomes are expected to fall due to low productivity. In India, agriculture workers experienced 64% of the potential hours lost and 55% of the potential income losses in 2022, as per Lancet Countdown on Health and Climate Change.[27]

Rapid rise in temperature and rainfall patterns has also made farms home to newer variety and higher quantities of weeds and pests. According to the Food and Agriculture Organization, insect attacks cause a global loss of $70 billion annually, and plant diseases lead to a loss of $220 billion. Moreover, every year, 20% to 40% of crops globally are lost to pests. Between 2015–2016 and 2021–2022, crops in 23 states of India were affected by pests.

ICAR study mentions that India has recorded over 100 invasive pest and weed species in the last 30 years across crops. Insects alone account for ~30–40 of these (e.g., fall armyworm, tomato pinworm, papaya mealybug). Fungal and bacterial invasives are also rising (e.g., wheat blast fungus Magnaporthe oryzae Triticum, detected in Bangladesh and a looming threat for India). Climate warming is projected to result in an additional 10–20 invasive insect species by 2050, many migrating from tropical to subtropical zones. As the temperature rises, the pathogen's incubation period is also shortening, leading to rapid proliferation in less time. October 2025 was the first time mosquitoes were found in Iceland, a possible harbinger of much warmer temperatures in the Arctic Circle.

These factors together are resulting in a higher input cost for farmers in terms of pesticides and fertilizers, while elevated temperatures and carbon dioxide enrichment are reducing the efficacy of them, and in turn severely affecting the SOC level by 5-45%.[28]

If current trends continue, by 2030 over 40% of India's smallholder land could be severely degraded, dramatically cutting farm incomes and driving rural poverty. The risks multiply: lower yields, rising costs, entrenched poverty, and even greater exposure to climate shocks.

100+
invasive pests and weed species detected in India in the last 30 years.

Climate change is projected to result in an additional 10–20 invasive insect species by 2050

3.1.2 India needs $136.49 billion per year to support its smallholder farmers

A new report by Climate Focus for the Family Farmers for Climate Action, an international agency states that India needs $136.49 billion per year to support its smallholder farmers in mitigating the impacts of climate change, suggesting investment in establishing early warning systems for crop safety, crop insurance, accessing climate-resilient seeds, and measures to prevent pest attacks, manage diseases, and address water shortages, all aimed at maintaining the quantity and quality of grains.[29]

To make farmers climate resilient, attention and innovation is needed in some key areas:

Soil:
soil today requires urgent attention, and the means to make it healthy again as it plays a key role in the overall crop health and yield.

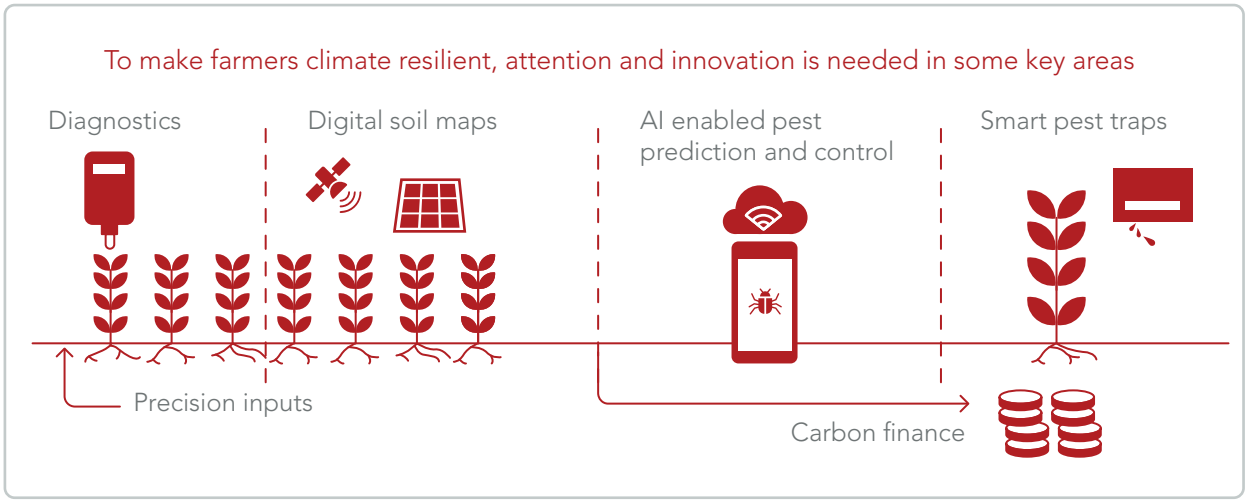
1.1 Diagnostics: traditionally, soil testing in India is time-consuming, requiring physical sampling and laboratory work. Additionally, India has only about 8,000 soil-testing labs. Innovations like portable spectrometers (Vis-NIR/MIR), handheld soil sensors, and smartphone-based tests can enable rapid SOC measurement.

1.2 Digital soil maps: tools like SoilGrids and ISRO's mapping platforms provide high-resolution SOC and nutrient data. These tools need to be more accessible for the smallholder farmers who are more vulnerable to losses.

1.3 Precision inputs: variable-rate fertilisation, fertigation, and micronutrient blends can help improve input efficiency.

1.4 Water-smart practices: practices like drip irrigation and rainwater harvesting can enhance both water and carbon retention.

1.5 Carbon finance: new MRV (measurement, reporting, verification) systems are linking SOC improvements to carbon credits, offering farmers potential income streams.



Pests:
climate change has led to more frequent and severe pest infestations. India loses an estimated $36 billion to pests.[30] Farmers lack timely pest-detection tools, forcing overuse of pesticides.

2.1 AI enabled pest prediction and control: this can provide farmers with real-time recommendations to manage pest infestations, such as pest identification, risk level, pest management practices and vendors.

2.2 Smart pests traps and sensors: technology enabling image-based traps and continuous monitoring for specific pests can help make pest control more efficient

These and other technology and biology driven innovations can help make agriculture resilient and ensure sustainable income to the marginal, small, and several other vulnerable farmers across the country, and save whatever soil is left today from degradation and help replenish the degraded soil back for a prosperous agriculture future.

3.2 the^delta take and ecosystem implications

India's soil degradation is now both a productivity and a livelihood emergency. Nearly 30% of cultivable land is degraded, with 37% at risk of desertification, directly threatening the incomes of 160 million farmers. Over 85% of soils lack organic carbon, 97% are nitrogen-deficient, and most hold less than 0.5% SOC—far below the healthy range of 1–1.5%. These deficits translate into declining yields, higher input dependency, and escalating vulnerability to floods, droughts, and pests. Coastal salinity, inland alkalinity, compaction, and acidity are further eroding farm viability, pushing smallholders toward unproductive cycles of re-fertilization and debt.

The livelihood implication is direct: degraded soil reduces both the quantity and the nutritional quality of produce while raising the cost of cultivation. For marginal farmers, this means thinner profit margins and higher exposure to climate risks.

Technology offers the most immediate path to reversal. Portable soil sensors and digital diagnostics can bring precision to fertility management; open soil data layers and AI-enabled decision tools can tailor input use; precision irrigation and fertigation can rebuild soil structure; and verified SOC restoration can unlock carbon-credit income for smallholders. Together, these interventions can re-anchor soil regeneration in measurable outcomes—turning what is today a diffuse environmental problem into an investable, tech-enabled pathway for resilient rural livelihoods.

4
Forestry: a long forgotten source of subsistence

India's current forest and tree cover is estimated to be 78.29 million ha, constituting 23.81% of the geographical area of the country (ISFR, 2011). The livelihoods of the people living close to forest and within the forests are closely linked to the forest ecosystem. India has a huge population living close to the forest with their livelihoods critically linked to the forest ecosystem. There are around 1.73 lakh villages located in and around forests (MoEF, 2006). Though there are no official census figures for the forest-dwelling communities in the country, different estimates put the figures from 275 million (World Bank, 2006) to 350- 400 million (MoEF, 2009). Forestry is the second-largest land use after agriculture, with about 27% of the country's population depending on forests for subsistence and income. (FAO and UNEP, 2020). People living in these forest fringe villages depend upon forest for a variety of goods and services. These includes collection of edible fruits, flowers, tubers, roots and leaves for food and medicines; firewood for cooking (some also sell in the market); house construction and fencing; fodder (grass and leave) for livestock and grazing of livestock in forest; and collection of a range of marketable non-timber forest products.

Moreover, a significant percentage of the country's vulnerable population happened to be living in its forested regions (Saha and Guru, 2003). A significant percentage of India's tribal population also lives in these regions. These forest-dwelling communities not just collect these forest products for their own consumption but for commercial sale as well, which fetch them some income. Generally, the income from sale of the forest products for these households constitutes 40 to 60% of their total income. Thus forests are an important contributor to the rural economy in the forested landscapes in the country.

