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Perspective

Economic Perspectives on Farm Biosecurity: Stakeholder Challenges and Livestock Species Considerations

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Abstract

Livestock farm biosecurity is crucial for animal health and economic sustainability, however uneven adoption/implementation across diverse livestock species and production systems persists. To improve uptake of biosecurity, it is necessary to identify critical economic behavioural, and systematic barriers, and to outline practical drivers. Perceived high costs, labour/time burdens, and uncertain benefits can suppress private investment, while poorly designed indemnities can create moral hazard. Conversely, targeted subsidies, risk-based insurance, and market standards (e.g., certification and procurement) can incentivise implementation. Knowledge and trust gaps, especially in smallholder and backyard settings, further limit compliance. Participatory, and context-specific training led by field veterinarians consistently outperforms top–down messaging, with effective element including: simple, low-cost "easy wins", tiered checklists, and decision-support tools to help embed routines and demonstrate the value of biosecurity. Integrating clear cost–benefit evidence, incentive-based tools, and co-designed training can transform biosecurity from a perceived practical and cost burden into a resilient, profitable practice that delivers public-good benefits for animal health, trade, and One Health across Europe and beyond.

Keywords: biosecurity practices; financial motivation; cost–benefit evaluation; risk-based schemes; stakeholder education

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1. Introduction

Farm biosecurity, defined as the set of management and physical measures designed to prevent the introduction and spread of infectious diseases in animal populations [1,2], has become a cornerstone of sustainable livestock production and global food security. In an era marked by increasingly interconnected food systems, accelerated trade, and intensified animal production, even minor lapses in on-farm biosecurity can cascade into crises, such as: catastrophic animal losses, export bans, volatile market prices, and severe threats to rural livelihoods and public health [2]. The economic impacts of such failures extend far beyond individual farms, underscoring that biosecurity is not merely a technical safeguard but an essential socio-economic strategy for stabilising supply chains and protecting communities. For instance, in Nigeria, an African Swine Fever (ASF) outbreak caused substantial economic losses at the farm level, with significant impacts on pig producers' livelihoods [3]. Establishing a single biosecurity coordination component within the competent authority, integrating official veterinarians (enforcement/notification), veterinarian's practitioners (advisory, monitoring, uptake support), and producer organisations (peer-compliance, mutual aid) through shared operating procedure, interoperable data standards, and joint risk communication create system-wide coherence while preserving each actor's distinct legal responsibilities [4]. This integrated approach is essential for preventing the introduction and spread of diseases, reducing the need for costly treatment interventions, and ultimately safeguarding food security and public health [5].

Evidence is increasingly demonstrating that robust biosecurity practices generate measurable economic benefits to both producers and consumers [6]. Higher levels of implementation of biosecurity measures are associated with farm productivity and health status in cattle farms [7], while a positive correlation between on-farm biosecurity and animal welfare indices has been observed in large-scale turkey production [8]. Farms that consistently apply biosecurity protocols experience fewer zoonotic risks and reduced losses [9]. For example, in Japanese pig farms implementing an all-in/all-out system, a significant reduction in antimicrobial use for pneumonia and oedema disease treatment was observed [10]. In France, this measure was linked to a decrease in *Salmonella* prevalence in pigs sent to slaughter [11]. Although vaccination or bulk-tank milk testing may not be strictly classified as biosecurity per se, they are treated as complementary health-management and surveillance tools that are associated with improved economic performance [12,13]. A global scoping review confirms that effective on-farm prevention reduces the need for antimicrobials, thereby lowering input costs and strengthening antimicrobial resistance stewardship [14]. Historical analyses in low-income contexts reveal that even low-cost interventions can avert mortality and disruption, yielding high returns [15]. Studies have shown that smallholder poultry producers receiving biosecurity training were 25% more likely to belong to the high-adoption cluster, and these farms reported significantly reduced flock mortality [16].

Yet adoption of biosecurity measures remains uneven across species, production systems, and regions. Factors such as economic frictions, upfront investment, labour demands, and delayed payoffs often deter farmers [17]. For smallholders facing liquidity constraints, even basic expenses for disinfectants or fencing can seem insurmountable. Meanwhile, producers in dense industrial systems may underestimate the risks or succumb to fatalism, perceiving outbreaks as inevitable [18]. This disparity is particularly evident in mountain dairy farms, where climatic and topographic constraints shape infrastructure management, leading to lower adoption levels of biosecurity compared with lowland systems [19]. Further complicating matters are knowledge gaps and misaligned institutional dynamics, including permitting and zoning frameworks that sometimes limit farm infrastructure upgrades which can deter or even prevent biosecurity investments. When communication is top–down or guidelines are overly abstract, they often fail to connect with local realities, undermining trust and reducing uptake [20]. Participatory strategies, such as co-designing feasible routines, engaging "champion farmers," and building peer credibility, have proven more effective in motivating adoption [21,22]. Additionally, complementary financial mechanisms, such as targeted subsidies or conditional insurance schemes, can shift cost–benefit perceptions and incentivise proactive disease prevention [23,24].

The urgency of aligning incentives becomes even clearer considering recent transboundary animal outbreaks, such as African Swine Fever, which continues to carry substantial economic risk both inside and beyond the EU, with EFSA (the European Food Safety Authority) detailing ongoing spread and impacts [25]. Recent studies indicate that indemnity schemes contingent on verified biosecurity measures can enhance compliance. Evidence from Finnish pig and cattle farms further shows that farm characteristics and perceived costs are key determinants of biosecurity adoption [26]. These studies document productivity shocks and cost dynamics that justify co-financed upgrades and risk-based insurance. Furthermore, cost-effectiveness research helps direct scarce funds, while farm-level data reveal routine implementation gaps that training, advisory support, and co-investment can help close [27–29]. In highly pathogenic avian influenza, prevention strategies are often more cost-effective than reactive suppression, and conditional indemnity schemes have proven valuable for rewarding preparedness [30,31]. A retrospective analysis of the 2017 highly pathogenic avian influenza type A (H5N8) outbreak in South Africa demonstrated how understanding the economic impact spurred greater producer willingness to invest in prevention [32]. For foot-and-mouth disease, recent synthesis emphasises that the most effective combination of vaccination, movement control, and surveillance varies by context, arguing against uniform strategies in favour of locally tailored incentive packages [33].

