The Social Science Review A Multidisciplinary Journal. September-October, 2026. Vol. 4. Issue 5. 85-100
Published by: Pather Dabi Educational Trust, (Regn No: IV-1402-00064/2023), Under Govt. of West Bengal, India

The Social Science Review
A Multidisciplinary Journal
ISSN: 2584-0789
(Open-Access, Peer-Reviewed, Refereed, Bi-Monthly, International e-Journal)
Homepage: www.tssreview.in

TRANSFORMING SMALLHOLDER DAIRY LIVELIHOODS THROUGH DIGITAL AND SUSTAINABLE MARKETING: MARKET ACCESS, PRICE REALIZATION, AND CLIMATE RESILIENCE

Anagha M [1] & Prof(Dr) Reshmi R [2]

RESEARCH ARTICLE

Author Details:
[1] Research Scholar, Farook College (Autonomous), Kozhikode, Kerala, India; [2] Department of Commerce and Management Studies, Farook College (Autonomous), Kozhikode, Kerala, India

Corresponding Author:
Anagha M

DOI:
https://doi.org/10.70096/tssr.260405013

Abstract
Smallholder dairy farming can provide cash income to rural households. In general, the amount that the rural household earns will depend less on how much milk they produce, but rather on the supply chain of where their milk goes. This study reviewed the relationship between digital and sustainable marketing and market access, price realization, and climate resilience. A total of 28 verified studies from 2016 to 2025 were reviewed. These include digital agriculture, marketing channels in dairy systems, vertical price transmission, climate risk in livestock systems, and dairy sustainability assessment. There is evidence that digital tools can improve access to information, buyers, finance and advisory services. The participation in market-information projects is positively correlated with market participation and household income. Projects with greater coverage, lower costs, digital literacy and trust, and milk collection points are considered more successful than others. Dairy studies show that channel choice is correlated with dairy income, economic efficiency and food security, and channels that include a cooperative are associated with the biggest returns. Empirical cases of price transmission find that selling into a formalized chain does not guarantee the milk produced a share of the final value. Climate risk was found to affect all nodes in the dairy chain where adaptive capacity is limited. The reviewed climate change and sustainability studies find that most emissions occur on dairy farms with wide variation in carbon footprints. They also do not test digital dairy marketing, realized prices and climate resilience together. This latter gap is the clearest priority for future research.

Keywords: *smallholder dairy; digital marketing; market access; price realization; climate resilience; sustainable marketing; milk marketing channels; dairy value chains*

Introduction

Dairy is also an important source of income to smallholder farmers because it generates cash on a daily or weekly basis. With one or two milking animals, a household can obtain daily/weekly cash. This income is used to meet regular expenditure on food, schooling and health care. In fact most crop-based enterprises pay out only once or twice a year, so the development of dairy is a livelihood strategy rather than a production strategy. According to survey results in Kenya and Ethiopia [1], purchased input use, amount of milk produced, and the profit margin of farmers increase with proximity to the service centre. Thus, dairy returns to the farm household are affected by the marketing environment around the farm.

For marketing challenges, it needs to be understood that milk is perishable and only small quantities of milk are produced each day. The producer only has a few hours to find a buyer after it is produced. Farmers most commonly sell to other farmers, on roadsides, traders, collection points, cooperatives and processors; in Kvemo Kartli, Georgia, 53.6% of smallholders reported difficulty selling their milk. Smallholders sold milk in bazaars, family-owned small supermarkets, milk collection points and roadside buyers [2]. In Ethiopia, those farmers selling raw milk or using mixed market channels earned more income from dairy than those selling only processed products [3]. Thus, the marketing channel chosen matters for household returns.

Digital technologies can address many of these issues. Mobile phones, market-information services, digital payment networks, advisory apps, and buyers' platforms can bring producers to market without the need for large investments in roads or cold chains. A scoping review of digital agriculture in sub-Saharan Africa found that digital finance, digital extension services, farm-management platforms and digital marketing platforms improve access to information, markets and services [4]. A review of digital services in low- and middle-income countries found that advisory services and extension services dominate the evidence, whilst income and market outcomes are less frequently assessed [5]. In Kenya, the evidence is clearer: farmers who participated in market-information projects delivered through ICT traded more in input and output markets and had larger household incomes [6].

However, these benefits are not automatic, the same literature identifying many factors determining the type of digital tools that individuals adopt and benefit from: coverage, cost, digital literacy, trust, gender, and support from organizations in the area [4,7,8]. Greater transparency through digital platforms might simply transfer power, as data and transactions remain with the end-buyers and the platform provider [9]. To analyze the actual value of a digital marketing solution for a remotely located producer, it should be analyzed if the information is able to drive an actual sale of milk at an acceptable price.

Climate change will only increase this. Heat stress, water stress, shortage of feed and animal disease also reduce milk volumes. These factors influence processing, transportation, marketing, and household incomes [10,11]. Drought, pests and diseases and high temperature have been identified as the most damaging risks to dairy income and animal performance in a survey of smallholder dairy farmers in semi-arid southern India [12]. While a marketing arrangement may work well under normal circumstances, it may fail when there are low levels of milk availability or when roads become impassable. Resilience is thus a useful criterion.

In downstream markets, increased demand exists for improved environmental performance of dairy supply chains. Most studies in a systematic review of dairy supply-chain decarbonisation found that emissions were concentrated at the farm level [13]. Carbon footprints vary widely between farms. For instance, mean values per kg of fat- and protein-corrected milk in Brazil range from 1.75 to 3.27 kg CO_2-equivalent across four types of farms [14]. Sustainable marketing can be a practical issue for smallholders, as their records on farm practices are often insufficient to make such a claim.

This review sets out to address the intersection of digital/sustainable marketing, market access, price realization and climate resilience in smallholder dairy systems, through three objectives: to synthesize the existing evidence on structural barriers to smallholder dairy market access and the role of digital marketing pathways and the circumstances under which they can deliver positive outcomes. Thirdly, we need to define how to measure and improve price realization, climate resilience and sustainability performance. There is no point in assuming benefits, they need to be proven. We reviewed 28 verified studies published between 2016 and 2025.

Scope and Approach of the Review

We compiled a sample of 28 studies that we verified against publisher webpages, Crossref, etc. These studies were about one or more of the following topics: digital market access and inclusion; price realization and value chains; climate resilience and adaptation; and low-carbon dairy supply chains and sustainable marketing. The papers published between 2016 and 2025 were farmer surveys, econometric studies, systematic reviews and scoping reviews, conceptual papers, life cycle assessment studies, and scenario models. When Google Scholar was used it was for verification and checks on discoverability, and not claimed as proof of indexing in any database.

Also, as the four domains were not mutually exclusive, this review has considered them to be part of a single pathway. Figure 1. Further detail for each domain is below. Marketing interventions function through information access, transaction costs and access to finance, resulting in market access, price realization and improved climate resilience. These, in turn, feed into household income and food security. The enabling conditions at the bottom of the figure determine whether the pathway is likely to work for a given producer.

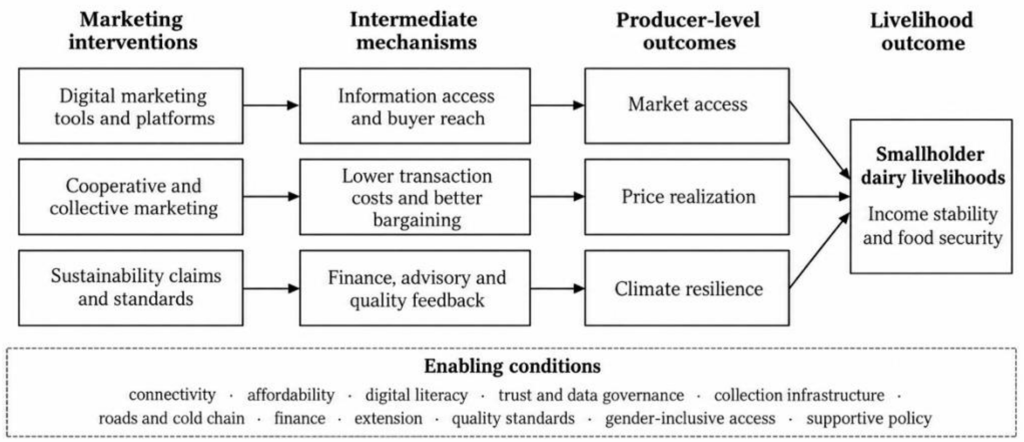

Figure 1. Framework used to organise the review. Digital and sustainable marketing interventions act through intermediate mechanisms that affect market access, price realization and climate resilience in smallholder dairy systems. Compiled by the authors from the mechanisms and enabling conditions reported in [1,4,5,9,12,13].