4.1 Honey and non-wood products are a vital part of the forest economy

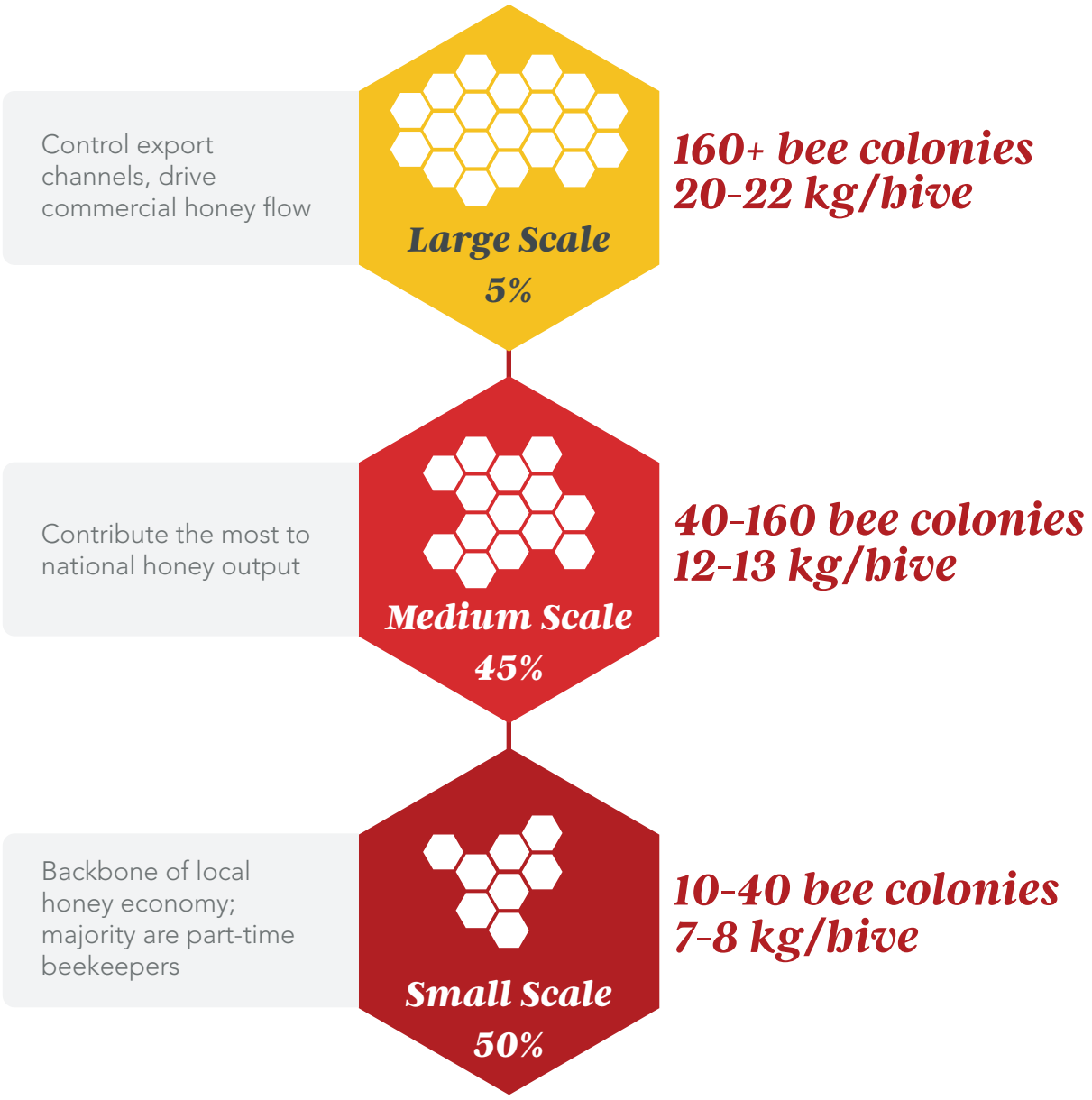
With over 12.26 lakh bee colonies and 10,000 registered beekeepers, India is among the leading honey-producing countries in the world. Beekeeping supports over 2 lakh farmers and beekeepers. The sector provides direct income through honey and other hive products, including beeswax, royal jelly, pollen, and propolis, while also generating indirect income through pollination services.[31]

The majority of beekeepers have had additional jobs and income sources. Small-scale beekeepers have 10 to 40 bee colonies; medium-scale bee colonies span between 40 and 160 bee colonies; and large-scale apiarists manage at least 160 bee colonies. About 5% of beekeepers are large-scale, 45% are medium-scale, and about a half are small-scale. There are differences in the honey yield among small-, medium-, and large-scale apiarists, ranging between 7-8 kg/hive, 12-13 kg/hive, and 20-22 kg/hive, respectively. However, the majority produce is harvested by small- and medium-scale apiarists while large-scale producers are involved in most commercially oriented activities, especially controlling the major pathway to exportation of honey. With proper management, farmers maintaining 50 colonies can earn an annual income of ₹4–6 lakh from honey production, beeswax extraction, and pollination services.[32]

The honey market in India reached ₹27 billion in 2024. Looking forward, IMARC Group expects the market to reach ₹50 billion by 2033, exhibiting a growth rate (CAGR) of 7% during 2025-2033.[33] The market for honey is interestingly growing, providing opportunities for innovation and advanced technologies for better production and processing. According to the International Diabetes Federation, the prevalence of diabetes in Indian adults was 8.8% (72,946,400 cases) in 2017 (Policy Research Foundation, 2018). The predominance of heart failure cases in India (owing to coronary illness, diabetes, hypertension, rheumatic coronary illness, overweight and obesity) ranges between 1.3 to 4.6 million, with a minimum of 4,90,000 new cases of heart failure being diagnosed each year (Central Bureau of Health Intelligence, 2019). The surge in the rate of acute and chronic diseases is causing many people to choose honey over sugar.[34]

Non Timber Forest Products (NTFPs) are another essential area for the livelihoods of forest-dwelling communities. They contribute an income equivalent to $ 2.7 billion per year and absorb 55% of the total employment in the forestry sector. About 50% of forest revenues and 70% of forest-based export income come from such resources. These products generally include vegetables, fruits, medicinal plants, mushrooms, non-edible items, spices and other food items. Some of the common NTFPs found across Indian states are tendu leaves (central and eastern India), mahua flowers (MP, Odisha, etc.), medicinal plants, resins, etc.

the scale and economics of beekeeping in India



> With proper management, farmers maintaining 50 colonies can earn an annual income of ₹4–6 lakh from honey production, beeswax extraction, and pollination services.

4.1.2 Despite high livelihood dependence, forest resources are depleting at an alarming rate

As per The National Forest Commission report 2006, around 41% of total forest in the country is already degraded, 70% of the forests have no natural regeneration, and 55% of the forests are prone to fire. A study by Indian Institute of Science, Bangalore covering the entire forests of the country reported that more than two-thirds of the forested grids are likely to undergo vegetation change by the year 2100. Almost all major forest types are likely to be impacted by climate change.[37]

When it comes to honey, excessively dry climate affects pollen production and nutritional quality. Bees are unable to pollinate in time due to climate change. As average monthly temperatures rise, flowers bloom earlier in the spring, causing a potential mismatch in seasonal timing between when flowers produce pollen and when bees are ready to feed on that pollen. A study in Punjab indicated that flowering seasons have shifted by 2-3 weeks, impacting bee foraging times.[38] Even a small mismatch of 3-6 days can negatively affect their health. Erratic weather patterns, such as prolonged droughts or unseasonal rains, also affect bees' ability to gather food and build strong colonies. According to recent projections, climate change could reduce honey production in India by up to 15-20% over the next 10-20 years.[39]

Uncontrolled fires have caused tremendous damage to the forest biodiversity of the country. Over 1,00,000 forest fires have been reported from 2004-2005 to 2010-2011 in the country (FSI, 2012). Forest fires generally occur under conditions of high temperature, extreme dryness, strong winds, and low moisture in the forest floor. Lightning has been a major cause of forest fires and tree deaths in tropical forests; more than 440,000 instances of lightning were recorded in Jharkhand in 2021-22.[40]

Another key product that has suffered the impact of climate change is lac—a scarlet resin secreted by an insect. Lac is used in furniture polishing and making bangles and perfumes. A study published last year highlighted that in 62 Jharkhand villages, involving 387 collectors of non-timber forest produce, the price of lac has fallen over the years because of climate change and poorer quality. For instance, in 2012-13, "lac was being sold at 370 to 250 ₹/kg whereas the price has fallen to almost half, i.e. 150 to 100 ₹/kg in (2019–20) for various varieties of lac, i.e. Rangeeni, Kusmi.[41]

Though forest-dwelling communities spend hours collecting and processing products, the returns are barely commensurate with the amount of work they put in. A primary reason is the absence of an organized market, with middlemen reaping much of the benefit. While mahua is sold for ₹50-100 a litre in the market, collectors get as little as ₹5 for every kilo of mahua flowers they sell. As soon as the produce is collected and processed, it is sold to contractors and middlemen. There are two reasons for this: One, most of the forest products have a relatively short shelf life; and two, there is a near absence of a proper collection mechanism or availability of storage centres.[42]

Climate change poses a serious threat to the forest-dwelling communities. Increasingly erratic rainfall, rising temperatures, and frequent forest fires are altering forest composition and productivity, reducing access to key non-wood forest products such as honey, resins, and medicinal plants. Without urgent measures to make the livelihoods of these forest-dwelling communities climate resilient, they are at complete risk of losing their income, sometimes the only source of income for the most vulnerable of the population.

Decline in resource productivity & regenration	
Erratic rainfall	Unpredictable rainfall impacts the regeneration cycle of NFTPs trees. Collectors spend more days in forests with lower yields per trip.
Temperature rise	Higher temperatures negatively affect growth rates and regeneration success of NTFP species. Also, heat stress causes early ripening and leaf shedding.
Drought stress	NTFPs like lac, which depend on specific host trees, decline sharply when drought kills the hosts.
Altered monsoon	Shifted or delayed monsoons disrupt natural regeneration cycles and seed availability.
Pest & Disease	
Pest proliferation	Climate change increases survival and spread of damaging insect pests on NTFPs.
Disease outbreaks	Warmer conditions increase frequency and intensity of diseases affecting NTFP yields.
Warmer winters encourage pests and diseases	Climatic changes increase pest outbreaks in amla, chironji, and honey.
Stress on pollination and honey systems	
Climate mismatch between flowering and pollinator activity reduces forage.	Bees find fewer nectar sources, resulting in a reduced honey yield.
Heatwaves lead to colony collapse	High temperatures kill broods or stress colonies. Labour is wasted in rearing new colonies, cutting productivity.
Heavy rainfall damages hives and spreads diseases.	Hives are lost to floods or dampness. Beekeepers must rebuild structures and care for weakened colonies, requiring extra effort.
Extreme events and fire risks	
Forest fires destroy NTFPs and resin sources	Entire seasonal income disappears, and labour invested in collection is wasted. Recovery requires re-plantation.
Floods and cyclones uproot trees and destroy hives.	Extreme weather destroys resources and livelihood
Heatwaves create unsafe working conditions.	Collectors reduce work hours or suffer health risks. Labour productivity per day declines, creating income insecurity.