Despite the integration of biosecurity into European Animal Health Law, practices remain heterogeneous, particularly in resource-limited contexts where infrastructure, knowledge, and financial support, and uneven legal requirements limit uptake [34]. Species-specific economic drivers add complexity: cattle, swine, poultry, aquaculture, and small ruminants each face and pose distinct risks, cost structures and behavioural challenges. Intensive systems may formalise protocols, while smallholder or backyard systems can struggle with access to training, materials, and markets. Economic models show that biosecurity can be economically beneficial in small mariculture farms when mortalities are high and stocking densities are increased, underscoring the need for tailored economic analyses [35]. This emphasises the fact that economically optimal approaches on how to control a disease are not static. Instead, they depend on factors such as the cost and efficacy of control measures, severity and likelihood of disease risks and prices of inputs used and outputs obtained.

This perspective is derived from four years of analysis and stakeholder engagement within the COST Action Biosecurity Enhanced Through Training Evaluation and Raising Awareness (BETTER) CA20103, that was established to systematically identify critical knowledge gaps, mismatched incentives, and stakeholder perceptions that continue to impede the cost-effective implementation of livestock farm biosecurity. The Action had over 300 participants from 47 countries, including full COST Members, near neighbour countries (Jordan, Kosovo and Tunisia), international partner countries (Australia, Argentina, Burkina Faso, Canada, Cameroon, India and New Zealand), and one COST partner member (Israel). The network represented a broad range of expertise researchers, veterinarians, producer organisations, and international bodies collaborating. Since its launch the Action has implemented 16 short term scientific missions, 5 virtual mobility grants, 2 training schools and 10 webinars, and involved numerous members participating in the working groups and the management committee. This wide range of geographical representation and diverse roles, alongside collaborative activities like regular meetings, webinars, round tables, world cafes, short-term scientific missions, and virtual mobilities, ensured that collective expertise and evidence were systematically synthesised through expert consensus and thematic analysis of discussions. Building on the collective expertise and evidence gathered through this pan-European network, the initiative advanced strategic, species-tailored, and context-sensitive recommendations designed to embed biosecurity within routine farm management. By reframing biosecurity from a perceived regulatory burden into a recognised driver of productivity, resilience, and One Health sustainability, these recommendations provide a forward-looking roadmap for policymakers, veterinary professionals, and producers to improve the adoption of economically and behaviourally informed practices adoption across diverse livestock systems. The insights presented reflect a robust participatory methodology for identifying and addressing key challenges in biosecurity adoption.

2. Economic Barriers to Biosecurity Adoption

Even when livestock producers are well-informed about recommended biosecurity measures, economic realities frequently determine whether those measures are implemented. Most farmers are fundamentally business-oriented decision-makers (homo economicus), and their adoption behaviour is shaped by perceived cost–benefit considerations [36]. When biosecurity measures are seen as increasing production costs without delivering immediate, visible returns, reluctance to adopt them becomes the prevailing response [17]. Across livestock sectors, financial and cost-related constraints consistently emerge as one of the most significant barriers to biosecurity uptake. In a comprehensive scoping review of disease control practices in cattle farming, cost was identified as the most frequently cited obstacle to implementing biosecurity or herd health programmes [1]. Although the long-term economic benefits are substantial, the initial biosecurity investments required such as perimeter fencing or controlled-entry equipment, can be perceived as prohibitive, with some farms estimating a 9–10% reduction in annual profit, even though these expenses are far outweighed by losses incurred during an outbreak [37]. The salience of barriers, however, varies by sector, production system, supply-chain integration, and outbreak history. In some settings, time and labour constraints are even more influential than direct cost. Common improvements such as perimeter fencing, concrete disinfection pads, controlled-entry equipment (e.g., footbaths or showers), additional sanitation labour, and on-farm quarantine facilities impose not only financial but also operational burdens. For small-scale farmers operating on tight profit margins, the opportunity cost of diverting scarce resources to preventive measures with delayed or uncertain return is perceived as too high. Larger enterprises can experience recruitment and retention issues in the workforce.

Farmers' perceptions of cost may diverge substantially from actual costs. Out-of-pocket expenditures for biosecurity are immediate and tangible, whereas the benefits of avoiding disease outbreaks are invisible, uncertain, and strongly influenced by individual risk perception. This uncertainty may affect farmer's willingness to adopt preventive measures. Effective prevention results in "nothing happening", creating a psychological disconnect that makes the investment feel unrewarding. Moreover, an individual farmer is mainly focusing on impacts of disease on his/her farm only, and not necessarily taking into account externalities in other farms. This situation reflects a market failure in animal health: individual farmers underinvest because they do not fully account for the broader societal and industry-wide benefits of disease prevention. Farmers without personal experience of devastating disease incursions frequently tend to underestimate their exposure and undervalue preventive investments [17]. Conversely in high-density farming regions where pathogens are endemic, this underestimation often fosters fatalism; outbreaks are perceived as inevitable, making even modest investments appear futile [18]. Bridging this economic–behavioural gap is essential. Decision-support tools, epidemiological modelling, and context-specific risk analyses can demonstrate that even small per-animal investments can prevent disproportionately large losses. For instance, while biosecurity upgrades in pig farms require upfront expenditure, these costs are typically justified by the prevention of catastrophic mortality during ASF outbreak [38]. Presenting farmers with locally relevant evidence of potential economic losses recalibrates their cost–benefit calculations and motivates proactive uptake.

Economic barriers extend beyond direct expenditure to include labour and time constraints, which are often decisive in day-to-day implementation. Many biosecurity protocols, such as rigorous cleaning and disinfection routines, downtimes between herd or flock movements, along with systematic record-keeping, demand consistent effort and staff capacity. Smallholder and family-operated farms, already working with minimal labour, often cannot absorb the additional workload. Perceived as burdensome or excessively time-consuming, these measures may be selectively applied or eventually abandoned. Surveys of cattle producers confirm this trend: lack of time emerged as the second-most cited barrier (after lack of information) to adopting biosecurity, while "high cost" ranked lower [39–41]. Larger enterprises typically apply stricter biosecurity protocols than smallholder farmers, primarily because they possess greater financial and human resources to support labour-intensive measures [42,43]. Training and knowledge gaps remain a significant barrier to effective implementation. In one multi-country study, only approximately 11% of the poultry producers reported receiving prior biosecurity or extension training [44], and similar deficiencies have been observed in Ethiopian commercial poultry farms [45]. Furthermore, recent One Health modelling has demonstrated that biosecurity compliance improves both livestock and farmworker health, reinforcing the importance of structured training and sustained investment in preventive infrastructure [46]. Compliance fatigue, where adherence erodes over time, becomes a genuine risk when recommended measures are too onerous or poorly aligned with daily routines. Therefore, designing streamlined, cost-effective practices that fit smoothly into existing workflows is essential. Low-cost interventions, such as footbaths made from locally available materials or improvised barn partitions, offer meaningful risk reduction without significant expenditure, offering "easy wins" for resource-limited farmers.

