

RESEARCH ARTICLE

Precision Livestock Farming in Uzbekistan Through Evidence Synthesis and A Technology-Context Fit Framework

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Abstract

This study assesses which precision and digital livestock technologies suit Uzbekistan, where household farms keep about nine in ten cattle, and in what order they should be introduced. It combines an integrative review of six recent sources with national statistics and policy documents, re-examines published efficiency and productivity estimates, and scores 14 technologies on six context-fit criteria. Uzbekistan's livestock sector operated at a meta-frontier efficiency of 0.672 in 2000-2023, close to its income-group mean of 0.684, but its total factor productivity fell 0.6% a year, the weakest result in the group. Reported gains from precision livestock farming are large but come almost entirely from intensive, high-income farms. Six technologies reach the top tier, all of them shared services: animal identification, veterinary surveillance, mobile advisory, breeding services, digital milk collection and satellite pasture monitoring. Wearable sensors and precision feeding suit commercial farms, while robotic milking and computer vision rank last. The ranking is robust to weigh (Spearman's ρ of 0.94 and 0.98). The study proposes a three-phase adoption plan with measurable gates.

KEY WORDS

Precision livestock farming; digital agriculture; technology adoption; smallholder farms; meta-frontier analysis; Uzbekistan.

INTRODUCTION

Livestock accounts for about half of Uzbekistan's agricultural GDP, provides 45-67% of rural household income and emits over 13% of national greenhouse gases [24]. Household (dehkan) farms keep about nine in ten of the country's 14.1 million cattle [21; 22]. Output per animal is low: household cows give about 3 L of milk a day against 20 L on agribusinesses, and under business-as-usual domestic production would cover only 59% of milk demand and 52% of meat demand by 2035 [24].

The government has made livestock and digitalisation joint priorities. Animal identification became mandatory in August 2026 [19], the World Bank finances a national veterinary information system and a traceability system [24], and a USD 463 million package for 2026-2028 includes a "Smart Farmer" mobile platform for identification, veterinary calls and advice [25]. Policy makers must therefore decide which digital technologies to fund first, and for whom.

International evidence on precision livestock farming (PLF)

shows gains in feed efficiency, reproduction and early disease detection [10], but it comes almost entirely from intensive, high-income systems with large herds, reliable power and strong advisory services [4]. To our knowledge, no study has assessed how PLF transfers to a smallholder-dominated, post-Soviet livestock sector, and efficiency studies measure technology gaps without identifying the technologies that could close them.

This study asks three questions. RQ1: where does Uzbekistan's livestock sector stand on efficiency and productivity growth relative to its peers? RQ2: What measurable effects do current technologies have, and under what conditions? RQ3: which technologies fit Uzbekistan's farm structure, infrastructure and institutions, and in what order should they be introduced? It links efficiency diagnostics to a reproducible fit test, re-examines two widely used sources and adds power reliability and data governance to the adoption criteria.

LITERATURE REVIEW

PLF uses sensors, automation and analytics to monitor individual animals continuously. Reported effects are substantial: precision feeding improves feed efficiency by 5-15% in dairy systems, sensor-based oestrus detection raises conception rates by 10-20%, rumination and activity data reveal disease three to five days before clinical diagnosis, and automatic milking raises yield by 2-12% [10]. Many machine-learning results, however, rest on validation within a single farm, and most applications make existing tasks more precise rather than changing the production system [10].

In a survey of German and Finnish livestock farmers, mobile apps (60.6%) and farm management software (52.1%) were the most used tools, while drones (4.2%) were rare [9]. Its

percentages imply about 34 Finnish and 93 German respondents, and some headline figures count neutral answers as positive: the reported 97% of Finnish farmers seeing lower operating costs falls to 36.4% when only approving answers are counted.

The barriers to adoption are well documented: high investment and recurring costs, uncertain payback, farms too small to justify investment, rural connectivity gaps, low digital skills among older farmers and devices that cannot exchange data [4; 10]. Most farm data are non-personal machine data outside personal-data law, so farmers can lose control of records held by technology providers [4]. Germany's Commission on the Future of Agriculture concluded that sensors cannot replace the stockperson's trained eye, that farmers must keep control of their data and that small farms need support to use digital tools [14]. Automation also raises exposure to blackouts: forced-ventilation poultry and pig houses reach a critical state within minutes to hours without power, and large dairy herds cannot be milked by hand [8].