Table: Impact of climate stressors on forestry

4.2 the^delta take and ecosystem implications

Forests remain a livelihood backbone for nearly 350 million Indians, yet 41% of forest cover is degraded and regeneration cycles are collapsing under climate stress. Erratic rainfall, rising temperatures, and recurring droughts are weakening soil moisture, killing host trees for species like tendu and lac, and disrupting natural seeding and regeneration. Altered monsoons and declining pollination success are further reducing forest productivity and future resource availability. Honey systems mirror this stress—flowering cycles no longer align with bee foraging; heatwaves cause colony collapse; heavy rains flood hives; and loss of flowering plants cuts nectar sources—together shrinking honey output by up to 20% for smallholder apiarists.

Extreme events amplify these pressures. Forest fires, floods, and cyclones now erase years of ecological recovery in one season, destroying NTFPs like resins, gums, and medicinal plants, while heatwaves and saline intrusions reduce safe working hours and viable land. The cumulative impact is a sharp erosion of rural incomes, forcing migration, debt dependence, and loss of cultural links to forest-based livelihoods.

Technology can anchor recovery: satellite-based regeneration mapping, predictive fire and weather models, digital NTFP traceability, drone-based pollination monitoring, and decentralized cold-storage and e-market systems can stabilize yields and incomes. Integrated into one forest-livelihood data grid, these tools can transform degradation tracking into a regenerative, income-sustaining system for India's forest communities.

5
Fisheries: a sunrise sector navigating uncharted waters

India is the second largest producer of fish with around 8% share in the global fish production. India achieved a production of 184.02 lakh tons of fish during 2023-24.[43] Over 70% of the total production is derived from inland fisheries (freshwater sources) and the remaining from marine (coastal and deep-sea waters). India's exports of marine products amounted to 1.78m tonnes, valued at $7.38bn, in 2023-24.[44] The sector contributes about 1.09% to the country's Gross Value Added (GVA) and over 6.724% to the agricultural GVA.[45]

Inland and aquaculture fisheries achieved an increase of 77.71 fish production from 2014-24 while the marine fish production doubled to 10.52 lakh tons (2004-14) from 5.02 lakh tons (2014-24).[46] The sector is projected to grow at a CAGR of 5.40% during 2025 to 2032, growing from $21.48 billion to $32.71 billion.

5.1 From coast to pond, India's marine and inland fisheries

Roughly 28 million people are part of the primary-level fisheries workforce across India. Of these, about 23.12million are in the inland sector and 4.95million in the marine sector.[47] Over 60% of fisherfolk fall under the vulnerable population category in terms of income.[48] The majority of small-scale fisherfolk are part of the inland fisheries landscape, compared to marine. Inland fisheries have over 90% small-scale fisherfolk. The monthly income of inland fishers is generally low, ranging from ₹2,500 to ₹10,000.[49]

Genderwise fishermen population across India

Fishing type	Male	Female	Total
Inland	13,013,978	10,103,842	23,117,820
Marine	2,651,652	2,294,066	4,945,718
Across India	15,665,630	12,397,908	28,063,538

Table: Fishing type and population division [Source: Fisheries statistics, Handbook 2022]

Number of fishermen involved in marine and inland fisheries

	Fulltime	Part time	Occasional	Unspecified
Marine	1,212,847	491,530	78,323	208,113
Inland	1,846,285	1,846,285	816,776	4,323,308

Table: Fishermen involved in marine and inland fisheries [Source: Fisheries statistics, Handbook 2022]

India has around 2.02 million square kilometres of Exclusive Economic Zone (EEZ: a maritime area extending up to 200 nautical miles from a country's coastline where that nation has exclusive rights to explore and exploit marine natural resources) and a coastline of 8,118 kilometres, making the country's estimated annual potential for capture fisheries to be of 5.31 million metric tons.[50] India has 3,288 marine fishing villages and 1,511 marine fish landing centers spread along the coastline, a 2017 research paper stated. There is a fishing village every 2 km and a landing centre every 4.3 km, on average, along the coastal mainland of India.[51]

Freshwater inland fisheries cover 1,95,210 kms of rivers and canals, 3.54 million hectares of minor and major reservoirs, 2.4 million hectares of ponds and lakes and about 0.8 million hectares of flood plain lakes and derelict water bodies. Inland fisheries is largely categorised as riverine fisheries (14 major, 44 medium and a number of small rivers and streams which form a combined length of 29,000 km), canal fisheries

(second most important source of irrigation for agriculture, covering a total length of 1,26,334 kms), wetland fisheries (floodplain wetlands, those associated with the Ganga and Brahmaputra river basins cover an area of 3.40 lakh hectares), and reservoir fisheries (man-made impoundments built across rivers or streams).[52]

Studies mention that India has one of the richest inland fishery resources in the world. The sector is also home to several of the fisherfolk communities who have been in the livelihood for generations now.

5.2 However, the sunrise sector is under pressure from climate change

Fisheries as a sector is under severe climate stress. Increasing oceanic temperatures, rising sea levels, and changes in marine ecosystems are disrupting the activities by reducing the quantity and quality of the seasonal catch of fisherfolks. Recent studies on climatic extremes indicate varying scenarios for major river basins of India. For example, temperatures have increased by 0.20–0.47 °C and the precipitation has decreased by 257– 580 mm over the Ganga river basin over the last few decades. These changes have a significant impact on the fish yields and reproductive cycles.[52]

Research shows that certain varieties of fish might become scarce in the coming decades. According to scientists, "increasing sea surface temperature results in migration of many economically harvestable fish stock to relatively cooler waters, leading to a shift in fish distribution and affecting the fish catch."

5.2.1 climate change is leading to fish dying and incomes drying up

In 2017, for example, Cyclone Ockhi led to a fall of 46% of annual fishing days in Kerala. The change in ocean temperature has also led to a drop in the population of vulnerable fish species, affecting the income of fishing communities and permanently altering marine life.[54]

The Godavari, the longest river in Peninsular India, is also experiencing a significant increase in its annual temperature ranges indicating the presence of changing seasonal cycles over the river basin. These changes have had a significant impact on the fish yield and their reproductive patterns.The Krishna, the second largest east–flowing Peninsular river is also showing an increasing trend in the mean monthly maximum and minimum temperatures under projected scenarios. An increase of 1.67–2.57 °C has been projected by the end of the 21st century. Predictions indicated an increase in mean monthly minimum temperature by 2–4 °C in 2050 and a decline in the number of rainy days. The Cauvery River is one of the major rivers of the Peninsula. The Cauvery has a total drainage area of 81,155 km2 (2.5% of the total geographical area of the country) and is more intensively dammed than any other river in India. The annual rainfall over the basin during 1950–2010 has increased, with higher maximum rainfall observed during 1950–70. However, the seasonal trend shows a decrease in the number of rainy days during the south west monsoon and an increasing trend during the northeast monsoon. The minimum temperature appears to be marginally declining while the maximum temperature shows an increase of 0.022 °C.[55]

The ocean is becoming more acidic, impeding the ability of corals and shell-forming organisms to build the skeletons and shells that they depend on for life. Increasing sea surface temperature results in migration of many economically harvestable fish stock to relatively cooler waters, leading to a shift in fish distribution thus affecting the fish catch." Also, rising temperature is causing a decline in dissolved oxygen levels in inland water bodies. This can make aquatic species susceptible to diseases due to weakened immune systems. Rising temperatures could mean that some species look for cooler water by shifting towards the poles or seek out deeper water.[56]

Hatchery & Seed Systems	
Broodstock Management	Deviations in water temperatures reduce spawning success - disrupt the timing and success of spawning events
	Floods/cyclones damage broodstock ponds.
Seed Quality & Survival	Heatwaves increase larval mortality
	Flood-driven pathogens reduce seed survival.

Pests, Diseases & Biosecurity	
Disease Surveillance	Climate variability increases disease frequency
	Lack of local monitoring systems.
Climate-Sensitive Outbreaks	Warmer water accelerates pathogens;
	floods spread disease across ponds.

Pond Preparation & Water Systems	
Pond Infrastructure	Erratic monsoon hinders pond drying
	Floods breach bunds causing escapes.
Water Quality	Heatwaves lower dissolved oxygen
	Salinity intrusion from sea-level rise contaminates ponds
Water Availability	Droughts reduce freshwater supply
	lack of affordable pumps/aerators during dry spells.

Harvest & Post-Harvest Handling	
Harvest Scheduling	Floods/cyclones prevent timely harvest
	fish escape during extreme weather.
Post-Harvest Losses	High humidity disrupts sun-drying;
	heat increases spoilage without cold chain.
Quality & Grading	Heat accelerates spoilage
	no climate-resilient grading/standards adopted.

Table: Impact of climate stressors on the fishery value chain

5.3 the^delta take and ecosystem implications

Fisheries—a ₹1.8 lakh crore sector supporting 28 million workers—has become one of India's most climate-exposed livelihood systems. Inland and coastal waters now face simultaneous stress from rising temperatures, erratic rainfall, and salinity shifts. Average water-temperature increases of 0.2–0.5 °C and declining precipitation across major river basins are altering breeding windows, oxygen balance, and fish migration patterns. Broodstock mortality, disease outbreaks, and infrastructure loss from floods and cyclones are becoming routine, while sea-level rise and saline intrusion are rendering freshwater ponds and estuaries less productive.

For small-scale fishers—who form over 90% of the inland workforce earning ₹2,500–10,000 a month—these changes directly translate into fewer harvest cycles, higher input costs, and volatile incomes. Declining dissolved oxygen, algal blooms, and feed-price shocks erode margins further, while disease-driven mass mortalities and weak diagnostics can wipe out an entire season's cash flow. Communities dependent on single species or waterbodies face the highest displacement and debt risk.

Technology and systems integration can reset this trajectory. IoT-enabled pond sensors and satellite water-quality tracking can anticipate low-oxygen or salinity events; predictive analytics can model disease spread; decentralized feed-processing and cold-chain systems can stabilize local supply; and genomic broodstock management with digital traceability can maintain genetic diversity and export credibility. A unified aquatic-data and early-warning infrastructure can turn fisheries from a climate-fragile activity into a precision-managed livelihood system linking ecology, productivity, and income resilience.