At a broader economic and policy level, the alignment of incentives is pivotal in shaping biosecurity behaviour. Market structures and government policies that unintentionally reward risky behaviour or fail to reward prevention can reinforce underinvestment. In several countries, government compensation schemes reimburse farmers at fair market value for culled animals during outbreaks regardless of the farm's prior biosecurity performance [23,47–49]. While such indemnities are crucial for disaster relief, they can unintentionally generate risky behaviours: farmers may reason that if an outbreak occurs, they will be financially rescued, reducing the incentive to invest in prevention. Conversely, producers who do adopt rigorous biosecurity often see no tangible market reward; their products are sold at the same price as those from less secure farms. This lack of market differentiation suppresses the private return on biosecurity even as the public benefit of disease prevention remains substantial.

The evidence suggests a multidimensional set of constraints: costs are salient, but information and labour frictions can be equally or more influential in practice. Addressing multifarious economic barriers demands targeted strategies: coupling risk-based insurance premiums or conditional compensation schemes with preferential market access for producers with a good level of biosecurity; providing transparent, locally relevant cost–benefit data; and embedding low-cost, easy-to-integrate interventions into daily routines. Such measures can reframe biosecurity from a perceived financial burden into a strategic investment in resilience, productivity, and collective agricultural security. Without this shift, biosecurity will remain undervalued as a public good, leaving livestock systems vulnerable to preventable economic and epidemiological shocks. Selected low-cost "easy wins" and incentive mechanisms are mapped in Table 1, and complementary training modules that address cost perception and decision support are detailed in Table 2.

Table 1. Farm biosecurity adoption gaps and targeted recommendations for the targeted audience.

Identified Gap/Challenge	Recommendation (Future Perspective)	Target Audience
Farmers' limited knowledge or misperceptions of biosecurity	Provide context-specific, economically framed education through on-farm demonstrations, peer mentoring, and accessible materials linking actions to profit.	F, V, E
One-size-fits-all messaging is failing to change behaviour	Use co-created biosecurity plans and collaborative farm visits framed as supportive coaching rather than enforcement.	F, V, G, E
High perceived costs and unclear benefits of biosecurity	Deliver robust cost–benefit analyses, decision-support tools, and real farm case studies; introduce market rewards, conditional insurance, and targeted subsidies.	F, V, G, I, F/Ins
Labour and time constraints on small farms	Simplify protocols into routine-compatible "easy wins" and promote low-cost interventions using locally available materials.	F, V, E
Lack of standardised metrics for small/backyard farms	Created digital tools and developed tiered checklists for different scales/species to enable incremental monitoring.	F, V, G, E, R
Smallholders and backyard producers are largely unreachable	Integrate them into national surveillance and support programmes; provide free outreach, vaccination drives, and community-based agreements on movement controls.	F, V, G, E, I
Data and transparency gaps	Establish anonymised data-sharing frameworks and multi-stakeholder reporting platforms to improve surveillance and trust.	G, V, I, R
Stakeholder trust and alignment issues	Foster a collaborative biosecurity culture: include farmers in policy design, recognise exemplary farms publicly, and create regular multi-actor forums for problem-solving.	F, V, G, I, C

Legend: Stakeholder codes: Farmers (F) are the primary implementers of on-farm biosecurity measures, balancing costs against perceived benefits. Veterinarians (V) provide technical expertise, conduct risk assessments, and advise producers on cost-effective strategies. Government authorities and regulators (G) establish policies, subsidies, compensation schemes, and enforce biosecurity standards that shape economic incentives. Industry and producer associations (I) coordinate certification programmes, negotiate market incentives, and advocate for sector-wide compliance. Feed and input suppliers (S) influence disease risk through product quality and farm entry practices and can co-promote or co-finance preventive measures. Extension and advisory services (E) act as knowledge brokers, translating research into practical guidance through participatory training and on-farm support. Researchers and academics (R) generate economic evidence, behavioural insights, and decision-support tools to inform policy and practice. Financial institutions and insurers (F/Ins) offer credit, loans, and insurance products linked to biosecurity compliance, shaping farmers' cost–benefit calculations. Finally, Consumers and retailers (C) create market-driven incentives by demanding certified, traceable products and rewarding farms that demonstrate strong biosecurity practices.

Table 2. Potential training modules on the economic dimensions of farm biosecurity.

Stakeholder	Module Title	Key Learning Objectives	Format and Delivery	Bloom's Taxonomy Level and Cognitive Focus
Veterinary Practitioners	Economic risk assessment in livestock health	Quantify farm-level financial risks of disease incursions. Prioritise cost-effective preventive strategies using risk models.	Interactive workshops using real datasets; scenario simulations.	Understanding: recall and explain key economic and epidemiological parameters and principles. Applying: use quantitative tools to estimate financial impacts. Analysing: interpret patterns and prioritise cost-effective interventions.
	Cost–benefit analysis of biosecurity investments	Evaluate returns on infrastructure (e.g., fencing, hygiene stations) and routine labour. Advise clients on capital vs. recurrent costs.	Spreadsheet exercises; group case discussions.	Understanding: describe core economic concepts (costs, returns). Applying: perform practical cost–benefit calculations. Evaluating: justify investment decisions based on evidence.

Table 2. *Cont.*

Stakeholder	Module Title	Key Learning Objectives	Format and Delivery	Bloom's Taxonomy Level and Cognitive Focus
Veterinary Practitioners	Insurance, compensation, and moral hazard	Understand compensation policies and insurance products. Explain how conditional indemnities influence farmers' decisions. Define "moral hazard" in the veterinary context (when coverage/payment designs blunt prevention incentives for vets or clients and compensation provider cannot observe this) Identify policy levers that restore prevention incentives (e.g., deductibles/co-pays, risk-based premiums, conditional compensation tied to documented biosecurity). Specify practical compliance evidence (checklists, logs, photos) and oversight (random audits/peer review of attestations).	Short courses with policy briefs; expert Questions and answers panels; case exercises and template checklists	Remembering: recall definitions of indemnity and moral hazard. Understanding: explain relationships between insurance design and behaviour. Evaluating: assess how financial tools influence preventive behaviour.
	Market incentives and certification	Interpret how certification programmes (e.g., secure pork supply) and preferential sourcing generate revenue advantages. Guide producers through compliance steps.	Webinars with industry speakers; compliance checklists.	Understanding: describe the market rationale behind certification. Applying: support producers in meeting certification criteria.
	Communicating economic evidence	Translate financial analyses into persuasive, farmer-friendly messages. Integrate profitability narratives into extension work.	Role-play training; peer review of advisory scripts.	Applying: use communication strategies effectively in real contexts. Creating: design customised communication materials and narratives.
Farmers	Profitability through prevention	Link outbreak prevention to stable income and market access. Calculate avoided losses versus preventive investments and enable asset valuation.	Farmer field schools; participatory budgeting sessions.	Understanding: explain the basic economic concepts and how and when prevention sustains income and trade. Applying: calculate economic trade-offs using simple tools and how economic value of assets is generated.
	Low-cost, high-impact measures	Identify affordable, high-return interventions (e.g., do it yourself footbaths, barn partitions). Compare cost of inaction vs. small investments.	On-farm demos; peer discussion circles.	Remembering: recall feasible low-cost biosecurity options. Applying: implement and evaluate those practices on-farm.
	Reducing losses and risk	Quantify production losses and cash-flow risk for priority hazards using farm records and simple expected-loss estimates. Prioritise the top three preventive measures with an avoided-loss calculator and outline a lean continuity plan to sustain operations and market access during disruptions.	Small-group clinic with real farm numbers; worksheet budgeting (paper or mobile); facilitator-led discussion and quick on-farm simulations.	Understanding: interpret production and financial records. Applying: use simple models to estimate risk. Evaluating: identify which measures best sustain business continuity.
	Accessing subsidies, grants, and insurance	Navigate finance and financial support options. Plan incremental investments using external funding mechanisms.	Community workshops; step-by-step guidance handouts.	Remembering: list available support programmes. Applying: develop investment plans using external funding.