The evidence across sections of the pathway is also disparate and should be taken into consideration during interpretation, with the market access and price realization section being the most researched, at the farmer level. Six of nine studies in the pathway are primary surveys/market data. Most evidence for digital inclusion and sustainability comes from reviews, conceptual papers, and modeled assessments. Only one digital paper reports farmer-level outcome estimates [6]. No sustainability papers reported outcomes for smallholder marketing. Because of this, statements regarding digital marketing and sustainability are based on indirect evidence while findings on channel choice and dairy income are based on direct evidence.

There is also differential weight given to the study designs: cross-sectional surveys and multinomial models identify associations (adjusting for observables), but cannot disentangle unobserved systematic differences between farmers adopting different channels. Propensity-score matching and endogenous switching regression reduce selection bias under stated assumptions that cannot be tested based on the same data. Life cycle assessments and scenario models quantify trade-offs under conditions from literature rather than under actual farmer choices. Table 1 describes each study's context, study design, main finding, and main limitation so that each specific claim can be traced back to its corresponding study.

Table 1. Metadata of the 28 reviewed studies, listed in order of first citation in the text, with thematic domain, study context, design, main finding and main limitation.

Domain	Study and context	Design and sample	Main finding relevant to this review	Main limitation
Market access, channels and price realization	van der Lee et al. (2020) [1]; dairy farmers in Kenya and Ethiopia	Survey of 215 dairy farmers (93 in Kenya, 122 in Ethiopia) across 18 villages; double proximity gradient with country-specific mixed-effects regressions	Proximity to local service centres was associated with better market quality, greater use of purchased inputs, higher yields and stocking rates and better margins, while remote Ethiopian farms faced weak demand, coarse collection grids and weak services	Cross-sectional and purposive; 18 villages in two countries, with no digital or direct climate-resilience measures
Market access, channels and price realization	Al Sidawi et al. (2021) [2]; dairy smallholders in Kvemo Kartli, Georgia	Mixed-method triangulation study with 140 smallholder farmers producing and selling milk and cheese, supported by qualitative evidence and earlier expert interviews	More than half of respondents (53.6%) reported difficulty selling milk; bazaars, small supermarkets, collection points and roadside sales were important channels, while feed, water, institutional gaps and pollution constrained the chain	Region-specific, self-reported and cross-sectional; no digital tools, quantitative price realization or measured resilience outcomes
Market access, channels and price realization	Chagwiza et al. (2020) [3]; smallholder dairy farmers in Selale, Ethiopia	Structured survey of 384 farmers (192 cooperative members and 192 non-members); multinomial logit, Welch ANOVA and Games–Howell comparisons	Farmers followed raw-milk (59%), milk-products (26%) or mixed (15%) strategies; strategy choice reflected household, production, distance, income-per-litre and cooperative variables, and raw and mixed channels yielded higher dairy income than processed products alone	Localised, cross-sectional and observational; no digital, climate-shock or adaptation variables
Digital tools and smallholder inclusion	Choruma et al. (2024) [4]; smallholder farmers in 14 sub-Saharan African countries	Scoping review; 613 initial records screened to 27 heterogeneous studies published between January 2012 and September 2023	Digital finance, extension, farm-management tools and digital marketing can improve information flow, market participation, productivity and income, but connectivity, affordability, literacy, infrastructure and gender disparities limit equitable adoption	Not dairy-specific; maps heterogeneous evidence rather than estimating pooled effects, and English-language coverage limits completeness
Digital tools and smallholder inclusion	Porciello et al. (2022) [5]; low- and middle-income countries, with India, Kenya, Ghana and	PRISMA-ScR scoping review of 315 studies of digital services	Evidence concentrates on advisory and extension services with outcomes mainly in knowledge and practice change; uptake depends on price, network access, gender, age, experience and whether use is voluntary, while environmental and resilience outcomes are rarely measured	Broad and heterogeneous; provides no dairy-specific estimates of price realization or resilience

Domain	Study and context	Design and sample	Main finding relevant to this review	Main limitation
	Uganda prominent			
Digital tools and smallholder inclusion	Okello et al. (2020) [6]; smallholder farmers in Kenya	Farmer survey data analysed with propensity-score matching; authoritative metadata did not report the sample size or detailed project sampling	Participation in ICT-based market-information projects was associated with greater input- and output-market participation and higher household income	Matching is non-random and unobserved confounding may remain; not dairy-specific and resilience is not tested
Digital tools and smallholder inclusion	Gumbi et al. (2023) [7]; global evidence with a sub-Saharan African emphasis	Systematic review of 25 articles, including 12 on sub-Saharan Africa and four on South Africa; contexts, methods, sectors and digital ecosystems coded	Research on digital skills, affordability and viable business models is thin; infrastructure, affordability and literacy recur as barriers, and inclusive ecosystems must be contextualised, trusted and affordable	Sets a research agenda rather than providing causal evidence; does not isolate dairy price, market or resilience outcomes
Digital tools and smallholder inclusion	Smidt and Jokonya (2022) [8]; small-scale farmers in South African agricultural value chains	Systematic literature review; more than 100 papers identified, 52 examined and 36 selected, interpreted through the Choice Framework	Digital adoption is shaped by economic, political, social, institutional and governance factors, and effective state support with locally adapted implementation frameworks is important	Not a farmer-level study; cannot establish digital effects on dairy prices, livelihoods or climate outcomes
Digital tools and smallholder inclusion	Kos and Kloppenburg (2019) [9]; smallholder inclusion in global value chains	Conceptual and narrative review of mobile phones, satellites, drones, sensors, blockchain and related applications; no original sample	Real-time digital data can improve access to finance, advice, buyers and value chains and can lower transaction costs, but unequal connectivity, literacy, data control and power can reproduce exclusion	No causal estimates or representative smallholder sample; dairy and climate links are conceptual
Climate risk, adaptation and resource use	Godde et al. (2021) [10]; global livestock food supply chains	Evidence review across hazards, supply-chain stages, food systems and adaptation; no single farm or participant sample	Climate change affects the livestock chain from production through processing, storage, transport, retail and consumption to prices, food access and livelihoods, and risks are highest where adaptive capacity is limited	Broad review with no pooled effect, no digital intervention and no representative smallholder sample; substantial uncertainty remains
Climate risk, adaptation and resource use	Rojas-Downing et al. (2017) [11]; global livestock systems	Narrative review of climate impacts, livestock emissions, adaptation and mitigation; no original sample	Heat, feed, water, disease, reproduction and production effects threaten livestock systems and food security; diversification and mixed systems are promising adaptation options, while mitigation effectiveness varies	No standardised systematic protocol or pooled estimates; broad and partly cattle-focused evidence requires local contextualisation
Climate risk, adaptation and resource use	Shantharaju et al. (2024) [12]; smallholder dairy farmers in	Cross-sectional survey of 104 dairy farmers with descriptive analyses and statistical tests of risks, strategies, constraints and determinants	Drought, pests and disease and heat reduced dairy income and animal performance; insurance, low debt and drought-tolerant grasses were important responses, while missing	Small, regional and self-reported; causal inference and generalisation to other marketing systems are limited