Meta-frontier analysis measures how far a group's technology lies from global best practice; the technology gap ratio (TGR) divides efficiency against the global frontier by efficiency against the group frontier [2]. Shah et al. [11] applied it to the 50 largest livestock producers in 2000-2023 and attributed total productivity (TFP) growth of 2.0% a year to efficiency change (2.1% a year) with flat technical change. Section 5.1 shows that this attribution conflicts with the paper's own tables.

Study context

Uzbekistan's livestock sector is large, household-based and short of feed (Table 1).

Table 1. Uzbekistan's livestock sector: indicators used in this study

Indicator	Value	Date	Source
Cattle (of which cows)	14.14 million head (5.05 million)	1 Jan 2024	[22]
Sheep and goats	24.12 million head	1 Jan 2024	[22]
Poultry	103.0 million birds	1 Jan 2024	[22]
Cattle kept on household farms	92.0%	1 Oct 2022	[21]
Milk production	12.4 million t	2024	[23]
Meat production, live weight	2.9 million t	2024	[23]

Indicator	Value	Date	Source
Average milk yield	2.4 t per cow per year	2022	[15]
Milk per cow per day	3 L household, 8 L commercial, 20 L agribusiness	2023	[24]
Feed crop area per livestock unit	32 m ²	2019	[7]
Internet users	33.1 million (89% of population)	Oct 2025	[16]

Household farms dominate in 2022 they held 92.0% of cattle and produced 93.4% of milk [15; 21]. Feed is the binding constraint: forage area fell by 70% over three decades while the cattle herd grew by 150%, household farms keep about 95% of the herd on 13% of the forage area, and yields are limited mainly by feed rather than genetics [7]. The 2022-2026 livestock programme targets 22 million t of milk and 5 t per cow by 2026, roughly double the 2022 levels [15].

Pastures cover more than 20 million ha; up to 40% of desert and semi-desert pastures are degraded and their productivity has fallen by about 21% [6]. A 2025-2027 national programme is rehabilitating degraded pastures with GPS and satellite mapping [18], and average temperatures may rise by up to 4.8 °C by the 2090s under a high-emission pathway [13].

Law ZRU-1079 of 6 August 2025 makes identification of animal's mandatory from August 2026 and links owners' identity data to each animal's movements, diseases and treatments in a central database [19]. The August 2026 package adds insemination of 500,000 cows a year (about 10% of cows), milk collection points in 13 livestock districts and the Smart Farmer app [25]. Connectivity is high, with 89% of the population online in October 2025 [16], but power is less dependable: a regional grid fault in January 2022 caused a nationwide blackout, and winter outages are common in rural areas [17]. Amendments to the personal data law in March 2026 relaxed data localisation [20], but no rule yet covers the non-personal data that farm sensors and software generate, and men receive agricultural advice about twice as often as women [5].

Six binding constraints follow: feed scarcity; weak reproduction and breeding services; animal disease and missing traceability; heat stress and water scarcity; rangeland degradation; and poor market access and product quality.

METHODOLOGY

The study combines an integrative review [12], a re-reading of published efficiency estimates and a multi-criteria fit assessment. The core evidence base comprises six documents published in 2021-2026, chosen to cover effect sizes [10], farmer perceptions [9], cross-country productivity [11], and governance and resilience [4; 8; 14]. Uzbekistan-specific statistics, laws and official reports were added (Section 3), with regional evidence from Kazakhstan [1]. Survey shares from [9] were recomputed as approve plus strongly approved.

For RQ1 we used the 2000-2023 country means reported in [11] for meta-frontier efficiency and for the Malmquist-Luenberger index (MLI) with its efficiency change (EC) and technical change (TC) components for Uzbekistan's 13-country income group plus Kazakhstan and Belarus. Two checks preceded interpretation. The rule of thumb $n \geq \max\{m \times s, 3(m + s)\}$ for data envelopment analysis [3] requires at least 27 units for four inputs and five outputs; the 13-country group frontier may fail it, and 12 of the 13 countries score exactly 1.000 on it, so only meta-frontier scores are interpreted. In addition, [11] reports Uzbekistan's 2024 output of meat, milk and eggs combined as 4.73 million t, less than half of national milk output alone (12.4 million t [23]), so the scores are treated as indicative.

For RQ3, 14 technologies were scored from 1 (poor fit) to 3 (good fit) on six criteria: C1 evidence strength; C2 relevance to the six binding constraints; C3 fit with household and commercial farm sizes; C4 dependence on power, connectivity and vendor service (lower dependence scores higher); C5 cost to the user, assuming public or shared delivery for identification, veterinary surveillance, breeding services, milk collection and pasture monitoring; and C6 skills required (lower requirements score higher). A score of 3 means, for example, replicated quantified effects (C1), use by household farms (C3) or basic smartphone literacy (C6); a score of 1

means prototype evidence, viability only on large farms or a need for specialist skills.