Table 2. *Cont.*

Stakeholder	Module Title	Key Learning Objectives	Format and Delivery	Bloom's Taxonomy Level and Cognitive Focus
Farmers	Collective economic action for community biosecurity	Recognise shared financial risk within producer networks. Form cooperatives or pooled funds for shared infrastructure.	Community meetings; participatory mapping of economic risk.	Understanding: describe shared risk concepts and collective benefit. Creating: design cooperative or pooled funding mechanisms.
	Market access and consumer trust	Understand how strong biosecurity protects trade continuity and earns premiums. Learn from real farms that maintained sales during crises.	Peer-led storytelling; visual case study booklets.	Understanding: explain the relationship between biosecurity and consumer trust. Analysing: compare successful and unsuccessful market-access cases.

Legend: This table presents the proposed training modules on the economic dimensions of farm biosecurity for key stakeholder groups. Columns outline the intended audience, the module title, specific learning objectives, delivery format, and their alignment with Bloom's Taxonomy of Educational Objectives. Bloom's Taxonomy levels are interpreted as follows: Remembering: recalling facts and basic concepts; Understanding: explaining ideas or concepts; Applying: using information in practical contexts; Analysing: drawing connections and identifying patterns; Evaluating: justifying decisions or actions; Creating: designing new solutions or frameworks.

3. Stakeholder Knowledge Gaps and Perceptions

Successful biosecurity implementation is ultimately a challenge for human behaviour. It requires farmers and associated stakeholders along the value chain not only to understand recommended measures but also to believe in their necessity, feasibility, and cost-effectiveness. Across the literature, persistent gaps in knowledge and perception continue to hinder consistent application of biosecurity protocols. Some studies indicate that farmers possess a basic grasp of key principles sufficient to follow standard practices [20]. However, other evidence reveals serious deficiencies in understanding of disease transmission and prevention, particularly among smallholders, remote producers, and those operating in sectors with weaker extension services. These discrepancies arise from diverse production systems, geographic and socio-economic contexts, and the uneven performance of advisory networks. As result, biosecurity literacy remains fragmented; well-informed producers coexist with those who lack even fundamental awareness of disease risks and protective measures. Capacity building, structured training, and access to validated, locally relevant biosecurity information are therefore crucial.

Equally important as the content of information is the way it is conveyed. Traditional, top–down communication strategies such as generalised advice or prescriptive inspections, often fail to change behaviour, as they overlook farm-specific constraints and are sometimes perceived as detached from real-world operational contexts. When recommendations are delivered in an enforcement-oriented tone or in misaligned with local realities, producers may respond with resistance or distrust. For instance, a multi-country European focus group study found that farmers reacted negatively when officials' farm visits resembled inspections rather than supportive engagement [20]. Evidence from small-scale Alpine dairy farms highlight veterinarians' pivotal role in strengthening biosecurity awareness and supporting adoption, especially in resources-limited settings [50]. These findings underscore that knowledge transfer must be participatory, trust-based, and context sensitive. Collaborative approaches, such as farmer-field schools, peer-to-peer workshops, and on-farm demonstrations enable producers to co-design practical solutions, exchange experiential knowledge and internalise biosecurity as a shared responsibility rather than an externally imposed obligation. Veterinarians, researchers and advisors are encouraged to shift from the provision of top–down expertise to also adopt a facilitation role in co-creation and integration of local knowledge into evidence-based frameworks.

Improved access to reliable information demonstrably increases the adoption of biosecurity practices. A latent class analysis of Kenyan smallholder poultry producers revealed that farmers with any biosecurity training or extension contact were 25% more likely to belong to the high-adoption cluster, and these farms experienced significantly lower flock mortality [16]. Conversely, surveys of cattle producers repeatedly rank poor information and inconsistent advice above financial cost as barriers to biosecurity adoption [39–41]. These data indicate that many farmers are willing to protect their animals but lack clear, trusted guidance. Strengthening extension services, ensuring message consistency, and framing advice in terms of concrete economic benefits are therefore foundational strategies for enhancing biosecurity compliance. The training modules presented in Table 2 are designed as optional, standalone components, allowing for flexible and tailored implementation based on the specific stakeholder needs and contexts. They address crucial economic dimensions of farm biosecurity while simultaneously closing knowledge and communication gaps. To strengthen their pedagogical clarity and ensure structured learning progression the learning objectives for these modules were developed following Blooms Taxonomy of Educational Objectives [51].

Trust and perceptions of fairness further shape biosecurity behaviour. Qualitative research in intensive poultry regions reveals that farmers may accept their primary role in disease prevention but feel scapegoated when authorities appear to shift full responsibility onto them without offering adequate support [17]. This erosion of trust can depress investment in biosecurity, particularly when regulations are perceived as impractical or disconnected from on-farm realities. Recasting regulatory visits as collaborative mentoring sessions, joint biosecurity assessments conducted by farmers and veterinarians can counteract these tensions, reinforcing the idea that authorities and producers share the responsibility of disease prevention. Cultivating a “biosecurity culture” grounded in shared responsibility, transparent communication, and visible support is therefore essential for long-term behavioural change and sustainable adoption.