Domain	Study and context	Design and sample	Main finding relevant to this review	Main limitation
	three semi-arid regions of South India		forecasts, high costs and weak institutions constrained adaptation	
Sustainable marketing and low-carbon dairy chains	Ni et al. (2025) [13]; global dairy supply chains	PRISMA systematic review of English-language open-access literature from Web of Science (2014–2025); 262 global-warming-potential values identified	Farms were the principal emission hotspots in the reviewed evidence, with enteric fermentation, manure and feed dominant; the review synthesises farm, processing, logistics, standards and carbon-pricing interventions	Single-database and open-access restrictions create coverage bias; no smallholder marketing, income or adaptation estimates
Sustainable marketing and low-carbon dairy chains	Vogel and Beber (2022) [14]; dairy farms in Paraná, Brazil	Survey of 911 farms representing about 56,700 animals and 122,412 tonnes of annual fat- and protein-corrected milk, analysed with principal component analysis, K-means clustering and life cycle assessment	Four dairy-farm groups had mean footprints from 1.75 to 3.27 kg CO2-equivalent per kilogram of corrected milk; larger farms with technology and technical support had lower footprints, while less-specialised farms had higher footprints	Paraná-specific and non-experimental; marketing, prices and access changes are not tested, so causal adoption claims are not warranted
Market access, channels and price realization	Liverpool-Tasie et al. (2020) [15]; small-scale producers in developing regions	Protocol-driven scoping review of 202 studies of market links; no primary farmer sample	Non-contract interactions with small and medium enterprises frequently supplied inputs, credit, information, logistics and technology, and were associated with improved welfare and productivity	Does not directly examine dairy, digital marketing, prices or climate resilience
Market access, channels and price realization	Cheelo and van der Merwe (2021) [16]; smallholder milk producers in Zambia	Multinomial logit analysis of 251 smallholder milk producers; detailed sampling location was not reported in the supplied abstract	Gender, milk volume, education, distance to major markets and off-farm income influenced choice among direct, traditional and modern channels; the study recommends information, support, transparency and value-chain investment	Cross-sectional associations are not causal; Zambia-specific evidence limits generalisation and climate outcomes were not measured
Market access, channels and price realization	Kifle et al. (2025) [17]; smallholder dairy farmers in three districts of Sidama, Ethiopia	Multistage stratified random sample of 361 producers analysed with a two-stage multinomial endogenous switching regression	Milk-marketing participation improved estimated economic efficiency and food security, with relatively larger gains for cooperative participation, and counterfactuals suggested non-participants could benefit from entering a channel	Geographically limited to one Ethiopian region; no digital marketing or climate-resilience outcomes
Market access, channels and price realization	Dicecca et al. (2016) [18]; agri-food value chains serving smallholder s	Conceptual article using systematic literature review and literature-derived cases for theory building; no single primary sample	Consultants, knowledge-transfer organisations and brokers support distinct innovation and value-chain reconfiguration pathways for smallholders	Does not establish causal income, price or resilience effects and is not dairy-specific
Market access, channels and	Ma et al. (2024) [19]; multi-	Narrative synthesis introducing a special issue; summarises 15 studies	Market participation, e-commerce, cooperatives, information, infrastructure and education can	Not a systematic meta-analysis or primary study;

Domain	Study and context	Design and sample	Main finding relevant to this review	Main limitation
price realization	country synthesis of farmer–market linkage	selected from 46 submissions across varied countries and methods	improve market reach, income and price-related outcomes, while market power requires policy attention	provides no pooled effect and is neither dairy- nor climate-specific
Digital tools and smallholder inclusion	Satpathy (2022) [20]; smallholder agriculture, centred primarily on India	Narrative and conceptual synthesis; no original survey, experiment or sample	Digital applications, advisory services, sensors, the internet of things, artificial intelligence, remote sensing and blockchain may improve information, finance, market access, resource management and sustainability if availability, affordability, accessibility and literacy are addressed	Prospective claims are not validated treatment effects; no dairy-specific, price or resilience measures
Market access, channels and price realization	Hillen (2021) [21]; Swiss dairy and cheese value chains	Monthly farm-gate, wholesale, export and retail series from January 2004 to March 2018 (171 observations per series) analysed with asymmetric VAR and VEC models across 24 price pairs	There was little long-run price transmission and no significant asymmetry for most price pairs, and artisanal and concentrated industrial chains showed no systematic difference in pass-through	Retail and export aggregation and omitted discount-store data may weaken estimates; the setting is not smallholder-specific
Climate risk, adaptation and resource use	Kangogo et al. (2020) [22]; smallholder farming in Kenya, illustrated with potato production	Conceptual framework supported by descriptive comparisons from a 2019 household survey; sample size was not reported	Entrepreneurship, farmer organisations and farmer–buyer collaboration are theorised to improve resilience through access to information, inputs, credit, training, insurance and secure markets	Conceptual and potato-focused, with no causal resilience estimate and no direct dairy, digital or price evidence
Climate risk, adaptation and resource use	Bosire et al. (2019) [23]; smallholder dairy systems in nine Kenyan counties	271 household surveys combined with county data; baseline and three modelled intensification pathways involving breeds, feed and milk output	Modelled intensification raised total water and land footprints, but breed and feed improvements reduced milk-production water footprints by up to 75% in some lowland scenarios, with impacts varying by agro-ecological zone	Modelled scenarios are not observed adoption or causal outcomes; selected pre-commercial Kenyan systems limit generalisation and marketing relevance
Climate risk, adaptation and resource use	Silva et al. (2016) [24]; intensive-grazing dairy systems in the Azores, Portugal	Representative dairy typology integrated into a linear-programming decision model; no respondent sample	Modelled methane reductions of 10% to 75% consistently reduced farm income, grazing intensity and herd size, leading the authors to argue that alternative income sources are needed to preserve viability	Scenario and model assumptions drive results; the Azorean context is not readily transferable to smallholders and no marketing intervention is tested
Climate risk, adaptation and resource use	Bilotto et al. (2024) [25]; global livestock farming systems	Integrative review covering livestock roles, shocks, climate change, transition and prerequisites; no farm or household sample	Climatic, economic and geopolitical shocks require place-based adaptation, and mitigation and livelihood options must be co-designed because production, conservation, prosperity and emissions involve trade-offs	Integrative review without causal estimates or direct digital-market, price or smallholder evidence

Domain	Study and context	Design and sample	Main finding relevant to this review	Main limitation
Sustainable marketing and low-carbon dairy chains	Herrero et al. (2016) [26]; global livestock sector	Sector-wide synthesis and analysis of historical emissions and technical and economic mitigation potential; no participant sample	Livestock emissions were estimated at 5.6–7.5 GtCO2e per year for 1995–2005; technical mitigation includes intensification, manure management, sequestration and demand reduction, but costs and adoption constraints greatly reduce economic potential	Broad global livestock scope is not dairy- or marketing-specific and cannot estimate digital effects, prices or household resilience
Sustainable marketing and low-carbon dairy chains	Herron et al. (2022) [27]; pasture-based dairy systems in Ireland	Cradle-to-farm-gate life cycle assessment comparing national-average and high-performance spring-calving pasture systems; no participant sample	An updated model reduced estimated impacts through improved factors and data; a high-performance system lowered impacts per kilogram of milk but raised global-warming potential per hectare, showing the need to report both indicators	Irish modelled systems may not generalise to smallholders or tropical systems; no economic, marketing or observed adaptation outcomes
Sustainable marketing and low-carbon dairy chains	Herrero et al. (2020) [28]; global food systems	Multi-author synthesis using technology identification and readiness assessment; no human, farm or household sample	Technological and systemic innovations can accelerate sustainable transition, and eight action points emphasise incentives, regulation, social licence, stakeholder dialogue and credible transition pathways	Broad systems framework offering no dairy-specific causal estimates, market-price data or validated smallholder livelihood effects

Structural Barriers to Market Access in Smallholder Dairy Systems

Barriers in smallholder dairy marketing are not independent: transaction costs increase with distance, sub-optimal market institutions enable ungoverned transaction costs, fragmented value chains create low bargaining power, and low digital capability contributes to poor information flow and prioritization. As the constraints are self-reinforcing, for our purposes we view them as a continuous set, rather than a discrete set of problems.

Distance, Collection Infrastructure and Transaction Costs

One of the strongest predictors of commercial success for a dairy farmer is the distance to an operating collection system. A study of 215 dairy farmers in 18 villages of Kenya and Ethiopia found a bidirectional proximity gradient [1]. Closer proximity to local service centres was linked to higher market quality, more purchased inputs, and higher yields, stocking rates, and margins. Remote farms in the Ethiopian study had weak demand, a coarse collection grid, and few services. Likewise, farmers are unlikely to invest in feed or better stock unless they have a reliable buyer to sell to, while buyers are unlikely to extend their collection routes for a small quantity.