6
Livestock: the sector that supports 70% rural Indian households

India has the largest livestock population in the world, over 530 million animals, as per the 20th Livestock Census. The livestock sector provides livelihood to about 70% rural households in India, employing about 80 million people, with a significant proportion being small and marginal farmers, and landless labourers.[57]

The sector has grown rapidly over the years, making India the global leader in dairy, second largest producer in eggs and fifth largest in poultry meat, and second largest producer of goat meat. The ever increasing demand of these products have made sure that the growth of livestock as a sector never slows down. The sector contributes 30.23% to agricultural GVA and 5.5% to the national economy.[58]

Dairy, poultry, and goatery are three of the core pillars strengthening the sector, having grown rapidly due to technology-led innovations and fair share of government/policy interventions. All three sectors have a share in global exports today, leading production and processing. However, climate change has increased the vulnerability of the population engaged in these livelihoods, leading to an increasing trend in losses related to livestock, income, and productivity. These sectors demand resilience today, which can be driven through market-driven tech-enabled innovations to help minimise the losses and ensure higher productivity as climate change intensifies.

India is the global leader in dairy

2nd
largest producer of eggs

5th
largest producer of poultry meat

2nd
largest producer of goat meat

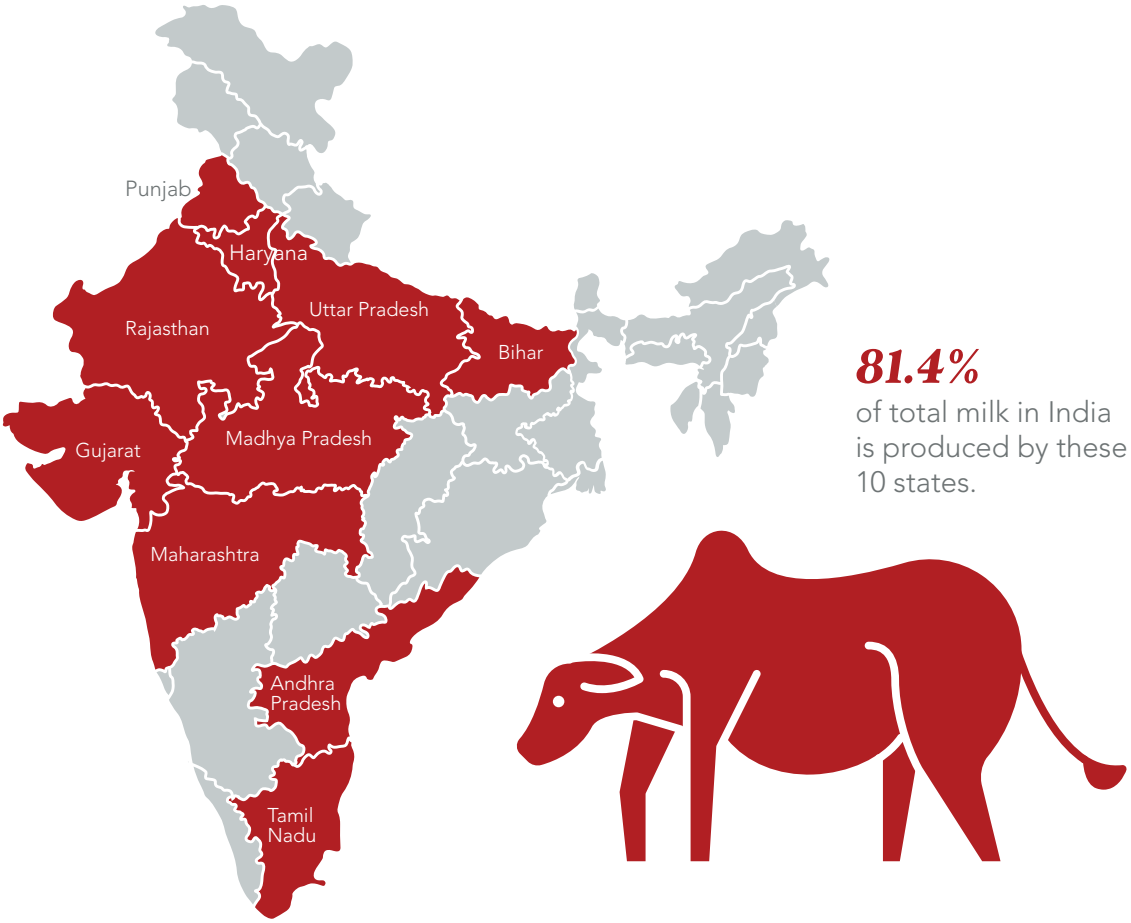
6.1 From milk scarcity to global leadership: sustaining India's White Revolution in a changing climate

India is the world's largest producer of milk since 1998. As per government data, the contribution of milk from buffaloes is the highest accounting for 49% followed by cows and goats at 48% and 3% respectively. The top ten milk producing states are Uttar Pradesh, Rajasthan, Madhya Pradesh, Andhra Pradesh, Gujarat, Punjab, Maharashtra, Haryana, Bihar and Tamil Nadu. Together they contribute 81.4% to the total milk production in the country.

Before 1970, the pace of milk production was not aligned with the pace at which population was growing in India - milk production grew at 1.36% per year during 1950-51 to 1973-74 while the population grew at over 20% during this period. Since 1970 as Operation Flood kickstarted, milk production exceeded population growth, such that per capita milk production rose to 387 gram per person per day by 2018-19 (higher than average Recommended Dietary Allowance for the country which is 377 gram per person per day) compared to 110 gram per person per day per year in 1973-74.[59]

Today, after over 5 decades of Operation Flood, India produces 22% of the milk produced globally.[60] The production of milk has grown year on year. During 2019- 20, India has produced 198.4 million tonnes (Mt) of milk valued at ₹7.72 lakhs crores (as per 2018-19 prices) which is greater than the valuation of wheat and paddy combined. The production rose to 239.30 million tonnes for 2023-24, valued closer to ₹19 lakh crore.[61] The economic value and market potential of the sector is immense. At present, dairy contributes about 5% to the GDP of the country and nearly 25% to the total agricultural GDP. As per IMARC 2025 report, the total size of the dairy market was about ₹18.98 lakh crores in 2024 and is expected to grow to about ₹57.00 lakh crores by 2033.[62]

Dairy is the main source of income (not necessarily the only source of income but the most reliable source of income) for 80 million households in India - the majority (close to 80%) being small-scale, marginal farmers.[63] They contribute 62% of the total milk produced in India.[64] However, the sector's participation in the global market remains limited, only amounting to $560.7 million in 2023, fairly restricted to four major



Top ten milk producing states

dairy products - milk powder, butter, other milk fats and oils, and certain cheeses. More than 40% of the total milk produced in India is consumed internally, remaining being available for commercial consumption - a larger share of which is being used to meet domestic demand. The lack of availability of diversified milk products and avenues for market innovation for export is leading to a massive loss of opportunity for dairy farmers to improve their livelihoods and hold a larger value share in the global milk market. India has managed to attain top position in milk production globally owing to its huge bovine population (303.76 million as per the 20th Livestock Census), however, the full potential of the Indian milch herd remains unattained.

The dairy industry is highly fragmented and often battling with inefficiency. A large number of farmers operate in an informal and unregulated market, with a lack of proper infrastructure and a lack of access to technology and capital. The industry has seen a slower growth for several reasons - the employment of non-scientific procedures, ineffective cattle breeding, lack of adherence to quality standards, transparency and most importantly, a lack of proper technological support which eventually leads to information asymmetry in the multilayer supply chain which hinders the sustainability.[65]

Climate change is further adding to the emerging crisis, as the livelihood of dairy farmers is at higher risk of loss of produce and reduced productivity due to increasing heat stress and extreme weather situations in India. The negative impact of climate change on total milk production in India is estimated to be more than 15 million tons by 2050.[66] It is estimated that there is a loss of 1.8 Mt of milk a year due to heat stress among cattle and buffaloes, which is attributable to approximately ₹2661 crores.[67] Thus, it is of utmost importance to look beyond domestic demand and increase the market share and revenue channels for these farmers, especially the ones operating at small scale, to cover losses and build resilience.

6.1.1 Some of the key areas of impact in dairy are:

Animal physiology:
Exposure to extreme temperatures, especially high heat, is disturbing the animals' physiology, ultimately affecting high quality semen and higher milk production.

Feed:
In standard dairy production systems, feed costs can account for up to 70% of total expenses. As a result, high feed costs significantly affect the profitability of dairy farming.[68]

Currently, India produces fodder on only 5% of its cultivable land. The mismatch between supply and demand is driving prices up. Further, warmer temperatures and drier conditions are decreasing the protein and mineral content in plants, which negatively impacts the nutritional quality of animal feed. Small dairy farmers involved in dairy farming, struggle to afford adequate feed and fodder.

> In Bundelkhand region there have been 30 years (out of the last 50) with rainfall below normal, and 15 years, when rainfall was lower by more than 25% of the normal. Crop failure due to drought restricts availability of crop residue thus making rearing of livestock most difficult to farmers. It had been estimated by a survey that during three months of peak summer, 300 thousand cattle and other animals died due to fodder and water shortage in the region.[69]

Shelter and housing:
Beyond breeding and production, frequent heat waves, floods, and storms are damaging traditional animal shelters, exposing livestock to illness, injury, and even death. In Rajasthan, for example, rising temperatures have led to more cases of heat stress in cattle, especially when shelters lack proper ventilation or shade.

> During the 2020 floods in Assam, over 1.4 lakh animals were affected, with many shelters submerged or destroyed. Without secure housing, livestock become more vulnerable to disease outbreaks and reduced productivity, directly affecting the income of families that depend on them.

Animal health and cattle loss:
Climate change and related disasters are severely affecting the health and survival of cattle as India lost over 8 lakh cattle to climate-related disasters between 2018-19.[70] Research studies have found that meteorological parameters like temperature, humidity and rainfall explain 52 and 84% variations in the seasonality of Foot and Mouth (FMD) disease in cattle in hyper-endemic division of Andhra and meso-endemic region of Maharashtra states, respectively.[71] Though there are 535.78 million farmed animals in India, there are only a little more than 73 thousand registered veterinary practitioners, which works out to be around one veterinarian for every 7,000 farmed animals.[72]

Cold-chain logistics:
Climate change and related disasters have also severely impacted the cold-chain logistics across several states in the country.