4. Comparative Regional Frameworks and Governance Contexts

Regional differences in governance, market structure, and disease ecology greatly influence the design and effectiveness of biosecurity measures. While the core principles of prevention and readiness are generally shared, the ways they are put into practice vary considerably across regions, reflecting differences in legal systems, disease histories, production methods, and economic strength. In Europe, a comprehensive legal framework rooted in EU Animal Health Law sets mandatory biosecurity standards for member states. This structure offers clear legal guidance for prevention, surveillance, and coordinated response; however, implementation is highly uneven due to national differences in veterinary infrastructure, market organisation, and farm setup [52,53]. Gaps in compliance remain in smallholder-dominated areas, such as in repeated African swine fever outbreaks in Romania and Poland [25,54]. Even in highly industrialised regions, governance issues can arise, as seen during the 2025 foot and mouth disease outbreak in Germany, exposing weaknesses in farm-level vigilance and emergency preparedness. North America relies more on voluntary, industry-led programmes like Secure Pork Supply and Secure Beef Supply, which provide preferential market access during outbreaks to encourage preparedness and enable producers to stay operational if they follow biosecurity protocols [24]. Although these programmes are well-structured, their adoption is uneven, especially in regions that have been free of major exotic diseases for a long time, where complacency and a perceived low risk can weaken vigilance [18]. The reliance on voluntary participation instead of strict regulations contributes to variability in readiness, with larger, export-focused producers generally performing better than smaller domestic suppliers. Asia shows significant contrasts. Highly industrialised sectors in China and Japan operate alongside extensive smallholder systems across Southeast Asia, where awareness, enforcement ability, and resource availability lag behind rapid production growth [55,56]. The African swine fever crisis in China exposed the limited resilience of small- and mid-sized farms, which struggled to recover more than large-scale operations. This difference accelerated structural changes in the sector, leading to larger, more industrialised, and biosecure farms [57]. In many developing regions of Africa and Latin America, and in countries and regions in which challenges in recruitment and retention are experienced, inadequate veterinary infrastructure, weak enforcement, and chronic underinvestment in animal health worsen low biosecurity adoption. These gaps remain even as global initiatives like FAO's Progressive Management Pathway for Biosecurity [58] and WOAH standards [59] attempt to offer step-by-step, adaptable frameworks suited to local needs. A recent review by Militzer et al. (2023) notes that most documented biosecurity programmes are concentrated in high-income countries, highlighting a critical gap in global equity and emphasising the need to build institutional capacity in resource-limited settings [2]. Closing these gaps requires more than just technology transfer; it also needs context-specific adaptation, financial support, and ongoing institutional engagement.

5. Species-Specific Biosecurity Considerations Across Livestock Systems

Current debates on farm biosecurity often emphasise governance and regulatory instruments but frequently underestimate how profoundly real-world outcomes are shared across species-specific disease dynamics and production-system structures. Policy ambitions are rarely neutral; they are designed around the production systems that are most visible, most regulated, and best connected to formal markets, typically intensive poultry and pig sectors. These sectors, because of their economic weight and export orientation, often set the regulatory benchmark, receive targeted investment, and benefit from well-defined compensation schemes when crises occur [1,16,31]. However, this framing overlooks the epidemiological and economic weight of smallholder systems, which are structurally less integrated into formal control mechanisms but are repeatedly implicated in pathogen persistence, silent circulation, and delayed detection. African swine fever in smallholder pig systems in Eastern Europe [60], Newcastle disease in village poultry systems in South Asia [61], and peste des petits ruminants in marginal pastoral communities [62] all illustrate how policy blind spots at the periphery can undermine national and regional biosecurity strategies. These vulnerabilities are further reinforced by the exclusion of smallholder farmers from financial instruments such as credit and insurance. Livestock insurance schemes often fail to reach smaller farms due to high transaction costs, eligibility thresholds, and product design mismatches [63,64]. Even where compensation exists, it is frequently structured in favour of larger, commercial producers that meet formal registration and reporting requirements, leaving smallholders uncovered or under-compensated [23]. This asymmetry effectively channels public risk-mitigation resources to those least likely to generate persistent disease risk at scale, while marginalising those most vulnerable to shocks. A critical species-by-system perspective therefore is not merely descriptive but diagnostic; it identifies areas in which epidemiological and economic risks are concentrated but least managed, and where targeted, equitable investment in biosecurity would yield the greatest collective return. Table 3 outlines these contrasts systematically, linking economic drivers, disease risks, adoption barriers, and evidence-based interventions across major terrestrial livestock and aquaculture systems.

Table 3. Comparative economic drivers, disease risks, adoption barriers and recommended interventions for biosecurity across major terrestrial livestock and aquaculture systems.

Species	Production System	Key Economic Drivers	Key Disease Risks	Adoption Barriers (Incl. Finance/Market Access)	Recommended Interventions	References
Cattle (beef and dairy)	Intensive	Market security and productivity: maintaining access to lucrative markets by preventing trade-disruption outbreaks; improved welfare/health boosts productivity and profitability. Risk-mitigation economics: herd-health/biosecurity programmes can yield net benefits when implemented well.	Transboundary and endemic: FMD trade shocks; endemic BVD, brucellosis, TB; emerging risks (e.g., lumpy skin disease). Historic crises (FMD/BSE) illustrate huge cull/export effects.	Costs and labour: upfront (fencing, facilities) and ongoing labour/time burdens. Knowledge/trust gaps: inconsistent advice; some producers unconvinced of costs and benefits without lived outbreak experience.	Incentives and education: tailored, trustworthy vet-led training; risk-based herd plans; conditional subsidies/insurance/compensation linked to verifiable biosecurity; simple checklists and farmer-led monitoring to sustain compliance.	Buchan et al., 2023 [1] Brennan & Christley 2013 [39] Renault et al., 2021 [40]
	Smallholder/backyard	Household protection: reduce avoidable morbidity/mortality; incremental access to formal buyers.	Same as intensive; higher contact mixing through informal trade/movements.	Finance/indemnity exclusion; thin margins; information asymmetry; weak buyer linkages.	Micro-grants/micro-insurance; mobile extension; cooperative marketing rewarding compliance; compensation contingent on basic biosecurity.	OECD (2017) [23]
Swine (pigs)	Intensive	Catastrophic-loss avoidance (ASF/CSF/PRRS); export access; supply-contract continuity.	ASF, CSF, PRRS; wildlife interface where relevant.	Cost/logistics of all-in/all-out and strict access control; compliance fatigue.	Fencing; controlled entry (visitor/vehicle logs and disinfection); all-in/all-out; company-supported upgrades; surge surveillance.	EFSA AHAW (2021) [60]
	Smallholder/backyard	Livelihood preservation; avert whole-herd wipe-outs; keep local sales running.	ASF persistence in back-yard/outdoor units with weak biosecurity; proximity to infected premises.	Finance/compensation gaps; swill feeding as a low-cost practice; weak enforcement; fatalism.	Phase-out or heat-treat swill with affordable alternatives; simple, auditable checklists; rapid reporting with fair, conditional compensation; local feed alternatives; community messaging on ASF consequences.	Boklund et al., 2020 [65]; Penrith 2020 [66]
Poultry (broilers and layers)	Intensive	Avoid mass culls and trade bans; retailer standards; productivity gains from healthier birds.	HPAI (H5Nx), ND, Salmonella.	Protocol fatigue; uneven enforcement across firms/regions.	Company QA and audits; downtime and cleaning; contingency planning; vaccination per risk.	Ukita et al., 2025 [31]
	Smallholder/backyard	Mortality reduction and income stability; potential on-ramps to better outlets.	HPAI/ND in backyard settings; mixed flocks; wild-bird contact.	Low training coverage; limited resources; no premium for safer product.	Community ND vaccination; simple entry control (handwashing, footbaths), isolation of new birds; targeted extension; routes into local certification to reward prevention.	Otieno et al., 2023 [6]; Samanta et al., 2015 [55]; Napit et al., 2023 [61].