With equal weights, totals range from 6 to 18: a total of 15 or more forms Tier 1 (scale nationally), 11-14 forms Tier 2 (target commercial farms) and 10 or less forms Tier 3 (pilot or defer). Two sensitivity variants double C1 and C2 or drop C1; their totals are rescaled to the 0-1 interval with the same relative cut-offs, and rank agreement is measured with Spearman's ρ . The scores are the authors' judgements and should be validated by an expert panel.

RESULTS

Efficiency and productivity (RQ1)

Uzbekistan's mean meta-frontier efficiency in 2000-2023 was 0.672, close to the mean of its 13-country income group (0.684), but its TFP fell 0.6% a year, the weakest result in the group, whose members grew by 2.4% a year on average (Figure 1). Both components were negative (EC -0.4% and TC -0.2% a year), while the group's technical change averaged $+1.8\%$ a year. Kazakhstan grew 3.9% a year from a lower efficiency level, and Viet Nam, a smallholder-based frontier producer, grew 6.1% a year through technical change [11].

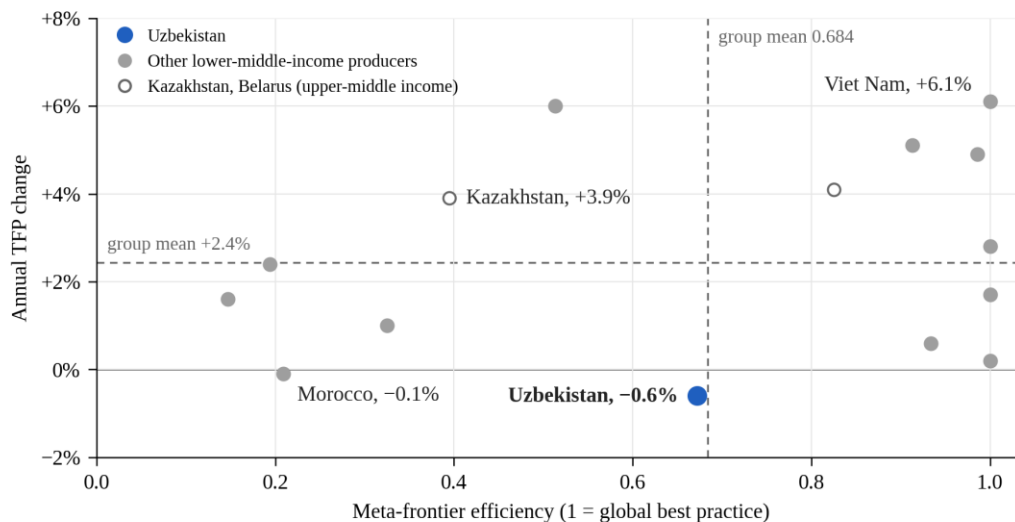


Figure 1. Meta-frontier efficiency and annual TFP change of Uzbekistan and its peers, country means 2000-2023 (computed from [11])

The checks also exposed errors in [11]. Its headline split of TFP growth (efficiency change $+2.1\%$, technical change -0.1% a year) cannot be an average of its income groups, because every group shows technical change above efficiency change and no group exceeds $+0.9\%$ efficiency change; the country table implies 0.0% efficiency change and $+1.5\%$ technical change. The reported global means (0.799 for efficiency and 0.863 for the TGR) also exceed the means of the country values (0.750 and 0.821). Read from the country data, outward frontier shifts drove growth, and Uzbekistan did not take part in them.

Technology effects (RQ2)

The strongest gains come from sensor-based reproduction and health monitoring and from precision feeding, almost all measured on intensive farms (Table 2). Recomputed survey shares show that farm-level gains appeared in both countries, with better working conditions reported by 73.5% of Finnish and 63.4% of German farmers, while chain gains appeared mainly in Finland, where 73.5% reported better cooperation with other chain actors against 32.2% in Germany [9].