Where collection infrastructure was limited, producers absorbed additional costs. In Kvemo Kartli, smallholders sold milk and cheese through bazaars, small supermarkets, collection points and on the roadside. More than half of smallholders said it was difficult to sell their milk. [2] When producers have selling points at too many smaller locations, the selling effort takes more time, spoilage occurs, and per-unit prices depend on which market is willing to buy the fruits on a given day. A scoping review of 202 studies found that small and medium enterprises provide inputs, credit, information, logistics and technology without contracts to small-scale producers [15]. Informal traders therefore perform real coordination functions, although the terms on which they do so are rarely clear to the producer.

Fragmented and Informal Marketing Channels

Smallholder choices among a plurality of informal output channels with different prices, payment reliability and quality thresholds are poorly characterized. In the Selale region of Ethiopia, 59% of 384 interviewed farmers sold raw milk and 26% sold dairy products. 15% utilized both. The selected marketing channels were affected by household characteristics, the intensity of milk production, distance to the market, income per liter and cooperative membership [3]. The preference for direct, traditional and modern marketing channels was influenced by gender, volume of produced milk, level of education, distance to the nearest main markets and off-farm income among 251 Zambian milk producers [16]. The channels chosen depend on the household's existing resources.

Fragmentation further disempowers producers: a farmer who sells small quantities to many small buyers cannot command a better price and is more easily excluded from the market. The findings suggested that a lack of sufficient supply to justify higher prices was not recorded. The Zambian study concluded that better information, support, transparency and value-chain investment would convince producers to shift to organized systems [16]. Fragmentation makes quality control difficult because it is hard to monitor and test the many informal sources from which milk is collected, and formal processors often refuse to pay differentiated prices.

Institutional and Organisational Constraints

The collective institutions that confront fragmentation are well supported by the dairy evidence. A study among 361 producers in 3 districts of the Sidama region of Ethiopia used a two stage multinomial endogenous switching regression [17]. These showed that participation in milk-marketing channels increased estimates of economic efficiency and food security. The gains to dairy-cooperative members are larger. Counterfactual estimates suggest that those left out might also gain from participation in a channel. It therefore appears that the constraint is entry into these institutions and not a lack of returns from them.

Other organisations mediate what is possible for smallholders in a value chain. For instance, consultants, knowledge transfer organisations, and brokers can connect smallholder producers with alternative pathways of innovation and value chain change [18]. A systematic review of farmer-marketing linkages highlights the importance of policy attention towards market power and equitable distribution of benefits, and shows that market participation, electronic commerce, cooperatives, information, infrastructure and education reduce transaction and information barriers and improve reach, income and price outcomes [19]. Institutional gaps are thus present at two levels: whether to establish coordinating organisations and, if so, on what terms for smallholders.

The Digital Divide as a Marketing Barrier

Due to user readiness, accessibility is also a value proposition for digital agriculture in smallholder contexts. A systematic review of 25 studies revealed few studies on digital skills, affordable products and business models. However, infrastructure, price and literacy were all repeatedly mentioned as challenges to technology adoption [7]. In a review of the processes of adoption of digital technologies in the agricultural value chains of South Africa, 36 research papers were case studies of the Choice Framework [8]. The review concluded that drivers of adoption included economic, political, social, institutional and governance, state support and local adoption, and the technology.

Adoption follows standard social influences. A scoping review of 315 studies in low- and middle-income countries found that uptake also depends on price, network access, gender, age, experience and whether use is voluntary [5]. Similar factors are experienced in sub-Saharan Africa where connectivity, cost, literacy, infrastructure and gender disparities impact equitable adoption [4]. However, connectivity does not necessarily give producers greater control, and concentrating control over the data generated from digital transactions can deepen inequalities and exclusion [9]. Producers that were already less favored, as was the case with remote producers and producers with small herds, also experienced difficulties in using digital channels.

Digital Marketing Pathways to Improved Market Access

Digital marketing in the smallholder dairy value chain includes discovering prices and buyers, transacting, making payments, assuring quality, and aggregating milk from sparsely distributed smallholder suppliers. These functions are dispersed across the value chain. Climate stressors disrupting these functions are also dispersed across the value chain. Functions and stressors of the milk value chain are shown in Figure 2.

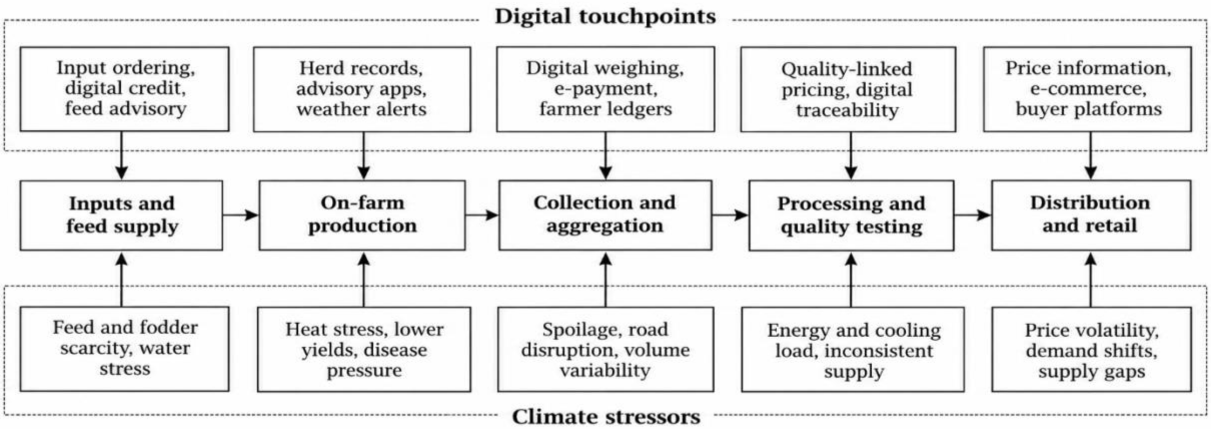

Figure 2. Digital touchpoints and climate stressors at each stage of the smallholder milk value chain. Compiled by the authors from the applications and stressors described in [1,4,5,9,10,11,12,13].

Market Information and Commercialisation Outcomes

Market information is the clearest area that has shown an impact. In Kenya, farmers that participated in projects that provided market information through information and communication technologies (ICT) had, after propensity-score matching, greater participation in input and output markets and higher household incomes [6]. The result links the intervention to commercialisation and income outcomes. As the matching only accounts for observables, unmeasured differences between intervention participants and non-participants may persist.

Broader studies have found similar mechanisms, although with more uncertainty about effect size. At the household level, studies of digital finance, extension, farm-management tools and digital marketing have found that these technologies improve information flows, market participation, productivity and income of smallholders in sub-Saharan Africa [4]. Research on farmer-marketing linkages reaches similar conclusions for e-commerce and market information, with better coverage and price outcomes [19]. In a conceptual framework for Indian agriculture market information is grouped with advisory services, sensing, artificial intelligence and blockchain into a single digital pathway with respect to availability, cost, accessibility and literacy [20].

Information alone nevertheless has clear limits in dairy: there is no point knowing the going price if no buyer will come to pick up the milk over the next few hours before it spoils. The Kenya and Ethiopia proximity evidence shows physical access to collection points continues to govern yields, sales and margins [1]. Consequently digital market information is likely best integrated with collection networks, cooperatives, transport and finance.

Digital Transparency, Traceability and Quality-Linked Pricing

Secondly, transaction visibility, with information from mobile phones, sensors, satellites and distributed ledgers in real time, provides smallholders with improved access to finance, advice, buyers and value chains and reduced transactions costs. [9] In dairy, this pathway is most relevant at collection and testing, with digital weighing, electronic payment and farmer ledgers creating an audit trail for volume, quality and reliability. It enables quality-linked or premium prices to be paid to an individual producer rather than to a pooled group.