Table 3. *Cont.*

Species	Production System	Key Economic Drivers	Key Disease Risks	Adoption Barriers (Incl. Finance/ Market Access)	Recommended Interventions	References
Small ruminants (sheep and goats)	Intensive	Maintain output quality; disease-free status.	PPR; pox; brucellosis.	Distributed herds; movement patterns.	Scheduled vaccination; coordinated movements; record-keeping.	OIE-FAO. 9 (2015) [67]
	Smallholder/ pastoral	Safeguard "living bank" assets; avert high-mortality shocks; protect nutrition.	PPR with very high morbidity/mortality in naïve flocks.	Sparse veterinary reach; cash/credit limits; communal grazing; mobility.	Free mass vaccination with para-vet networks; community quarantine; micro-finance for pens/water points; targeted awareness.	Rahman et al., 2021 [62]; Govindaraj et al., 2023 [68]; FAO/WOAH 2025 [69].
Aquaculture	Intensive	Protect dense, high-value biomass; meet export certification.	ISA (salmon), vibriosis; rapid water-borne spread.	Water connectivity; input quality risks.	Certified seed; water treatment; area-based management; synchronised fallowing; early testing and removal.	World Bank 2014 [70]; Godoy et al., 2013 [71].
	Smallholder	Avoid pond wipe-outs; steady cash flow in village economies.	Same as intensive; amplified by shared water and fry trade.	Finance/coordination gaps; weak extension; neighbours' non-compliance undermines private returns.	Cluster/zone biosecurity; hatchery accreditation; emergency funds/insurance with simple compliance proofs; adopt FAO/WOAH PMP/AB (stepwise, inclusive).	FAO (2023) [72].

Legend: ASF, African swine fever; BSE, bovine spongiform encephalopathy; BVD, bovine viral diarrhoea; CSF, classical swine fever; FMD, foot-and-mouth disease; HPAI, highly pathogenic avian influenza; ISA, infectious salmon anaemia; ND, Newcastle disease; FAO, Food and Agriculture Organization of the United Nations; WOAH, World Organization for Animal Health PMP/AB, Progressive Management Pathway for Aquaculture Biosecurity; PPR, peste des petits ruminants; PRRS, porcine reproductive and respiratory syndrome; QA, quality assurance; TB, tuberculosis; PMB/AB, Progressive Management Pathway for Aquaculture Biosecurity. In addition to species and system-level variability outlined in Section 5, the uneven adoption of biosecurity measures is strongly shaped by the interaction of economic, behavioural, and institutional drivers. These three domains act simultaneously, and their alignment or misalignment largely determines whether biosecurity is implemented consistently or remains fragmented, particularly in resource-limited smallholder settings. Figure 1 provides a conceptual framework that maps these relationships.

The effectiveness of farm biosecurity is not determined solely by technical guidance, but by how economic incentives influence behavioural dynamics, and how institutional capacity intersects with specific production systems. In practice, this alignment is uneven; intensive farms are embedded in formal market and regulatory structures, while smallholders operate at the periphery, facing weaker economic signals, fewer institutional supports, and limited channels of trusted information. This structural gap has tangible epidemiological consequences; smallholder and backyard systems are disproportionately implicated in the persistence of endemic and transboundary diseases, yet they remain the least integrated into incentive and governance architectures that drive preventive action [16,73,74].

Some critical aspects are depicted below.

Economic incentives: Economic levers such as subsidies, compensation schemes and insurance can play a decisive role in determining whether preventive measures are adopted. For smallholders however, high relative costs, limited liquidity and dependence on informal markets can reduce the economic rationale for investment [16]. Many smallholders are excluded from compensation and insurance schemes through eligibility thresholds, administrative complexity or lack of formal registration [22,73]. This creates structural asymmetries that shape uptake long before behavioural or regulatory factors come into play.

Cost and subsidies: Biosecurity investment decisions hinge on when and how costs and benefits are realised. For smallholders, upfront expenditures combined with uncertain and delayed benefits often suppress investment, even when interventions are demonstrably cost-effective at sector level. Targeted subsidies and cost-sharing schemes can ease these immediate financial pressures, enabling farmers to adopt preventive measures earlier. Equally, compensation systems that reward verified biosecurity compliance shift incentives from post-crisis recovery to ex ante prevention. In contrast, unconditional indemnity schemes weaken prevention incentives by embedding risk without encouraging mitigation. Well-designed instruments such as conditional compensation, micro-insurance, and risk-based subsidies can make biosecurity a rational economic choice rather than an unaffordable burden for small producers.

Insurance and risk-sharing: Affordable insurance products that reward compliance (e.g., reduced premiums or payout guarantees tied to verification) can convert catastrophic outbreak losses into manageable costs and provide another powerful incentive for farmers to comply with biosecurity measures, sending a market signal valuing prevention. When farmers feel that adopting biosecurity will meaningfully reduce their risk of ruin (or earn them insurance benefits), they are more inclined to act. In summary, economic drivers revolve around reducing the private costs of biosecurity and increasing its private benefits, thereby shifting it from a perceived expense to a sound investment.