Case of Sikkim:

The curdled milk received by the Sikkim Milk union is increasing year after year. The rise in temperature and monsoon rainfall causes roadblock, thereby resulting in delay in transportation. The State is also known for its torrential rains which have increased in recent years due to climate change. As a result of unexpected torrential and erratic rains, there are frequent landslides. Consequently, the roads are closed and it becomes extremely difficult for the collection vans to reach designated collection centers in time. This transportation delay results in rapid multiplication of bacteria and results in increasing acidity and spoilage of milk.

A 1°C increase in average maximum temperature is resulting in 2.4% fall in cattle milk yield, and 2.1% fall in buffalo milk yield.

The corresponding figures for rise in minimum temperatures are 3.6% and 2.5% for cattle and buffaloes, respectively. From breeding and production to value addition and market connectivity, climate change is impacting the dairy value chain across different stages in the value chain. These are also the areas where innovation can lead to resilience of the dairy sector against climate change as well as a higher share in the global market through exports to diversify the market and revenue opportunities.

6.1.2 There is a need to explore market-driven tech-enabled innovations in some of the key areas in dairy

Artificial insemination and breed improvement:
As per data reported by the States on Bharat Pashudhan portal, the success rate of artificial insemination in India is not more than 35% today. The quality maintenance of semen after leaving the laboratory and while reaching the farmer is of key importance as it can alter the possibility of successful insemination. A higher quality breed can help increase productivity and reduce environmental impact from dairy.

Cattle management:
Reducing feed and management costs while enhancing feed quality is important to boost farmers' earnings, allowing cows to produce up to 20 liters of higher-quality milk daily. High-income markets that charge premium prices enforce strict standards on animal feed, antibiotic residues, and contaminants, which are areas where India's compliance mechanisms need significant strengthening. A comprehensive disease management strategy and investments in research and technology are also important for early detection and prevention.

Value addition:
Investing in processing infrastructure is essential to shift focus from merely fluid milk production to developing capabilities for a variety of cheeses, whey proteins, and functional dairy ingredients that align with global demand trends and also increase the lifespan of raw milk at a farmer level. There is a need to elevate quality standards by implementing more effective testing methods for milk in the unorganised dairy sector while also enhancing the efficiency of cold chain logistics, enabling contribution to international demand as well.

Global export market expansion:
Consistent production of different variants of skim milk powder through high quality raw milk and better equipment can help capture a higher share in the global export market. India’s proximity to markets makes UHT milk (ultra-pasteurised milk), flavored milk, fresh cream, and ice cream mixes attractive export

options. There are also opportunities in mozzarella and white cheese spreads produced from buffalo milk. Tailored products such as milk powder with vegetable fat, though not in high domestic demand, are well-accepted in Africa, Iraq, the Middle East, and Southeast Asia.

India's dairy sector has the potential to build resilience and navigate the challenges to hold a larger share in the global market. If the sector is able to tap on the demand opportunity of milk and related products and improve the quality (largely through market driven technology innovation) to command better prices, the exports can grow and India can become one of the top exporters in dairy alongside Germany, The Netherlands, and New Zealand.[75] The dairy sector is of extremely high importance today considering the number of people engaged in dairy farming and the share of the vulnerable population dependent on dairy as a source of income.

Reproduction and breeding	Specific Climate-Related Problems (India)
Natural Fertility	Heat stress reduces expression of estrus (silent heats), making it harder to detect breeding cycles in cows and buffaloes.
	Embryonic mortality rises significantly during heatwaves; conception failures most common in the first 40 days of pregnancy.
	Cold stress also delays puberty and lengthens calving intervals in northern India winters.
Artificial Insemination (AI)	High ambient temperatures degrade semen during storage & transport; maintaining cold chains in rural India is challenging.
	Power outages during heatwaves/floods compromise semen quality, reducing conception success rates.
	Field inseminators face delays during floods/heatwaves, missing optimal fertility windows.
Male Fertility	Heat stress lowers sperm concentration, motility, and viability in bulls.
	Reduced libido and mating activity during summer months reported across Bundelkhand and Marathwada regions.
Housing and shelter	**Specific Climate-Related Problems (India)**
Heat Stress & Infrastructure	Traditional thatched/corrugated shelters lack ventilation; animals exposed to >40°C in north India summers.
	Frequent floods and cyclones (Assam, Bihar, Odisha) damage cattle sheds, leaving animals exposed.
	Poor housing leads to direct mortality during disasters – e.g., 2020 Assam floods affected 1.4 lakh cattle.
Cold Stress	Inadequate insulation in Himalayan & north Indian states causes stress, pneumonia, and reduced productivity in winter.

Table: Climate stressors on the dairy value chain

Feed and water	Specific Climate-Related Problems (India)
Natural Fertility	Droughts reduce crop residues (major fodder source); Bundelkhand droughts cause 300,000+ livestock deaths in seven years.
	Shortfall of 35.6% green fodder and 10.5% dry crop residues at national level; worsens in drought-prone states.
	Elevated CO_2 lowers protein & mineral quality of fodder; heat increases mycotoxin risks in stored feed.
Water Availability & Quality	Erratic monsoons and droughts reduce freshwater availability for cattle, especially in Rajasthan & Bundelkhand.
	Floods contaminate drinking water with sediments, salts, and pathogens, causing livestock disease outbreaks.
Cold Stress	In Himalayan states, cold stress lowers forage digestibility by ~15%, affecting energy intake.
Health	**Specific Climate-Related Problems (India)**
Heat Stress & Disease Susceptibility	Heat weakens immunity → higher incidence of mastitis, parasitic infections, and tick-borne diseases.
	Foot and Mouth Disease (FMD) outbreaks strongly linked to temperature & humidity in Andhra & Maharashtra .
Extreme Events	Between 2008–2019, India lost over 8 lakh cattle to floods, storms, and other climate-related disasters.
	Vector-borne diseases (e.g., bluetongue, haemorrhagic septicemia) increase post-floods due to stagnant water.
Veterinary Gaps	India has only ~73,000 registered vets for 536 million livestock (~1 vet per 7,000 animals) . Climate extremes further widen the service gap.
Processing and marketing	**Specific Climate-Related Problems (India)**
Transport of Animals & Milk	Heat stress during transport without water access → dehydration, mortality
Cold Chain & Processing	Flooded rural roads in Assam/Bihar delay milk transport, causing spoilage .
	Rising temperatures + erratic power supply disrupt chilling centers; milk curdling cases rising in hill states like Sikkim.
	Lack of climate-resilient logistics leads to greater spoilage of perishable dairy products (paneer, curd, ghee).

Table: Climate stressors on the dairy value chain

6.2 the^delta take and ecosystem implications

India's dairy economy—worth nearly ₹19 lakh crores and engaging 80 million households—now faces converging biological and climatic limits. Rising heat, erratic monsoons, and recurring droughts are directly suppressing reproductive performance, milk yields, and feed quality. Heat stress alone cuts annual milk output by about 1.8 Mt (₹2,661 crores), while extreme events have claimed over 8.4 lakh cattle in a decade. Droughts have shrunk fodder supply by more than 35%, pushing up feed costs that already account for 70% of production expenses. Warmer, wetter conditions heighten mastitis and tick-borne disease incidence, while floods, power failures, and broken cold chains—from Bundelkhand to Sikkim—routinely spoil milk and destabilize farmer income.

For small and marginal producers, these pressures compress profit margins and threaten the reliability of dairy—their most stable cash source. Reduced fertility, degraded semen quality, and delayed insemination cycles weaken herd renewal, while veterinary shortages (1 vet per 7,000 animals) magnify disease losses.

Technology offers measurable buffers: precision heat-stress monitoring, digital insemination and semen-trace systems, AI-based health diagnostics, and IoT-linked cold-chain infrastructure can protect yields. Climate-resilient fodder crops, feed analytics, and decentralised milk-processing units can localise resilience and cut spoilage. A data-integrated dairy ecosystem—spanning breed genetics to logistics—can convert India's climate-vulnerable White Revolution into a precision-managed, export-ready livelihood system.

7

India's poultry story: growing beyond backyards in a changing climate

India is a leading producer in the global poultry industry, ranking 2nd in terms of total egg production and 5th in poultry meat production. Total meat production in India was 10.25 million tonnes in 2023-24, poultry meat contributing close to 49% to the total meat production. Egg production stood at 142.7 billion, with over 86% coming from fowl. The broiler industry is concentrated in the southern and western states and accounts for a major share of total output. Similarly, the layer industry is dominated by well developed states like Andhra Pradesh, Tamil Nadu and Maharashtra, accounting for nearly 60% of the production.[78]

The India poultry market size reached ₹2,304 billion in 2024. The poultry sector has shown rapid growth, with chicken meat growing at an average annual growth rate of 9% and eggs growing at 6% from 2000–01 to 2018–19 (DAHD 2020).[79] The market is expected to reach ₹8,430 billion by 2033, exhibiting a CAGR of 12.60% during 2025-2033.[80] This industry contributes about ₹125 lakh crores accounting for 1% of national GDP and 14% of livestock GDP.[81]

Of the total poultry production, eggs are the most widely eaten animal source protein with 78% of people having eaten them, followed by chicken/meat (75%).[82] However, who consumes most of this produce? Most consumption is domestic, where meat consumption is driven by fresh meat from live markets (90%) and not processed/chilled or frozen meats (around 7–10%). Although India is a competitive poultry meat producer, due to lack of processing facilities, small farm sizes and no-brand credibility, Indian poultry exports have been low. Currently, India contributes to less than 0.4% of the global poultry and poultry-based trade.[83] India exports smaller quantities of frozen whole chicken and cuts to South Asia, Middle East and more recently, to Japan and South-east Asia (USDA FAS 2016).

Although poultry farming is one of the most dominant backyard farming activities in India, it requires scientific management and care for successful rearing and production.