Traceability relates to meeting marketing and environmental requirements. Dairy supply-chain decarbonisation reviews identify standards, logistics and carbon pricing as chain-level interventions that operate downstream of the farm, requiring data aggregation on the chain level [13]. However, producers who cannot document their practices are unlikely to qualify, no matter how well they perform. The trade-off for this transparency, when data and transaction governance is transferred to buyers or platform operators, is that data governance becomes a marketing issue instead of a technical detail [9].

Bundling Digital Finance, Advisory Services and Logistics

Digital interventions are most effective when bundling multiple different services together: for example, digital financial services, extension services, and farm-management tools are referred to as a connected set rather than as different applications [4]. Advisory and extension services are the most common documented digital services in low- and middle-income countries. This suggests that farmers meet digital tools first as sources of guidance [5] and that bundling is important in dairy (where constraints occur simultaneously). A producer needs feed credit, animal health advice, a reliable pick-up point, and prompt payment to stay in business.

Informal arrangements already provide part of this bundle. 202 studies of market linkages showed small and medium enterprises providing inputs, credit, information, logistics and technology, though often without formal contracts [15]. Digital systems can extend and formalize these arrangements, including recording deliveries, automating deductions, and making repayment histories visible, making it cheaper to serve small suppliers. The analysis of market-linkage research and our own observations support this observation. Aimed at building cooperatives, infrastructure, and education apart from using the digital service [19].

Conditions for Inclusive Adoption

Whether they reach those producers most in need of them probably depends on shared issues (e.g. infrastructure, costs and literacy). An inclusive digital system relies more on localization, trust and affordability than technical complexity [7]. Economic, political, social, institutional and governance factors are also important to adoption along agricultural value chains, where enabling factors include government support and local adaptation [8]. Other influences on adoption include price, access to networks, and gender, age and experience of farmers, indicating that not all innovations will be adopted in the same way [5].

Because women typically milk cows and sell small volumes, varying access to handsets, accounts and digital literacy within the household changes the beneficiaries of the digital channel. Older producers with small herds may not be able to reach the minimum volume requirements of digital platforms, limiting their reach to larger and better-connected producers. Thus, inclusive design is not just about the user interface but also about enrolment conditions, payment methods, and data rights [4,9]. Table 2 shows the most common digital services and their functions, including opportunities and conditions for using each type of service in dairy marketing.

Table 2. Digital applications relevant to smallholder dairy marketing, their function in the value chain, and the conditions required for producer benefit.

Digital application	Function in the dairy chain	Principal opportunity for smallholder producers	Condition required for benefit	Supporting evidence
Mobile market-information services	Delivery of prevailing prices, buyer locations and demand signals	Improved bargaining position and reduced search time before a sale	Network coverage, handset access, and price data that is timely and locally relevant	[4,6,19]

Digital application	Function in the dairy chain	Principal opportunity for smallholder producers	Condition required for benefit	Supporting evidence
Digital advisory and extension applications	Guidance on feeding, animal health, breeding and milking hygiene	More consistent milk quality that qualifies for better-paying channels	Literacy, language-appropriate content and trust in the information source	[4,5,20]
Digital payment and farmer ledgers	Electronic recording and settlement of milk deliveries	Verifiable payment history and reduced dependence on cash intermediaries	Agent networks, account ownership and reliable settlement periods	[9,15]
Digital collection and weighing records	Automated capture of delivered volume and quality at the collection point	Individual supply record that supports differentiated rather than pooled pricing	A functioning collection point, testing equipment and shared access to the record	[1,9]
Traceability and quality-linked pricing	Linking milk batches to the farm of origin and to quality or practice attributes	Eligibility for premium, standard-linked or sustainability-linked markets	Chain-wide data standards, buyer willingness to pay and clear producer data rights	[9,13]
Digital financial services and credit	Delivery of savings, credit and insurance against recorded transactions	Working capital for feed and animals, and risk transfer during shocks	Affordable products, regulatory support and credible repayment records	[4,12]
Electronic commerce and buyer platforms	Direct matching between producers or producer groups and downstream buyers	Access to buyers beyond the immediate locality and to more stable demand	Aggregation capacity, logistics, cold chain and feasible minimum volumes	[19,20]
Digital climate and weather information	Forecasts, advisories and early warning relevant to feed and herd management	Earlier response to drought and heat stress, protecting saleable volume	Forecasts at a usable scale, reliable delivery channels and institutional support	[10,12]

Price Realization: Mechanisms, Evidence and Measurement

Reaching a market and earning value from it are separate. A producer may be locked into a channel, and earn a price which does not change when downstream prices change. Price realization is the price received net of transport and the cost to provide a reliable flow of the crop to the buyer. Price realization is the process by which access to markets leads to improvements in livelihoods.

Marketing-Channel Choice and Producer Income: On the dairy side, where channel choice and income are most closely related, farmers selling raw milk or mixed products had higher dairy incomes than if they sold only processed dairy in the Selale study [3]. Strategy choice depended on milk yield, distance to the market, income per liter, share of crossbred cows, age of the household head and cooperatives' member status. In Zambia, an overlapping set of factors is used to choose between direct, traditional, and modern channels [16]. Since the results of both papers are based on multinomial regression models and cross-sectional data, they do not attempt to model the effect of the transition of any farmer from one channel to another.

Some evidence from Sidama directly tackles the selection problem. Using endogenous switching regression, participation in milk-marketing channels was shown to improve economic efficiency and food security, though the largest gains were for those individuals in the cooperatives [17]. Counterfactual estimates show that non-participants benefit from joining a channel, conditional on selection on observed and unobserved covariates. This makes the result more strong, although it still depends on the model used and will only be valid for the Ethiopian region studied. Read in conjunction with evidence of geographical proximity to Kenya and Ethiopia, the pattern is consistent with the notion that more organized channels favor producers and are not equally accessible [1].

Vertical Price Transmission and Value Capture: Production participation in channels does not guarantee a fair distribution of the final value to producers. For instance, a study on Swiss dairy and cheese marketing chains analyzed 24 price pairs from the farm-gate, the wholesale level, exports, exports to retail value, and retail between January 2004 and March 2018 [21]. Using asymmetric vector autoregressive and vector error-correction models, the analysis found only passing long-run transmission and no asymmetry, and no systematic difference between transmission in the artisanal and industrial chains for most pairs. Moreover, closer downstream linkage did not by itself produce fuller or faster pass-through to the farm gate.

Since this configuration is not equivalent to a smallholder system, the result cannot be interpreted as a direct estimate. However, it highlights the dividing line between access and value capture: if, even in a high-income market, integration into a formal chain with relatively high levels of transparency does not guarantee proportional pass-through, one cannot assume that access through this digital linkage will increase smallholders' farm-gate price. The bargaining position, perishability, quality requirements, terms of contract and downstream concentration affect how much of the price change reaches the producer.

Measuring Price Realization: Because access and value capture may differ, price realization should be measured by several indicators. Table 3 lists these indicators with their definitions, data requirements, and limitations where appropriate. This distinction is important to the assessment of the digital intervention, as the platform may increase the price offered, and simultaneously increase the quantity it rejects on the basis of quality or time to sale.

Table 3. Indicators for measuring price realization in smallholder dairy marketing, with data requirements and limitations.