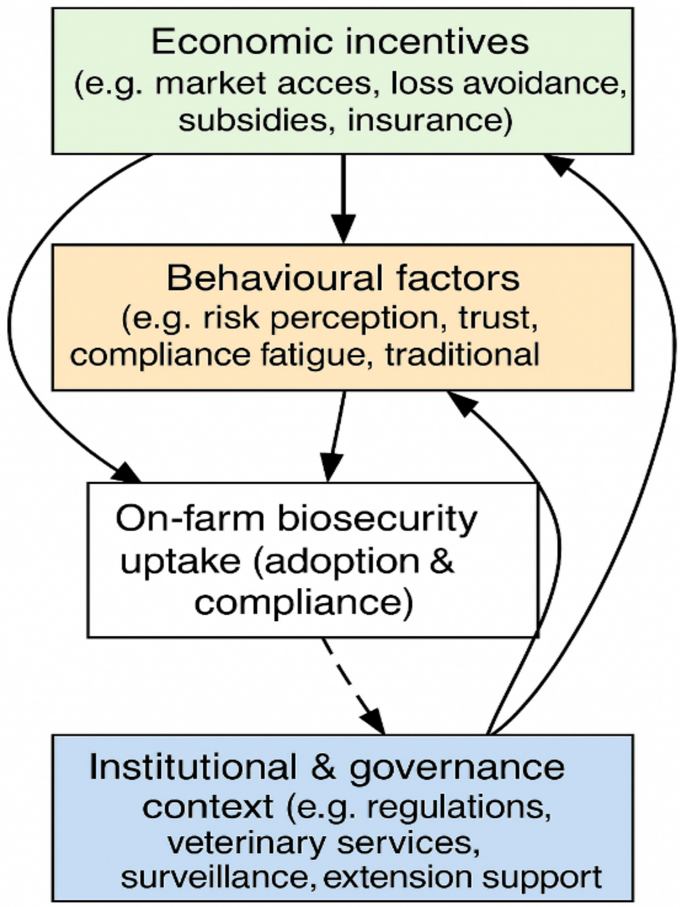

Figure 1. Conceptual diagram illustrating how economic incentives, behavioural attitudes and institutional/governance factors interact to shape on-farm biosecurity adoption (uptake) in livestock systems. Arrows indicate hypothesised causal pathways (solid line) and feedback loops (dashed lines) linking these elements to the outcome (farmer adoption/uptake/compliance with biosecurity measures).

5.1. Behavioural (Farmer Attitudinal) Factors

Risk perception: Farmers' subjective perception of disease risk and severity heavily influence biosecurity behaviour [17,73]. If a farmer underestimates the likelihood or severity of impact of an outbreak on their farm, they may see little need for preventative biosecurity. This is common when the farm or community has not recently experienced a serious disease event; the absence of visible outbreaks can breed complacency and optimism bias. By contrast, personally witnessing or learning about devastating losses (e.g., a neighbour's herd being culled) can elevate risk perception and thereby motivate proactive measures. Effective communication of disease threats and potential losses (through extension messaging or peer examples) can therefore heighten risk awareness and encourage adoption.

Trust and information sources: Trust in those promoting biosecurity (veterinarians, government agencies, industry bodies) is pivotal [73]. Farmers are more likely to follow biosecurity advice if they trust the expertise and intentions of the source. Conversely, distrust in authorities or past experiences of inconsistent advice can reduce compliance [74]. Peer influence and social norms also play a role; if biosecurity is seen as a normal part of good farming practice within the community (possibly championed by respected farmers), others are more inclined to emulate it. Building trust through participatory approaches, e.g., veterinarians working collaboratively with farmers, or farmer-led biosecurity groups, have been shown to improve uptake compared to top–down mandates.

Compliance fatigue: Biosecurity often requires repetitive, daily actions (cleaning, disinfection, record-keeping) and strict protocols for visitors, equipment, etc. Over time, farmers and farm workers can experience compliance fatigue and waning diligence. If measures are overly onerous, time-consuming, or appear to conflict with practical farming rhythms, adherence tends to erode after initial enthusiasm. This highlights the need for simple, streamlined practices that integrate smoothly into daily work. Introducing small, "easy win" measures (e.g., low-cost footbaths, basic fencing) and an incremental approach to improvement can improve acceptability, help to prevent burnout, and establish enduring biosecurity habits. Regular feedback (for instance, herd health improvements attributable to biosecurity) may also reinvigorate commitment.

Cultural and traditional practices: Long-standing farming traditions or beliefs can either support or hinder biosecurity [75]. Farmers may also hold beliefs about disease (fate, luck, or herbal remedies) that compete with biosecurity recommendations. Tailoring biosecurity messages to respect local knowledge, and which align with farmers' values and priorities, will improve acceptance and encourage uptake. Personal or indirect experience can shift attitudes, for example, more experienced farmers who have lived through outbreaks often become strong advocates of preventive practices, whereas newcomers or those never hit by disease might be more sceptical until they gain awareness [73]. Overall, in order to address behavioural factors, interventions which incorporate an understanding of the farmer's mind-set, their fears, motivators, habits, and social milieu, should be designed [76].

5.2. Institutional and Governance Context

Regulatory framework: The presence (and enforcement) of biosecurity regulations can significantly influence on-farm practices. Strong national or regional biosecurity mandates for example, requiring disinfection stations or movement controls set a baseline that farmers must follow [17]. Clear and well-communicated regulations can elevate biosecurity standards, especially if coupled with oversight (inspections, audits) and support. However, if rules are impractical or weakly enforced, compliance may be low [17]. Importantly, policy consistency and fairness matter for farmer buy-in; farmers are more willing to invest when they perceive that everyone is held to the same standard and that policies make practical sense for their operations.

Veterinary infrastructure and surveillance: A robust veterinary and animal health infrastructure enables better biosecurity uptake. Veterinary services provide the technical advice, disease diagnostics, and outbreak response that are essential for farmers to manage risks [73]. For instance, accessible vet outreach and regular farm visits can reinforce recommended practices and tailoring to farm conditions. Effective disease surveillance and reporting systems (often government-run) also encourage farmers to cooperate, as early detection and transparent reporting reduce uncertainty. When farmers see that reporting disease or investing in biosecurity leads to swift support (rather than solely punitive measures), their trust in the system grows. In contrast, gaps in veterinary coverage or slow response to outbreaks undermine farmers' confidence and can reduce motivation for preventive measures.

Extension and education services: Agricultural extension programmes and training workshops play a key role in translating biosecurity guidelines into on-farm action. Interactive training, such as participatory exercises, on-farm demonstrations, or peer learning sessions, has proven more effective than a one-way flow of information. For example, farmers who received hands-on biosecurity training and collaborative planning support were found to have significantly higher adoption rates and lower mortality in their flocks. Well-resourced extension services that offer tailored advice, biosecurity planning tools, and continuous follow-up can gradually change practices and develop norms. The institutional support system is then allowed to provide the knowledge and capacity that subsequently enables farmers to implement the desired behaviours.