Table 2. Quantified effects in the reviewed sources and their transfer to Uzbekistan

Technology	Reported effect	Setting	Transfer to Uzbekistan
Precision feeding	Feed efficiency +5 to 15%	Intensive dairy [10]	High; feed is the binding constraint
Feed optimisation	Enteric methane per unit of product –5 to 10%	Cattle [10]	High; livestock emits over 13% of national GHG
Sensor-based oestrus detection	Conception rate +10 to 20%; detection accuracy above 90%	Dairy [10]	High; supports the insemination target
Rumination and activity sensors	Disease detected 3 to 5 days before diagnosis	Dairy [10]	High; false alarms unresolved
Automatic milking	Milk yield +2 to 12%	Dairy [10]	Low; saves labour at high cost
Digital investment, all types	+0.42 kg milk per USD per cow; best returns on medium farms	98 farms, Kazakhstan [1]	High; cross-sectional design
Sensor-based input control	Fertiliser –1 to 82%; water –2.5 to 75%	Crops [4]	Relevant to irrigated fodder

Technology-context fit (RQ3)

Six technologies reach Tier 1, and all six are services that one provider can deliver to many household farms (Table 3, Figure 2). Wearable sensors and precision feeding have the strongest evidence but need commercial herds, stable power and trained staff. Robotic milking and computer vision rank last.

The ranking is robust: Spearman's ρ with the base case is 0.94 for the impact-weighted variant and 0.98 for the evidence-blind variant. Under impact weighting, sensors and precision feeding move into Tier 1 and pasture monitoring into Tier 2; the other five Tier 1 services keep their tier under every specification.

Table 3. Technology-context fit scores for Uzbekistan (1 = poor fit, 3 = good fit)

Technology	C1	C2	C3	C4	C5	C6	Total	Tier
1. Animal identification and registration	2	3	3	3	3	2	16	1
2. Digital veterinary records and surveillance	2	3	3	3	3	2	16	1

Technology	C1	C2	C3	C4	C5	C6	Total	Tier
3. Mobile advisory and decision apps	2	2	3	3	3	3	16	1
4. Digital breeding records and insemination services	2	3	3	3	3	2	16	1
5. Milk collection with digital testing and payment	2	3	3	2	3	2	15	1
6. Satellite pasture and drought monitoring	1	3	3	3	3	2	15	1
7. Wearable activity and rumination sensors	3	3	2	2	2	2	14	2
8. Precision feeding and ration control	3	3	2	2	2	2	14	2
9. Electronic and walk-over weighing	2	2	2	2	2	3	13	2
10. Barn climate monitoring and control	2	3	2	1	2	2	12	2
11. Farm management information systems	2	2	2	2	2	2	12	2
12. GPS collars and virtual fencing	2	2	2	1	2	2	11	2
13. Automatic milking systems	3	1	1	1	1	1	8	3
14. Computer vision monitoring	2	2	1	1	1	1	8	3

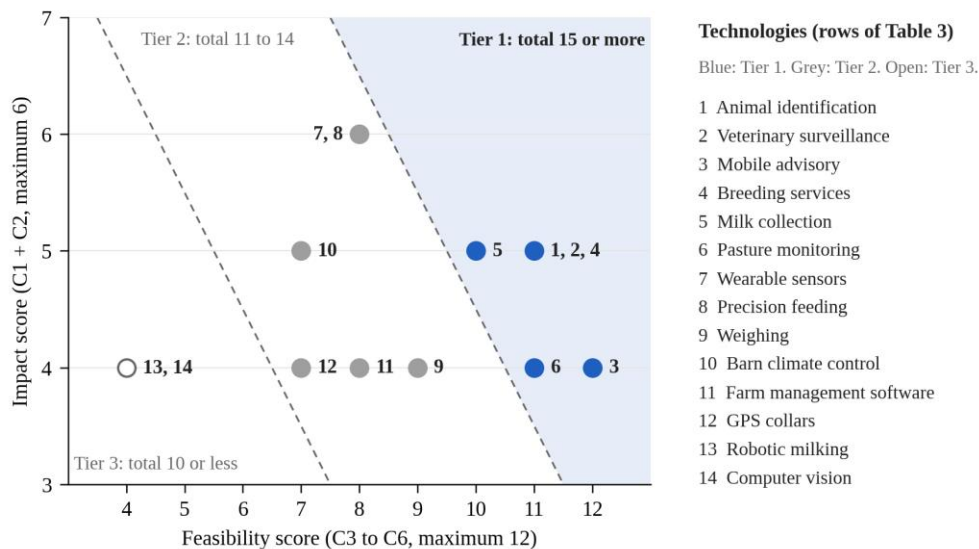


Figure 2. Impact and feasibility scores of the 14 technologies; dashed diagonals mark the tier boundaries of the total score

DISCUSSION

Uzbekistan's problem is stalled productivity rather than a low starting point: it missed the frontier shifts that drove its peers'

growth. The fit scores show which technologies can reach a household-based sector, and they imply a sequence rather than a menu (Figure 3). The gate criteria in Figure 3 are proposals for discussion, not government targets.