Indicator	Definition	Data requirement	What it reveals	Main limitation
Farm-gate price per litre	Price received by the producer at the point of sale	Transaction-level price records by channel and period	Nominal price level and variation between available channels	Excludes the cost of reaching the buyer and any rejected volume
Dairy income per litre	Net dairy income divided by the volume sold	Income and cost records alongside recorded sales volume	Returns remaining after production and marketing costs	Sensitive to how shared costs are allocated in mixed farming systems
Marketing margin	Difference between the producer price and the price at the next chain stage	Paired prices at two adjacent stages of the same chain	Value taken by intermediation at a specific point in the chain	Requires matched data that is often unavailable in informal channels
Producer share of final consumer value	Farm-gate price expressed as a proportion of the retail price	Farm-gate and retail prices for a comparable product	Overall distribution of value along the chain	Product transformation between stages complicates comparability
Vertical price transmission	Extent and speed with which downstream price changes reach the farm gate	Price series at several chain stages over an extended period	Whether producers benefit when downstream prices rise	Demands long time series that are rarely available for smallholder chains
Sales reliability and rejection rate	Proportion of offered milk accepted and paid for on agreed terms	Delivery and rejection records by producer and period	Stability of income and exposure to quality-based losses	Rejections are frequently under-recorded in informal transactions
Transaction and transport costs	Producer costs of search, travel, waiting and payment collection	Time-use and expenditure records linked to individual sales	Net benefit of a channel once access costs are accounted for	Time costs are difficult to value consistently across households

Some indicators, including income per liter in the Ethiopian channel choice study [3], already exist in the reviewed dairy literature and have thus practical rather than theoretical value. Margins and market participation are estimated by the Kenyan and Ethiopian proximity study [1], economic efficiency and food security are estimated by the Sidama proximity study [17], and vertical prices transmission is measured by the Swiss proximity series [21]. When these measures are reported together, an intervention that is helpful on one dimension but harmful on another is not recorded simply as successful.

Climate Resilience in Smallholder Dairy Value Chains

While climate risk in the dairy sector is often seen as a production problem, for smallholder households it is felt through the market. Lower production means less saleable product, delays in heat or transport affect quality, there are higher rejection rates, and poor roads impede transport of product from farm to dairy collection/chilling points. In this sense, resilience refers to the household's or household marketing systems' ability to maintain income when conditions of production deteriorate.

Climate Risks Along the Dairy Chain: A review of climate change impacts on the livestock food supply chain documented impacts on livestock production, processing and storage, transport, retail and consumption, prices, food access and livelihoods, with highest impacts in systems with low adaptive capacity. A second reviewed livestock systems and identified heat, feed availability, water, disease, reproduction and production as the priority impact pathways [10, 11]. It notes that diversification and mixed systems are useful adaptation options and that the effectiveness of mitigation measures can vary according to the local context. Both reviews treat climate risk as a property of the value chain, rather than of the farm alone.

This presents a design problem for such marketing systems. A collection network designed to the average collection volume will collapse during drought years when the volume is less than sufficient to guarantee the survival of a collection route. Processors, often designed to handle the maximum supply, are underutilized for meaningful periods, with resulting high unit costs that are passed back to producers. Table 4 summarizes the main climate stressors at each stage of the dairy supply chain, their implications for marketing and the adaptation options considered in the literature.

Table 4. Climate stressors reported at each stage of the dairy value chain, their consequences for marketing performance, and documented adaptation options.

Chain stage	Principal climate stressor	Consequence for marketing performance	Adaptation options reported	Evidence
Input and feed supply	Drought, water scarcity and fodder shortage	Higher feed costs compress margins and discourage continued supply	Drought-tolerant fodder, feed conservation and diversified sourcing	[11,12]
On-farm production	Heat stress, disease pressure and reduced reproductive performance	Lower and more variable saleable volume, weakening buyer relationships	Improved breeds and feeding, livestock insurance, mixed and diversified systems	[11,12]
Collection and aggregation	Spoilage risk, road disruption and volume variability	Collection routes become less viable, raising rejection and lost sales	Denser collection grids, cooling at the collection point and flexible routing	[1,10]
Processing and quality testing	Energy and cooling demand under inconsistent raw-milk supply	Higher unit processing costs that are frequently passed back to producers	Supply planning, quality-based payment and capacity matched to variability	[10,13]
Distribution, retail and household	Price volatility, demand shifts and constrained food access	Unstable prices and income reduce the capacity to invest in adaptation	Income diversification, market information and social protection measures	[10,11]

Farm-Level Adaptation and Its Constraints: Adaptation at the farmer level was illustrated by a study of smallholder dairy farmers in three semi-arid areas of southern India, which found the greatest risks to be drought, pests and diseases, and heat, and these impacting the dairy income and performance of animals [12]. Insurance, low levels of debt and drought-tolerant grasses were the main responses. The fact that farmers were constrained by the lack of usable forecasts, the costs of adaptation, and weak institutions is also of interest. Within this account, access to information and access to finance are as important as technical knowledge.

Additionally, organizational factors can extend the missing link. A conceptual framework of Kenyan smallholders suggests farmer entrepreneurship, farmer organisations and farmer-buyer collaboration improve resilience by increasing access to information, inputs, credit, training, insurance and secure markets [22]. It is illustrated with potato production, and does not provide a causal estimate, so we treat this as a mechanism and not a finding: adaptation can be closely related to the same organisations that influence marketing performance. In addition to price value, cooperative memberships and relationships with stable buyers have value that endures.

Resource Trade-Offs in Intensification: Intensification is generally seen as a pathway to increased incomes and resilience, but the evidence from models on resources is mixed. For example, a study aggregating 271 household surveys in nine counties in Kenya, with county-level data, considered baseline conditions and three scenarios of intensification (breeds, feed and milk output) [23]. Total water and land footprints increased with intensification. In some lowland scenarios, breed and feed enhancements decreased milk production water footprints up to 75%, but the effect varied by agro-ecological zone. Efficiency per liter and total resource demand have therefore gone in opposite ways.

A similar trade-off exists for farm income. A linear-programming model of intensive-grazing dairy systems in the Azores shows that the income of a dairy farm declines with predicted reductions of 10% to 75% in methane emissions, as does the grazing intensity and herd size. The authors concluded that alternative sources of income will be needed to maintain farm viability [24]. While not directly transferable to smallholder systems, the structural point is valid, as improved environmental performance may come at the expense of income that supports adaptive capacity. An integrative review of livestock systems reaches the same conclusion and calls for place-based adaptation and jointly designed mitigation, because production, conservation, income and emissions involve real trade-offs [25].

Sustainable Marketing and Low-Carbon Dairy Value Chains

Sustainable dairy marketing relies on a claim about the production of the milk, and the credibility of that claim depends on where emissions occur, how much variation there is between farms and how substantiable the claim is. In all three cases, the reviewed literature provided a reasonably clear answer, each having implications for smallholders in sustainability-linked milk markets.

Emission Hotspots and Mitigation Options: A systematic review of dairy supply-chain decarbonisation collated 262 GWP estimates from the Web of Science literature between 2014 and 2025 [13], identifying farms as emissions hotspots dominated by enteric fermentation, manure and feed. The review shows interventions at the farm, processing, transport, standards and carbon-pricing levels. However, most abateable emissions in the supply chain are upstream of the marketing stage. Improved performance in downstream logistics or marketing claims does not substitute for farm level mitigation.

This sectoral analysis places these options against a broader economic backdrop, in which it is estimated that, between 1995 and 2005, global livestock emissions were 5.6 to 7.5 $GtCO_2$-equivalent/year [26]. Technical mitigation options include sustainable intensification, manure management, rangeland carbon sequestration and demand-side change. Often, however, the costs of implementation and practical constraints mean that the economic potential is substantially smaller than the technical potential. For smallholders, the difference between economic and technical potential can be very large, because on a large commercial farm different approaches may be viable that are not possible for a two-animal household farm.

Heterogeneity in Environmental Performance: Because of the variation in environmental performance, it may be difficult to create one sustainability label. A study of 911 dairies in Brazil (Parana) found that just under 56600 cows produced an annual average of 122412 tonnes of fat & protein-corrected milk [14]. Using principal component analysis, clustering and life cycle assessment, four farm types were identified with average carbon footprints between 1.75 and 3.27 kg CO_2-equivalent per kg of corrected milk produced. Larger farms, and those with better access to technology and technical support had lower footprints, while multi-enterprise farms had higher footprints. Rather, they are part of the sustainability question, and not separate from it. The indicator chosen can also affect results from a life cycle assessment. For example, a cradle-to-farm-gate assessment of Irish pasture based systems found that a high performing system reduces impacts per kilogram milk, but increases global warming potential per hectare at higher stocking densities [27]. The product- and area-based indicators can therefore move in opposite directions within the same system. Reporting on only one of them provides an incomplete picture. Table 5 provides a summary of the most commonly used indicators in the reviewed sustainability literature along with their interpretations and cautions.

Table 5. Sustainability indicators used in the reviewed dairy literature, with their interpretation for smallholder marketing claims.