Feeding constitutes the fundamental and major management concern in poultry production since major expenditure (60-70%) in poultry rising is feed cost. Efficiency in feeding therefore is one of the key factors for successful poultry production. More than 40 nutrients are required by the poultry. Poultry's nutritional needs evolve as they grow. Chicks have higher protein requirements for rapid growth, while adult birds require different nutrient ratios. Birds of different sizes also have different metabolic rates and energy requirements. Birds grown for meat require more muscle weight gaining diets while those raised for eggs require more calcium rich diets. Thus a deep understanding of nutritional needs is required.[84]

Feed costs in terms of prices of maize and soybean also have a serious repercussion on the competitiveness of the poultry sector as input prices related to feed cover (60–70)% of the cost of production. To contain the cost of feed, it is important to enhance the feed conversion ratio. Indigenous breeds require simple shelters and access to free-range systems, compared to layers who require proper lighting, ventilation and nesting boxes. Backyard chickens require a higher per bird space in the coop with protection from harsh weather, similar to broilers who also need an additional temperature maintenance.[85] It is also essential to ensure protection against common diseases like Fowl Pox, and Avian Influenza, and a safe environment from litter and other harmful substances. Disease surveillance remains an area of concern for the poultry industry today.

7.1 Exploitation in the backyard poultry sector

Chicken farming is a significant industry in the nation's food production, giving chicken producers financial stability. Poultry has been popular among small-holder farmers who have boosted the nation's economy, so its significance to the economy cannot be stated more. In India, there are primarily two sub-sectors of the poultry industry: the commercial sector accounting for about 80% of the entire market share, and the unorganised sector (backyard poultry) accounting for about 20% of the total market share.

While the two sub-sectors exist, the value chain itself is not completely organised. Breeding, hatcheries and feeding operations in India are organised with complete vertical integration, while slaughtering, distribution and retailing are all unorganised with the predominance of wet/fresh-cut meat markets. Only 11% of poultry meat in India is produced from poultry processing plants, which include more than 21 large (>1000 birds/hour capacity) and around 20 smaller (<1000 BPH) units. The remaining 89% of the poultry meat in India is produced under wet market conditions through highly scattered road side poultry processing plants.[86]

According to the 19th Livestock Census, approximately 30 million farmers raise backyard chickens. About 18% of India's total egg production also comes from backyard poultry, reported by Basic Animal Husbandry Statistics.[87]

As per 20th Livestock Census, the total poultry in the country is 851.81 million in 2019 (807.8 million were fowls (domestic cock or hen), 33.5 million were ducks and 10.4 million were turkeys and other poultry birds, which increased by 16.8% over the previous Census. The total Backyard Poultry in the country is 317.07 million in 2019, increased by 45.8% over previous Census. The total Commercial Poultry in the country is 534.74 million in 2019, increased by 4.5% over previous Census. Poultry farms are largely classified into three categories: small (with 5,000-25,000 birds); medium (above 25,000-100,000 birds); and large (more than 100,000 birds) (Ministry of Environment, Forest and Climate Change, 2020). A vertical integration between large integrators/hatcheries and small farmers has been happening through the contract farming approach. In 2020, almost 80% of India's poultry production (in value terms) came from this organised contract farming segment. Interestingly, almost 70% of poultry farmers engaged through contract farming are smallholders with a flock size of 3,000-10,000 birds; 20% are medium scale farmers with 10,000- 50,000 birds, and only 10% are large scale farmers with 50,000-400,000 birds.[88]

A contract farming agreement in the case of broiler farming is referred to as a chick growing agreement, wherein an integrator supplies inputs and procures the output, thus establishing key control and ownership of major components of the value chain. The integrator provides day-old-chicks (DOCs), feed, veterinary services, and vaccines to the contract farmer and the contractor also takes charge of the final marketing of the output either in wet markets or for further processing and distribution. The contract farmer provides land, housing, equipment (litter shed), labour (family or hired) and takes care of day-to-day farm management. Contract farmers are given an incentive bonus if the Feed Conversion Ratio (FCR) and/or mortality rate is lower than those agreed upon in the contract. Thus, poultry growers benefit from considerable price assurance and risk mitigation. Integrators, typically, pay contract growers pre-decided prices for about 42 days old broiler birds.

Although 80% of India's poultry production comes from contract farming, it is found to be unfair and less profitable for farmers. There exists a 40-88% difference in profits for contract farmers compared to non-contract (independent) farmers. The per bird gross average return for independent farmers is estimated to be around ₹128.67, compared to about ₹19 for contract farmers. A contracting agency sells a bird for ₹191.17 and pays ₹17.17 per chicken to the broiler farmer who raises it.[89] Another study in Tamil Nadu suggests that the majority of broiler farmers preferred independent farming over contract farming while larger farmers preferred contract farming over independent farming.[90] Whether contract farming is a choice or the only choice is still unclear, however, there is a need to understand the market better to drive innovation in the right spaces to benefit the poultry farmers.

A study looked into the costs and returns of broiler poultry farming in the Mirzapur district of Uttar Pradesh. Primary data collected from 60 broiler units in the district was used for analysis. The overall average cost of production was around 138.46 per bird. The cost of production was highest for small farms and lowest for large farms. Chick and feed costs together accounted for more than 75% of the total cost of production. The net return realised per kg of broiler chicken was ₹11.34, ₹15.05, and ₹17.14 in small, medium, and large farms, respectively, with an overall average of ₹13.27.[91]

It costs a farmer around ₹4.50 to produce an egg. A 15,000-bird layer (egg) farm needs a capital investment of about ₹700 per bird, or over ₹1 crore total. This is till about 20 weeks when the birds start laying eggs, after which farmers incur feed and maintenance costs.[92]

Category	Feed Stages & Protein %	Feed Consumption	Notes
Indigenous Breeds	Utilises local feed (leftover grains, by-products)	Lower, due to adaptability and hardiness	Cost-effective, low input needs
Layers	- Starter (0–6 wks): 18–20% protein - Grower (6–20 wks): 16–18% protein - - Layer (20+ wks): 16–18% protein + calcium	~100–110 g per bird/day	Structured feed cycle supports egg production
Backyard Chickens	Balanced diet: 16–18% protein for adults, supplemented by forage/pasture	~120 g per bird/day	Relies partly on natural foraging
Broilers	- Starter (0–3 wks): 22–24% protein - Grower (3–6 wks): 20–22% protein - Finisher (6 wks–market): 18–20% protein	~1.6–2.0 kg per bird over 6–8 weeks	High-protein diets for fast growth

Table: Nutritional management of different poultry breeds [Source: Poultry farm Brochure DAHD]

It is estimated that by 2050, the need for poultry products is predicted to quadruple globally, mostly as a result of rising living standards. In the meantime, the quality of feed crops and forage, availability of water, poultry diseases, and poultry reproduction are all threatened by climate change, which poses a challenge to poultry production.[93]

7.1.1 Some of the key areas of impact in poultry industry are:

Breeding and production:

Seasonal fluctuations and poultry production and poultry behavior patterns are very interlinked. The problems associated with climate change and the resultant rise in temperature might very well lead to a reduction in the production of poultry and poultry-based products. It is reported that if an environment's temperature reaches anywhere near 34 degrees Celsius, heat stress-related mortality reaches an astounding 8.4%. At 31 degrees Celsius, egg production becomes erratic and might even reduce by 6.4%. Seasonal fluctuations might have a hand in affecting the semen quality in breeder cocks.[94]

> Chicks that are one day old have rapid metabolism and growth rates, which makes it challenging for them to adjust to the constant rise in ambient temperatures. Extended heat stress in broiler chickens can result in acid–base imbalance and activate lipid peroxidation, which can have negative impacts on muscle growth, fat metabolism, meat quality, and blood chemical profile. Furthermore, excessive heat waves cause chickens' protein content to drop and their fat deposits to rise.[95]

The same seasonal fluctuations could be responsible for producing poor-quality eggs by poultry hens. The eggs are more prone to breaking and will be of lower quality as the temperatures brew higher.[96] Research shows that high temperatures might increase respiratory rate. The higher respiratory rate leads to hypotension in poultry which results in poorer egg production quality.[97]

West Bengal saw a 25% annual decline in egg output during 2024 heatwaves (40–42°C), with Bankura farms reporting 20% fewer eggs and 10% chicken mortality. Eggs laid during heat waves have 12–15% thinner shells and 8% lower weight, increasing breakage risks.

Feed and water:

Rising temperatures and humidity increase the risk of mycotoxin contamination (like aflatoxins) in feed grains such as corn and sorghum, reducing feed quality and causing health issues in poultry.[98] Climate change also disrupts crop production due to erratic rainfall, droughts, and temperature spikes, leading to feed scarcity and higher costs. Feed costs in terms of prices of maize and soybean have a serious repercussion on the competitiveness of the poultry sector as input prices related to feed cover (60–70)% of the cost of production. To contain the cost of feed, it will be important to enhance the feed conversion ratio.[99] Availability of high quality, nutritious, and affordable feed is important for production sustainability. Availability of fresh water is also a big concern for poultry. It plays an important role in regulating body temperature, digesting food, and eliminating wastes. Accounting for up to 70% of their body weight. Starved birds may lose all their fat, about half of their protein, and about 40% of their body weight and still survive, but a 10% to 20% loss of their body water will result in death.

Heat wave + drought-like conditions caused water shortages in Karimnagar in 2023; >50% of poultry units shut down. Egg production dropped by 10-20%.

Shelter and housing:

Indian summers now regularly see temperatures soar above 40°C, far exceeding the poultry thermo-neutral zone (21–25°C). Chickens are especially vulnerable as they lack sweat glands and struggle to dissipate heat. High temperatures inside poorly ventilated or open-sided poultry houses lead to reduced feed intake, lower egg production, poor meat quality, and increased mortality. In contrast, during periods of cold stress, poorly insulated houses can expose birds to near-freezing temperatures, causing stress, disease outbreaks, and equipment failures (e.g., frozen water lines).

Broiler hatcheries in Palladam reported mortality rising from ~3% to 7–8% due to inadequate cooling/shelter in peak heat.