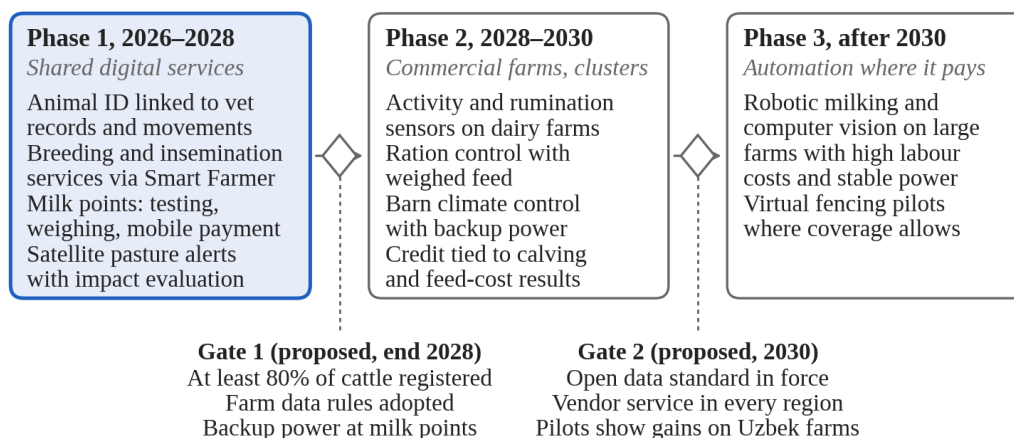


Figure 3. Proposed phased adoption plan with gate criteria

Phase 1 (2026-2028) builds the shared services in Figure 3 around the identification register required by Law ZRU-1079, so that veterinary, vaccination, movement and breeding records share one animal identifier. Gate 1 opens Phase 2 when at least 80% of cattle are registered, rules on farm data access and portability are adopted, and milk collection points have backup power.

Phase 2 (2028-2030) brings sensors, ration control and barn climate control to commercial farms, with public credit tied to

measured calving and feed-cost results. Returns to digital investment peak on medium-sized dairy farms in neighbouring Kazakhstan [1], which points to mid-size private farms as the first users. Gate 2 requires an open data standard, vendor service in every region and positive pilot result on Uzbek farms, and Phase 3 (after 2030) limits robotic milking and computer vision to large farms with high labour costs and stable power.

Three conditions decide whether the plan works. The first is

data rules: the identification database stores owners' identifiers next to animal health records [19], yet no rule governs the non-personal data that sensors and herd software produce. Farmers should be able to export their records in a standard format, public databases should offer a documented interface that private apps can use with the farmer's consent, and veterinary data should not be reused for unrelated enforcement without notice [4; 14]. The second is resilience: equipment financed with public credit should include backup power for ventilation, water and milking, and apps should store records offline and synchronise later [8; 17].

The third is inclusion and environmental integrity. Smart Farmer content should be available by voice in Uzbek, Karakalpak and Russian, women should be registered as users in their own right [5], and productivity programmes should track absolute emissions as well as intensity: in a feed-improvement scenario for Uzbekistan, a herd 20% smaller produced 20-40% more milk and meat with 15% lower emissions [7]. Digital tools also cannot replace feed. The target of 5 t of milk per cow by 2026 implies doubling yields in four years, which digital tools alone cannot deliver while feed remains the binding constraint [7; 15].

The study has limitations. The core evidence base is small and purposive, the fit scores need expert validation, the efficiency diagnostics rest on published estimates with documented errors, and most effect sizes come from other countries. Future work should replicate the farmer survey in Uzbekistan, evaluate staggered rollouts of Smart Farmer services and re-estimate efficiency with verified national data.

CONCLUSIONS AND RECOMMENDATIONS

Uzbekistan's livestock sector does not need the most advanced technologies first. It needs services that reach household farms, and the data rules and power supply that let more demanding technologies work later. The following measures are recommended:

- 1) use the identification register as the common reference for all livestock data and link it to veterinary, movement and breeding records;
- 2) adopt rules on farm data access and portability, and open public livestock databases through a documented interface;
- 3) equip milk collection points with analysers, scales, backup cooling and mobile payment, and pay for milk by

quality;

- 4) run satellite pasture monitoring as a public service tied to stocking decisions;
- 5) tie credit for sensors, ration control and barn climate control to measured results and backup power;
- 6) defer subsidies for robotic milking and computer vision;
- 7) train veterinarians, inseminators and extension staff in data use, and add digital livestock management to university curricula;
- 8) report the uptake of digital services by gender, farm type and region.

Validating the scores with Uzbek experts and re-estimating efficiency with verified national data should come before the framework guides investment.

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