Indicator	What it measures	Reported evidence in the reviewed literature	Implication for smallholder marketing claims	Caution
Carbon footprint per kilogram of corrected milk	Emissions attributed to a unit of standardised milk output	Four Brazilian farm groups recorded means from 1.75 to 3.27 kg CO_2-equivalent per kilogram of corrected milk [14]	Supports differentiated claims but exposes wide variation between farms	A product-based figure can improve while total emissions rise
Global warming potential per hectare	Emissions attributed to a unit of land occupied	An Irish high-performance system lowered impacts per kilogram of milk but raised warming potential per hectare [27]	Product-based and area-based indicators must be reported together	Area-based figures penalise intensification even where efficiency improves
Distribution of emissions along the chain	Share of chain emissions arising at each stage	Farm-stage subprocesses dominate emissions in the reviewed dairy evidence [13]	Places abatement responsibility upstream of the marketing stage	Downstream claims cannot offset weak farm-stage performance
Water and land footprint	Freshwater and land resources used per unit of output or per system	Kenyan intensification scenarios raised total footprints while lowering water use per litre in some zones [23]	Claims should state whether efficiency or total resource use improved	Zone-specific results limit transfer between agro-ecologies
Mitigation cost and income effect	Income consequence of adopting a mitigation measure	Modelled methane reductions of 10% to 75% consistently lowered farm income in an Azorean system [24,26]	Indicates when mitigation requires compensation or income diversification	Modelled trade-offs are not observed adoption outcomes

Credible Claims and Market Rewards for Smallholders: To substantiate these claims, a producer needs to keep records that most smallholders have no capacity to maintain. Any claim should indicate its system boundary and the metric used and declare if trade-offs exist between emissions per unit of production, per hectare, water use, land use, on-farm income and food security. Since informal channels are usually not subject to an audit trail that records feeds, herd composition, or quantity of milk, even producers that maintain good practices cannot provide proof. Digital records from production and testing can help meet the intersection of digital data management and sustainable marketing: data from collection and testing are the same data needed for an auditable sustainability claim [9,13].

From the wider transition literature, however, it is clear that technological and system innovations must be complemented by incentives, regulation, social license, stakeholder dialogue and credible transition pathways in order to enable the transition to sustainable food systems [28]. The second integrative review of livestock systems makes similar calls for joint, place-based approaches which recognize trade-offs between production, conservation, income and emissions [25]. None of the reviewed studies found that sustainability claims or low-carbon positioning improved realized prices for smallholder dairy producers. The case for sustainable marketing is therefore grounded on environmental and theoretical arguments rather than demonstrated producer returns.

Synthesis, Research Gaps and Implications

What the Evidence Supports: From the literature, three findings are consistent: marketing-channel choice is important for dairy income, economic efficiency and food security and organized channels or cooperatives achieve better outcomes [3,16,17]. Second, proximity to collection and service infrastructure shapes input use, yields, margins and market participation, so marketing performance is partly determined before any transaction takes place [1]. Third, ICTs expand access to information, buyers, finance and advisory services. One Kenyan study links participation in market information with higher commercialisation and income [4,6,19].

Another two are the contingencies of the digital economy, in terms of connectivity, costs, literacy, trust, gendered access, and data governance [5,7,8,9], and the distinction between value capture and market access, in the sense that joining formalized value chains does not guarantee flow-through of downstream price changes to the farm gate price for an equivalent share of income [21]. Digital dairy marketing evaluations should consider price and distributional effects as well as participation rates.

Research Gaps

The main gap is the connection between these domains. Digital studies measure access, adoption, information use, and commercialisation/income. Although no reviewed study tests the three factors together, most studies in this section assess production risk, adaptive behaviours and/or emissions and resource footprints. Thus the pathway in Figure 1 is coherent in principle though has not been tested all together.

Narrow gaps follow from the same structure. Digital evidence on dairy is scant, as the strongest evidence on the digital outcome does not concern dairy [6], and the strongest evidence on dairy does not concern the digital variables [3,17]. Price transmission has not been estimated in smallholder dairy supply chains in low- and middle-income countries, leaving the question of value capture where it is most important open. Most evidence of sustainability is in commercial systems of Brazil, Ireland, Switzerland and the Azores. No study has estimated the price premium for smallholder sustainability performance. Table 6 highlights the research gaps by research question and study design.

Table 6. Principal research gaps identified by the review, with corresponding research questions and study designs.

Research gap	Research question	Suggested design	Priority
Integration of the four domains	Does digital dairy marketing improve realized prices and climate resilience together rather than separately?	Longitudinal panel following a staggered platform rollout with matched comparison collection areas	High
Dairy-specific digital evidence	What effect does dairy-specific digital marketing have on farm-gate price and volume sold?	Quasi-experimental evaluation within dairy cooperatives using administrative delivery and payment records	High
Price transmission in smallholder chains	How fully and how quickly do downstream price changes reach smallholder farm gates?	Collection of price series at several chain stages combined with asymmetric time-series analysis	High
Distribution of digital benefits	Who gains and who is excluded when a digital marketing channel is introduced?	Analysis disaggregated by gender, herd size, distance to collection and connectivity status	High
Rewards for sustainability performance	Do verified sustainability attributes raise the prices received by smallholder producers?	Buyer choice experiments combined with observed premium payment data from operating chains	Medium
Resilience of marketing institutions	How do collection systems and cooperatives perform during and after climate shocks?	Event-based panel analysis around drought or flood episodes using delivery and rejection records	Medium

Implications for Practice and Policy: In terms of design of the programme, data suggest that bundled interventions, including a collection point, guaranteed payment to producers, and access to credit to purchase inputs (including feed), are the most effective. Given that small and medium enterprises tend to offer several of these services, this may reflect the demand-side dynamics of smallholder markets [4,15]. The terms of enrollment are also relevant, for example, minimum volumes, ownership of handsets, and ability to access accounts, as these determine whether or not it is possible for a digital channel to serve producers [5].

Three policy priorities follow from this. Investment in collection infrastructure and rural connectivity addresses this constraint that cannot be removed with digital tools alone [1]. Data governance policies are a part of agricultural policy, as the impact of digital transparency on producer power depends on transaction data and platform participation rules [9]. Supporting producer organisations is justified not only by efficiency and food security benefits stemming from cooperative participation, but also by their role in adaptive capacity [17,22]. Finally, sustainability standards for dairy chains should take into account the smallholder's record keeping capacity, as standards that require detailed farm level data and records will exclude producers who do not have such records [13,28].

Conclusions

In smallholder dairy livelihoods, the choice of marketing channel is associated with differences in dairy income, economic efficiency and food security. The relationship between the choice of marketing channel and other aspects is less clear. However, close proximity to collection and other service infrastructure still increases options for producers, despite digital tools for accessing information, financing and technical assistance. In a single case, commercialisation and household income were still found to be higher. Benefits depend on connectivity, trust and data governance and digital cannot replace having a collection point to meet citizen needs.

The review also uses the terms market access, where the player in the value chain does not automatically add value, and price transmission evidence, which shows that being in a formal value chain does not guarantee proportionate pass-through. In digital dairy marketing, farm-gate price, income per liter, marketing margin, reliability of sales and transaction costs should be presented together to avoid giving the impression the producer receives a greater price.

The same marketing structures that support climate resilience also support climate sustainability. Climate risk cascades through the dairy chain where adaptive capacity is lowest, including at the producer. Since most dairy emissions occur at the farm stage and vary widely from farm to farm, sustainability-linked markets will not benefit farmers unable to document their practices. The evidence described in these sections increases the link between documentation generated by these systems and sustainability claims and payment. No reviewed study tests these elements of digital dairy marketing, realized prices and climate-resilience outcomes together, and generating that evidence through longitudinal and quasi-experimental designs in smallholder dairy settings is our clearest priority for future research.