Health and disease management:

Poultry themselves cannot regulate their body temperature through sweating. Research suggests feathered poultry will pant to bring down body temperature. Prolonged panting can induce chronic stress in poultry. Seasonal fluctuation also leads to compromised immunity in poultry. The lack of proper immunity will lead to more poultry-related disease outbreaks and more widespread transmissions of said poultry diseases.[100] Frequent occurrences of avian influenza (bird flu) cause high levels of bird deaths and illness in India's fast-growing poultry industry and lead to economic losses as it affects markets and exports of avian products and sub-products are halted. Climate change has affected migratory patterns of birds, carrying viruses into new areas and seasons, raising the chances of disease spillover into poultry populations.

Storage and transportation:

Heat waves cause hens to lay eggs with thinner shells, making them more fragile and prone to breakage during collection and transport. Eggs laid during heat stress may also have compromised internal quality (yolk and albumen), further reducing their market value and storability. Without proper cooling, eggs spoil faster during hot months, forcing farmers to sell at lower prices or risk losses. Rising temperatures accelerate meat spoilage, with unrefrigerated meat lasting only 4–6 hours in summer heat. There are no cold storage facilities for meat sold for domestic consumers in the country, so the microbial count also

increases during the process of meat being sold. Chilled poultry must be stored at 4°C and frozen meat at -18°C, but outdated refrigeration and erratic power supply make compliance difficult. Farmers often sell live birds early due to extreme heat, causing loss of income and lower profitability.

7.2 where could we have a market play

For the industry to sustainably scale from backyard to commercial, it's important to focus on some of the core areas where technology innovation can help solve these challenges and reduce vulnerability for the people dependent on poultry as an important source of their income.

Market/product diversification:

90-95% of the poultry meat is sold in wet markets in India. This increases the risk of health hazards for the birds. A shift in focus from wet markets to markets for chilled chicken (shorter shelf life compared to frozen but longer compared to fresh) can be an opportunity where Indian exporters can identify and segregate poultry meat products and find markets for Indian chicken breast meat.

Disease management:

The single most devastating threat to the poultry sector are diseases like Avian Flu (highly pathogenic avian influenza(HPAI), A(H5N1) and H7N9), which can completely wreck the profitability and productivity of poultry, for big and small players, alike. The severity of these disease outbreaks disrupt both production and consumption patterns, as observed in India and other countries. Proactive monitoring of animal disease in the environment is important to protect birds from dying.

Feed:

Feed costs in terms of prices of maize and soybean have a serious repercussion on the competitiveness of the poultry sector as input prices related to feed cover (60–70)% of the cost of production. To contain the cost of feed, it will be important to enhance the feed conversion ratio (current is 1.65 which is decent). Finding alternate sources of nutrients for birds can also be an area of interest.

Storage and transportation:

Most of the loss in the poultry value chain is happening during transportation of live birds due to weight loss, injuries and death of birds. Entirely new vehicles need to be designed and fabricated as there are no exclusive livestock transport vehicles with built individual animal patrons. Vehicle body building infrastructure and the need for innovation of achieving this needs lots of R&D, me, manpower etc. This will add up the costs on livestock transport compared to the present. Something cost-effective yet in favour of farmers and transporters can be worked upon to ensure minimal losses during transportation. Cooling solutions for storage and transportation along with diversification of products beyond live markets can be a game changer for the industry.

Meat inspection:

Meat inspection is an additional responsibility to veterinarians in many states of India. Absence of sufficient meat inspectors increases the risk of disease transmission from slaughter houses. If there can be a human in the loop but more mechanisation and introduction of relevant and affordable technology for small-scale stakeholders to have better inspection practices in-house, the value of meat can be increased and the consumer market can rely on the suppliers of these animals more.

Backyard poultry contributes nearly half of household income in terms of livestock rearing for rural households in India. For these poultry farmers to grow their market scope and build resilience in the face of climate change, it is essential to work towards some of these core areas in a market-driven innovative approach such that the incomes can shift from backyard to commercial for these farmers, without having to worry about loss of livelihoods in the coming years.

Reproduction and breeding	Specific Climate-Related Problems (India)
Natural Fertility & Hatchability	High ambient temperatures (>34°C) reduce egg fertility and hatchability rates; broiler breeders show reduced semen quality during summer.
	Heat stress in hens reduces yolk quality, leading to poor chick survival post-hatch.
	Cold stress in north Indian winters delays sexual maturity and reduces hatchability.
Chick Mortality	One-day-old chicks are highly vulnerable; heat stress increases mortality due to dehydration and respiratory failure.
	Cold stress in poorly heated hatcheries increases early chick deaths.
Health	**Specific Climate-Related Problems (India)**
Heat Stress & Immunity	High temperatures suppress immunity, increasing outbreaks of Newcastle Disease and Avian Influenza.
	Continuous panting during heat stress causes acid–base imbalance → weakens immune response.
Extreme Events	Floods spread coccidiosis and E. coli in poultry farms.
Cold Stress	In poorly insulated housing, cold stress increases respiratory infections (IBD, bronchitis).
Feed and water	**Specific Climate-Related Problems (India)**
Feed Quality	Heat and humidity raise risk of mycotoxins (aflatoxins in maize, sorghum), reducing feed quality and immunity.
	Erratic rainfall and crop losses raise poultry feed costs (soya, maize prices spiked during 2022 heatwaves).
Water Scarcity & Quality	Summer droughts reduce water availability; water shortage reduces feed intake and growth.
	Contaminated water post-floods spreads bacterial diseases (salmonella, colibacillosis).
Egg and meat production	**Specific Climate-Related Problems (India)**
Egg Production	Heat stress reduces egg production by ~6–25% depending on severity; West Bengal reported 25% egg output drop during 2024 heatwave.
	Heat stress produces eggs with thinner shells (12–15% thinner), increasing breakage losses.
Meat Quality	Heat stress reduces protein content, increases fat deposition in broilers, lowering meat quality.
	High summer temperatures reduce carcass yield in Andhra Pradesh farms.

Housing	Specific Climate-Related Problems (India)
Heat Stress in Housing	Poultry lack sweat glands; heatwaves (>40°C in Indian summers) cause panting, dehydration, reduced egg laying, and mortality.
	Poorly ventilated sheds in Andhra Pradesh and Tamil Nadu see >10% mortality in summer.
Cold Stress	In north India winters, lack of insulation leads to frozen water lines and increased respiratory infections.
Extreme Events	Cyclones and floods (Odisha, West Bengal) damage poultry sheds, leading to direct losses of birds.
Storage and logistics	**Specific Climate-Related Problems (India)**
Egg Storage & Grading	High ambient temperature accelerates spoilage of eggs; collection delays in heatwaves reduce market value
Meat Cold Chain	Power outages and poor cold storage mean unrefrigerated poultry spoils in 4–6 hours in summer.
Transport 	Long-distance transport without climate control increases mortality and spoilage.

Table: Climate stressors on the poultry value chain

7.3 the^delta take and ecosystem implications

India's poultry engine—second in eggs and a top-five meat producer—now faces climate and value-chain constraints that directly hit smallholder incomes. Heatwaves, erratic rain, and water scarcity depress reproduction and growth: at >34 °C mortality spikes (~8.4%); at ~31 °C egg output turns erratic and can fall ~6% (West Bengal saw a 25% drop in 2024, with ~10% mortality). Feed—already 60–70% of costs—faces quality shocks from mycotoxins and price spikes; droughts and shortages (e.g., Karimnagar 2023) forced >50% of units to shut and cut eggs 10–20%. Poorly ventilated sheds raise summer deaths (>10% in parts of AP/TN), while floods/cyclones damage housing and spread coccidiosis/E. coli. Live-bird logistics and weak cold chains accelerate breakage, spoilage, and distress sales; disease events (AI/Newcastle) and thin veterinary cover amplify losses.

For backyard and contract growers alike, these mechanisms compress margins through lower FCRs, thinner shells (12–15%), reduced protein/carcass yield, and higher mortality—turning a reliable cash flow into volatile earnings.

A tech-first reset is feasible: thermal-smart housing and IoT monitoring (temperature, humidity, water); rapid mycotoxin screening and feed analytics; water treatment and contingency storage; digital hatchery/AI trace for semen, fertility windows, and chick quality; active disease surveillance and vaccination scheduling; cooled, purpose-built transport and node-level chilling; and product diversification from wet markets to chilled/frozen lines with basic inspection tech for small plants.

Done together, these measures turn a heat-exposed, breakage-prone chain into a precision-managed, biosecure poultry system that preserves yield and stabilises incomes as the climate warms.

8

A poor man's cow and a global opportunity: the potential of growth for goatery in India

Goats are one of the earliest domesticated livestock in India. They are known for their low investment, high prolificacy, and adaptability to harsh environments. India leads the world with 148.8 million goats, followed by China (133.31 million), Pakistan (80.33 million), Nigeria (76.3 million), and Bangladesh (59.5 million). The 20th Livestock Census of 2019 recorded a 10.1% growth rate in goat population compared to the previous census in 2012. Goats represent the second-largest category in India's total livestock population, contributing 27.74% of the total inventory, next to cattle.[102]

Out of 138 million Indian rural households, 33.01 million (23.92%) rear goats.[103] Approximately 83% of goats in India belong to landless small-scale farmers in ecologically vulnerable and drought prone areas.[104]

Goats contribute close to 9% to the GDP derived from livestock and approximately ₹38,590 crore annually in the national economy.[105] The production of mutton and goat meat in India in 2023 stood at 734.0 thousand metric tonnes. India is also one of the top exporters of goat meat, having exported 9,592.31 MT of goat/sheep meat to the world worth of ₹537.18 crores during the year 2022-23.[106] The estimated meat demand for 2030 is 9.2 million metric tonnes against the estimated production of 8 million metric tonnes.

On an average 10-12 kg meat can be obtained from one goat per year. Oftentimes productivity of the goats is low (up to 75% of their population), and mortality is high (up to 50%) because goats in India (>85%) are kept under sub-optimal production conditions (zero inputs). Goats are considered one of the most low-maintenance livestock animals in India. These animals are reared under varying patterns from stall fed to migratory pattern. The major feeding resources for goats are common property resources and crop residues.