Industry standards and collective action: In addition to government, private sector and producer organisations also contribute to the governance context. Industry-led standards (e.g., quality assurance schemes, certification programmes) can normalise biosecurity, making it part of business-as-usual. For instance, poultry or pig integrator companies may require contract growers to follow strict biosecurity protocols, with compliance monitored and rewarded, thereby raising the baseline level of biosecurity across the supply chain. Farmer cooperatives or associations can also foster collective action if neighbours and community members coordinate on disease prevention (sharing information, synchronising vaccinations or quarantine measures), strengthening overall biosecurity and creating social pressure to comply. In summary, the broader institutional environment spanning laws, services, and stakeholder networks creates the enabling conditions and can remove barriers for farmers to adopt and maintain biosecurity measures.

5.3. Interactions and Feedback Loops

No single factor acts alone: The dynamic interplay between economic, behavioural, and institutional elements ultimately shapes biosecurity uptake. The conceptual model (Figure 1) therefore highlights several interaction pathways.

Institutional–economic interactions: Governance decisions often determine the economic incentives facing farmers. For example, a government's compensation policy or subsidy programme can either encourage diligent biosecurity or inadvertently discourage it. Strong institutional support (like mandatory standards or certification schemes) can create market differentiation, allowing products from biosecure farms to earn premium prices. Thus, policy design can align private incentives with the public good of disease prevention.

Institutional–behavioural interactions: The actions of institutions influence farmer attitudes and vice versa. Trust in institutions is built when authorities genuinely engage farmers in a transparent and helpful manner (rather than being tokenistic or just imposing penalties). If extension officers and vets work closely with farmers (i.e., have an institutional presence on the ground), this will influence farmers' perceived self-efficacy and knowledge, leading to greater uptake. On the flip side, widespread non-compliance or grassroots pushback can signal to policymakers that current strategies are not working, prompting adjustments in regulations or outreach approaches. In this way, farmer responses feed back into institutional strategy.

Economic–behavioural interactions: A farmer's economic situation and opportunities influence their mind-set toward biosecurity. Prosperous farmers with high-value market contracts may be more risk-averse and therefore more willing to invest in safeguards, whereas those under economic strain might prioritise short-term income over long-term benefits of improved biosecurity. Additionally, if farmers know that good biosecurity will be rewarded (through insurance, market access, etc.), it can shift their attitudes from seeing it as a burden to viewing it as beneficial. Conversely, if risky behaviour (like not reporting disease) sometimes yields economic advantage (avoiding culling without getting caught), negative attitudes can be reinforced.

Outcome feedback: Importantly, the disease situation outcome of biosecurity adoption feeds back into the system. However, successful biosecurity (few outbreaks) can lead to a paradox: farmers might become complacent (nothing happened, so perhaps the risk was overstated) and biosecurity compliance can reduce. In contrast, disease outbreaks or close calls often serve as wake-up calls that heighten risk perception and prompt collective action. Major outbreaks can also trigger new policies or funding for biosecurity from governments (a reactive boost to institutional support). Over time, these feedback loops mean the system can evolve, periods of laxity may be broken by crises that re-emphasise biosecurity, while long disease-free periods test the system's ability to maintain vigilance.

6. Strategic Recommendations and Future Perspectives: Embedding Economic Incentives and Stakeholder Alignment into Farm Biosecurity

Strengthening farm biosecurity requires a shift from short-term, fragmented actions to long-term strategies that align economic incentives with effective governance and farmer engagement. Even when farmers understand the principles of disease prevention, adoption remains low if biosecurity measures are perceived as costly, are poorly incentivised, or are disconnected from everyday farm realities. Addressing these challenges demands a strategic response that integrates technical feasibility with financial viability and trust mechanisms. A critical starting point is the systematic integration of economic considerations into biosecurity planning. Cost–benefit analyses across multiple livestock sectors have repeatedly shown that preventive investments, particularly in routine, low-cost measures yield substantial economic returns at both farm and national levels. However, these gains are not always visible to farmers, especially smallholders, due to time inconsistency between investments and benefits, lack of clear communication, and structural exclusion from financial mechanisms. Targeted subsidies, conditional compensation schemes, and risk-based insurance products can reduce this gap by making prevention economically viable and rewarding early action.

Second, policy design must acknowledge system heterogeneity. Species and production systems differ significantly in disease risk profiles, biosecurity capacities, and incentive structures. Tailored approaches rather than uniform regulations are more likely to achieve durable uptake. For instance, intensive operations may respond to formal certification and export incentives, whereas smallholder systems often require more accessible financial instruments, low-cost measures, and cooperative support mechanisms to engage meaningfully in prevention.

Finally, governance must shift from reactive containment to proactive prevention. Investments in surveillance, veterinary infrastructure, and risk communication provide enabling conditions for sustained biosecurity. Regulatory frameworks should align public and private incentives, reinforce accountability, and avoid creating perverse effects such as moral hazard in compensation schemes. Strengthening extension services and participatory training can ensure that farmers at all scales, not only those in intensive systems can adopt effective measures that fit their operational context.

7. Conclusions

Farm biosecurity is not simply a technical challenge but a cornerstone of resilient and sustainable livestock systems. The evidence presented here demonstrates that uptake is shaped by the interaction between economic incentives, contextual and behavioural dynamics, and institutional capacity, rather than knowledge or technology alone. Table 3 and Figure 1 highlight how these factors converge differently across production systems, exposing critical structural vulnerabilities particularly in smallholder and backyard settings where disease risks are high, but resources and incentives remain limited.

Closing these gaps demands strategic, system-level alignment between public and private actors, with a deliberate focus on ensuring that smallholder farmers are not excluded from financial, regulatory, or advisory frameworks. Policymakers must design enabling and inclusive incentive structures including targeted subsidies, conditional compensation, and risk-based insurance that make preventive action economically viable for all farm types. Veterinary professionals are pivotal in translating policy into practice, ensuring that knowledge and support reach underserved rural areas. Industry and producer organisations can embed biosecurity requirements directly into value chains, transforming them into practical market incentives. Farmers remain the principal actors whose actions determine the success or failure of disease prevention on the ground, while researchers provide the evidence and tools to guide adaptive, context-sensitive interventions.

The strategic recommendations outlined in Sections 4–6, operationalised through Tables 1 and 2, show how targeted actions can reduce adoption barriers and enhance collective resilience. By aligning incentives with governance and trust, biosecurity can be transformed from a perceived financial burden into a shared societal investment. This shift is particularly vital for integrating smallholders into national and regional biosecurity strategies, reducing the silent reservoirs of infection that often undermine control programmes.

Strengthening this alignment is fundamental for building robust animal health systems, protecting livelihoods, sustaining market access, and reinforcing One Health security across scales. In an era of increasing transboundary threats, inclusive, economically sound, and behaviourally informed biosecurity offers one of the most effective pathways to safeguarding both agricultural systems and public health.

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