Acknowledgment: No
Author's Contribution: *Anagha M:* Literature Review; *Prof. (Dr) Reshmi R:* Literature Review
Funding: No
Declaration: The author/s has/have given consent for the publication.
Competing Interest: No

Notes & References

1. van der Lee, J., Oosting, S., Klerkx, L., Opinya, F., & Bebe, B. O. (2020). Effects of proximity to markets on dairy farming intensity and market participation in Kenya and Ethiopia. Agricultural Systems, 184, Article 102891. https://doi.org/10.1016/j.agsy.2020.102891
2. Al Sidawi, R., Urushadze, T., & Ploeger, A. (2021). Factors and components affecting dairy smallholder farmers and the local value chain—Kvemo Kartli as an example. Sustainability, 13(10), 5749. https://doi.org/10.3390/su13105749
3. Chagwiza, C., Ruben, R., & Machethe, C. (2020). Marketing strategy choice and the associated income differentials among smallholder dairy farmers in Ethiopia. Enterprise Development & Microfinance, 31(3), 194–207. https://doi.org/10.3362/1755-1986.19-00022
4. Choruma, D. J., Dirwai, T. L., Mutenje, M. J., Mustafa, M., Chimonyo, V. G. P., Jacobs-Mata, I., & Mabhaudhi, T. (2024). Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers. Journal of Agriculture and Food Research, 18, 101286. https://doi.org/10.1016/j.jafr.2024.101286
5. Porciello, J., Coggins, S., Mabaya, E., & Otunba-Payne, G. (2022). Digital agriculture services in low- and middle-income countries: A systematic scoping review. Global Food Security, 34, 100640. https://doi.org/10.1016/j.gfs.2022.100640
6. Okello, J. J., Kirui, O. K., & Gitonga, Z. M. (2020). Participation in ICT-based market information projects, smallholder farmers' commercialisation, and agricultural income effects: Findings from Kenya. Development in Practice, 30(8), 1043–1057. https://doi.org/10.1080/09614524.2020.1754340
7. Gumbi, N., Gumbi, L., & Twinomurinzi, H. (2023). Towards sustainable digital agriculture for smallholder farmers: A systematic literature review. Sustainability, 15(16), Article 12530. https://doi.org/10.3390/su151612530
8. Smidt, H. J., & Jokonya, O. (2022). Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa. Information Technology for Development, 28(3), 558–584. https://doi.org/10.1080/02681102.2021.1975256
9. Kos, D., & Kloppenburg, S. (2019). Digital technologies, hyper-transparency and smallholder farmer inclusion in global value chains. Current Opinion in Environmental Sustainability, 41, 56–63. https://doi.org/10.1016/j.cosust.2019.10.011
10. Godde, C. M., Mason-D'Croz, D., Mayberry, D. E., Thornton, P. K., & Herrero, M. (2021). Impacts of climate change on the livestock food supply chain; a review of the evidence. Global Food Security, 28, Article 100488. https://doi.org/10.1016/j.gfs.2020.100488
11. Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. Climate Risk Management, 16, 145–163. https://doi.org/10.1016/j.crm.2017.02.001

12. Shantharaju, A., Islam, M. A., Kath, J. M., Mushtaq, S., Muniyappa, A., & Singh-Peterson, L. (2024). Understanding constraints and enablers of climate risk management strategies: Evidence from smallholder dairy farmers in regional South India. Sustainability, 16(5), 2018. https://doi.org/10.3390/su16052018
13. Ni, H., Zeng, H., Liu, Z., Li, W., Miao, S., Yang, A., & Wang, Y. (2025). Towards decarbonizing the supply chain of dairy industry: Current practice and emerging strategies. Carbon Neutrality, 4(1), Article 8. https://doi.org/10.1007/s43979-025-00124-z
14. Vogel, E., & Beber, C. L. (2022). Carbon footprint and mitigation strategies among heterogeneous dairy farms in Paraná, Brazil. Journal of Cleaner Production, 349, Article 131404. https://doi.org/10.1016/j.jclepro.2022.131404
15. Liverpool-Tasie, L. S. O., Wineman, A., Young, S., Tambo, J., Vargas, C., Reardon, T., Adjognon, G. S., Porciello, J., Gathoni, N., Bizikova, L., Galiè, A., & Celestin, A. (2020). A scoping review of market links between value chain actors and small-scale producers in developing regions. Nature Sustainability, 3(10), 799–808. https://doi.org/10.1038/s41893-020-00621-2
16. Cheelo, T., & van der Merwe, M. (2021). What factors influence smallholder farmers' decision to select a milk marketing channel in Zambia? Agrekon, 60(3), 243–252. https://doi.org/10.1080/03031853.2021.1950017
17. Kifle, E., Zemedu, L., Jemal, K., & Ahmed, B. (2025). The impact of market channel choice on economic efficiency and food security: Evidence from smallholder dairy farmers in Ethiopia. Food and Humanity, 5, Article 100888. https://doi.org/10.1016/j.foohum.2025.100888
18. Dicecca, R., Pascucci, S., & Contò, F. (2016). Understanding reconfiguration pathways of agri-food value chains for smallholder farmers. British Food Journal, 118(8), 1857–1882. https://doi.org/10.1108/BFJ-05-2016-0194
19. Ma, W., Rahut, D. B., Sonobe, T., & Gong, B. (2024). Linking farmers to markets: Barriers, solutions, and policy options. Economic Analysis and Policy, 82, 1102–1112. https://doi.org/10.1016/j.eap.2024.05.005
20. Satpathy, B. (2022). Digital transformation for sustainable agriculture: A progressive method for smallholder farmers. Current Science, 123(12), 1436–1440. https://doi.org/10.18520/cs/v123/i12/1436-1440
21. Hillen, J. (2021). Vertical price transmission in Swiss dairy and cheese value chains. Agricultural and Food Economics, 9(1), Article 13. https://doi.org/10.1186/s40100-021-00187-3
22. Kangogo, D., Dentoni, D., & Bijman, J. (2020). Determinants of farm resilience to climate change: The role of farmer entrepreneurship and value chain collaborations. Sustainability, 12(3), Article 868. https://doi.org/10.3390/su12030868
23. Bosire, C. K., Rao, E. J. O., Muchenje, V., Van Wijk, M., Ogutu, J. O., Mekonnen, M. M., Auma, J. O., Lukuyu, B., & Hammond, J. (2019). Adaptation opportunities for smallholder dairy farmers facing resource scarcity: Integrated livestock, water and land management. Agriculture, Ecosystems & Environment, 284, 106592. https://doi.org/10.1016/j.agee.2019.106592
24. Silva, E., Brito Mendes, A., & Duarte Rosa, H. J. (2016). Dairy farming systems' adaptation to climate change. Agricultural Sciences, 7(3), 137–145. https://doi.org/10.4236/as.2016.73013
25. Bilotto, F., Harrison, M. T., Vibart, R., Mackay, A., Christie-Whitehead, K. M., Ferreira, C. S. S., Cottrell, R. S., Forster, D., & Chang, J. (2024). Towards resilient, inclusive, sustainable livestock farming systems. Trends in Food Science & Technology, 152, Article 104668. https://doi.org/10.1016/j.tifs.2024.104668
26. Herrero, M., Henderson, B., Havlík, P., Thornton, P. K., Conant, R. T., Smith, P., Wirsenius, S., Hristov, A. N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T., & Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector. Nature Climate Change, 6(5), 452–461. https://doi.org/10.1038/nclimate2925
27. Herron, J., O'Brien, D., & Shalloo, L. (2022). Life cycle assessment of pasture-based dairy production systems: Current and future performance. Journal of Dairy Science, 105(7), 5849–5869. https://doi.org/10.3168/jds.2021-21499
28. Herrero, M., Thornton, P. K., Mason-D'Croz, D., Palmer, J., Benton, T. G., Bodirsky, B. L., Bogard, J. R., Hall, A., Lee, B., Nyborg, K., Pradhan, P., Bonnett, G. D., Bryan, B. A., Campbell, B. M., Christensen, S., Clark, M., Cook, M. T., de Boer, I. J. M., Downs, C., … West, P. C. (2020). Innovation can accelerate the transition towards a sustainable food system. Nature Food, 1(5), 266–272. https://doi.org/10.1038/s43016-020-0074-1

Publisher's Note
The Social Science Review A Multidisciplinary Journal remains neutral with regard to jurisdictional claims in published data, map and institutional affiliations.

©The Author(s) 2026. Open Access.
This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/