More than 95% goat keepers rear their goats on zero input and earn an average profit of ₹12,500/ year from a unit of five adult females. The profit from five goats has the potential to become double or more by shifting goat management from extensive to semi-intensive or intensive management.[107]

Goats are known to utilise poor quality feed and convert them into products of high economic returns. They also have the ability to reduce their metabolic rate in order to conserve energy during scarcity conditions. Goats also have superior thermo regulatory mechanisms and can cope with water scarcity in addition to low methane emission. However, climate change has not left the sector untouched. Heat stress has been significantly altering growth and reproduction in goats by reducing their daily average gain and growth efficiency. The absence of artificial insemination techniques to spread high genetic potential semen, unlike in bovines, further hinders productivity.[108] Goats also face severe environmental challenges, such as rangeland degradation, competition for land use, and water scarcity alongside changes in quality and quantity of pasture, cultivated fodder and other feeding resources. Farmers in India report a loss of 30% in fodder production during extreme events of climatic conditions.[109] One field survey from 2017 reported 71.7% of livestock keepers noticed declining productivity, 54.2% noted livestock deaths, and 30.8% cited water access issues.

Climate change also affects the health of goats. Alterations in ecosystems change the efficiency and transmission of pathogens, eventually leading to rapid and widespread disease outbreaks. Diseases like diarrhea, acidosis, bloating, pneumonia, goat pox, foot-and-mouth disease and parasitic infection are prevalent and pose constant and significant issues in the goat production system.

The market for goats is also highly informal and unorganised, with no proper price fixation, middlemen exploitation, unhygienic local slaughter practices, and a lack of processing and cold chain facilities, necessitating the sale of animals within a day.

8.1 the market play

The sector has a lot of potential, primarily in terms of goat meat, but the potential remains unrealised as goats are reared in minimal conditions. Market-driven innovation and technology can help realise the full potential of goatery as a sector:

Breeding and diversification of market:

There is minimal presence of artificial insemination and other biological/technological practices to help improve productivity of goats, as climate change activities affect the productivity of goats. Goat milk is a highly valued ingredient in the commercial cosmetic market, beyond direct consumption. However, there

is inadequate exploration of this market today. Development of dairy goats can help provide more livelihood opportunities to the goat dependent population.

Better health maintenance and early disease detection:
Goats are more vulnerable to diseases due to climate change, affecting their health, productivity, and mortality. Early monitoring and surveillance and better cure can make the breeds resilient and more tolerant.

Shelter, housing, and feed:
Development of low-cost goat shelter and house models suitable for different agroclimatic regions can protect goats from extreme weather events and temperature. As resources are depleting for grazing, reduction in feed and fodder cost through technological innovations can help the rearers as expenditure on feed and fodder in goat farming account for more than 60% of recurring cost.

Storage and chilling systems:
Unhygienic local slaughter practices, and a lack of processing and cold chain facilities necessitate the sale of animals within a day, leaving lesser flexibility for negotiation for the rearers. Better storage and chilling systems can help diversify products and markets and increase shelf life, providing more flexibility and better value.

Often called the 'poor man's cow,' goatery sustains millions of small and marginal farmers in India. Yet, despite its resilience and adaptability, the sector remains largely informal, underinvested, and lacks market attention. Innovation holds the key to unlocking its full potential. With scientific breeding, improved productivity, and stronger value chains, goatery can move from being a survival enterprise to a major source of income growth, nutrition security, and export opportunity for rural India.

goatery in India: from survival to opportunity

The current reality	The climate stress trap	The opportunity ahead
• **148.8 million goats** (27.74% of total livestock) • **33.01 million rural households** (~24%) rear goats • **83% goats reared by small or landless farmers** • **>85% goats under zero-input systems →** productivity loss up to 75%, mortality up to 50% • **Average profit: ₹12,500/year** from 5 adult females • **30% fodder loss** during climate extremes For millions, goatery remains a survival enterprise — informal, climate-stressed, and low-return.	• **Feed & Water:** Shrinking pastures, 30% fodder loss, reduced crop residue. • **Shelter:** Kutcha sheds damaged by floods and cyclones; heat and cold stress raise mortality. • **Health:** Heat stress → oxidative disorders, goat pox, pneumonia, foot-and-mouth disease. • **Reproduction:** Heat delays breeding, lowers fertility, limited access to AI. • **Marketing:** Same-day distress sales, no cold chain, poor price realization.	• Heat-tolerant breeding + AI: Improves fertility and survival rates. • Digital goat IDs + health alerts: Enable traceability and disease prevention. • Community fodder banks + climate-smart shelters: Cut feed costs (>60% recurring expense). • Cold chain + hygienic slaughter units: Reduce spoilage, increase farmer income. • Market linkage via e-traceability: Expands export and domestic demand. • Economic scale: ₹38,590 crore annual GVA, 734,000 MT goat meat, ₹537 crore exports (2022–23). From survival to sustainability — goatery can become India's most climate-resilient rural enterprise.

Reproduction and breeding	Specific Climate-Related Problems (India)
Natural Fertility	Heat stress reduces growth efficiency and reproductive success; Indian goat breeds show reduced daily weight gain in summer.
	Extended droughts delay breeding cycles due to nutritional stress.
Artificial Insemination	Unlike cattle, AI is not widely available; lack of heat-tolerant breeding programs for goats limits adaptation.
Milk and meat production	**Specific Climate-Related Problems (India)**
Milk Yield	Drought-related nutritional stress lowers fat and protein content in goat milk.
Meat Marketing	Lack of formal slaughter and cold chain → goats must be sold quickly, often at low prices in summer.
Transport & Processing	Heatwaves increase mortality during transport; absence of cold chain causes spoilage of goat meat.
Health	**Specific Climate-Related Problems (India)**
Heat Stress & Immunity	High temperatures cause oxidative stress, metabolic disorders, and immune suppression, increasing susceptibility to goat pox, pneumonia, and FMD.
Vector-borne & Flood-linked Diseases	Post-flood increase in parasitic infections and foot-rot.
Extreme Weather Mortality	Lightning strikes in Jammu & Kashmir killed 63 sheep in 2022; climate models predict 10–25% increase in lightning events in India.
Feed and water	**Specific Climate-Related Problems (India)**
Pasture Shrinkage	Common grazing lands are shrinking due to urbanisation and expansion of protected areas; goats lose key fodder sources.
	Open grazing in semi-arid zones (Rajasthan, Gujarat) hit by recurrent droughts → loss of forage availability.
Crop Residue Dependence	Drought reduces crop residues (millets, pulses) which are major feed for goats in drylands.
Feed Quality	High temperatures increase spoilage and reduce nutritive value of stored fodder.

Table: Impact of climate stressors on the goatery value chain

Shelter	Specific Climate-Induced Problems
Heat Stress	Open/thatched sheds in arid states (Rajasthan, Bundelkhand) offer poor shade → reduced feed intake, milk yield, and higher kid mortality.
Cold Stress	Poorly insulated shelters in northern India expose goats to pneumonia and diarrhea; kid mortality rises in winters.
Extreme Weather Events	Floods/cyclones damage kutcha sheds (Assam, Bihar), causing direct losses; landslides in Himalayan states collapse goat shelters.
Gendered Dimension	Women goat rearers often lack resources to rebuild shelters post-disaster, forcing unsafe open grazing.

Table: Impact of climate stressors on the goatery value chain

8.2 the^delta take and ecosystem implications

Goatery underpins rural incomes at scale: 148.8 million goats, reared by 33 million households (≈24%), contribute ~9% of livestock GVA (~₹38,590 crore) and supply 734 thousand MT of meat—yet >85% are kept under zero-input systems with low productivity and high mortality. The climate signal is unambiguous: heat and drought depress growth and fertility; fodder production falls (~30% in extremes); pasture and residue availability shrink; disease pressure rises; and kutcha shelters fail in floods and cyclones. Field reports mirror the stress—72% of keepers seeing falling productivity, 54% animal deaths, 31% water access issues—while weak breeding services (minimal AI) and informal, same-day sales without cold chain cap value realization.

For landless and smallholders (who own ~83% of goats), the result is thin, volatile earnings—typically ~₹12,500/year from five does—well below the sector's potential if herds were upgraded and losses curbed.

A tech-first pathway is clear: heat-tolerant breeding and the introduction of AI for goats; digital animal IDs with herd health surveillance and early-warning for pox/FMD/parasites; low-cost, climate-smart shelters; community fodder banks, drought-resilient forage, and feed analytics to cut >60% feed costs; water treatment/points for arid belts; and basic hygienic slaughter, chilling, and traceable e-markets to move beyond distress, same-day sales.

Done coherently, goatery can shift from zero-input survival husbandry to a resilient, semi-intensive, market-linked system that lifts smallholder incomes while meeting rising domestic and export demand.

9
An ecosystem of food supply and fair livelihoods

India's climate crisis has converged with its livelihood systems, leaving millions of farmers, fishers, and food workers exposed to compounding shocks. Extreme heat, erratic rainfall, pest outbreaks, and water scarcity are reducing productivity across food systems already under strain. Yields of key staples are projected to decline by up to 10% by 2050, and over 80% of farmers now report at least one major climate-induced loss every three years. For a country where 160 million livelihoods depend on agriculture, this is not a future threat—it is the lived reality of the present.

Yet the country is not starting from zero. India's policy environment is primed for transformation: flagship missions such as the National Mission for Natural Farming, PM-KUSUM, the National Adaptation Fund on Climate Change, and Agri Infrastructure Fund now align climate goals with productivity outcomes. Complementary frameworks under SATAT, carbon markets, green credit programmes, and CSR-linked blended finance are unlocking capital for climate-smart interventions. This convergence of policy and finance can propel science-backed, technology-enabled innovations—from bio-CNG and regenerative agriculture to precision water management, AI-based pest prediction, and carbon-measured soil regeneration.

The moment calls for coherence: to connect these policy and financing streams into a cluster-based, data-driven transformation that restores both ecosystems and incomes. If scaled through inclusion, transparency, and technology, India's food systems can evolve from vulnerability to vitality—where livelihoods, innovation, and resilience advance together, and climate action becomes synonymous with economic renewal.

Annexure

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This report is part of the Climate & Food Systems distillation study, powered by Spectrum Impact, the^delta prize and The/Nudge Institute. It will be followed by a roadmap study in partnership with MicroSave Consulting (MSC), highlighting key opportunity areas for market-driven, tech-enabled innovations.

Climate and food systems distillation report

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