Panta Rhei
Research Program

Research Briefings · Public-Good Impact Dossiers

One Health · **Food, Life & Health Systems**

Tau for Food Safety, Livestock/Wildlife Interface, and Community Exposure Intelligence

Conditional public-good pathway for Food Safety, Livestock/Wildlife Interface, and Community Exposure Intelligence

Public-Good Impact Dossier

Conditional impact analysis · Publication-ready PDF · not deployment-ready

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Conditional scenario map. No validation, product, deployment, or policy claim.

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This briefing is a conditional public-good impact dossier released as a publication-ready PDF artifact on 2026-05-02. Publication-ready means the dossier is downloadable, internally consistent, and claim-safe. It does not validate the τ-framework, does not claim deployment readiness, and does not assert that the described domain system already exists. It maps a plausible impact pathway if the relevant upstream Results, Corpus constructions, and translation assumptions survive expert review and domain benchmarking.

What this dossier claims

- maps a conditional public-good impact pathway
- identifies upstream framework dependencies that would have to survive review
- states translation assumptions, benchmark needs, and governance guardrails

What this dossier does not claim

- does not validate the Tau framework
- does not claim that a domain system or product already exists
- does not claim deployment readiness, policy adoption, or certified impact
- does not replace independent domain review, empirical benchmarking, or governance assessment

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Contents

1 Executive Summary

Unsafe food causes 600 million illnesses and 420,000 deaths every year. One hundred and twenty-five thousand of those deaths occur among children under five. Low- and middle-income countries lose approximately USD 110 billion annually in productivity and medical costs from foodborne disease alone. These are not projections or worst-case estimates — they are the current WHO baseline, acknowledged by every major food-safety authority on the planet [1][2][3].

Behind that burden lies a structural problem that current systems cannot fully address: the human food system is deeply entangled with animal systems, wildlife corridors, ecosystems, and climate dynamics. Sixty percent of emerging infectious diseases reported globally originate in animals [4]. More than 75% of the new human pathogens detected over the past three decades are zoonotic [4]. FAO states that livestock supports the livelihoods of at least 1.3 billion people worldwide and provides approximately 34% of global food protein supply [5]. WOAH issued dedicated guidance in January 2026 on reducing disease transmission risk at the wildlife-livestock interface, explicitly citing HPAI, African swine fever (ASF), and foot-and-mouth disease (FMD) as globally disruptive threats [6][7].

This is not a domain where the institutions are asleep. WHO and FAO jointly maintain INFOSAN, spanning 189 countries, for rapid food-safety event exchange [10]. FAO runs GLEWS+ with WOAH and WHO for global animal-disease early warning [8][9]. WOAH maintains WAHIS as the global reference for official disease data [12]. The EU operates RASFF for food and feed alerts across 30+ countries. The US runs CDC PulseNet for genomic foodborne illness tracking. Yet despite all of this infrastructure, the field remains fundamentally reactive: contamination is detected after cases appear, interface risk is characterized after spillover events, and community advisories are issued after outbreaks have already seeded.

This companion dossier asks a focused question: if the τ (tau) framework provides a physically and biologically faithful, bounded-error, coarse-grainable discrete twin of food contamination pathways, livestock-wildlife interfaces, market and slaughter dynamics, household and community exposure, and cross-sector intervention effects — what public good could that unlock?

The short answer is: very large public-good value, with unusually strong fit to current One Health priorities, current institutional gaps, and humanitarian urgency.

Three hazard types illustrate the opportunity concretely. Aflatoxin contamination, driven by drought and temperature stress on maize and groundnuts, causes 317-death Kenya-scale disasters and USD 670 million annually in Sub-Saharan Africa alone — and the climate conditions enabling Aspergillus growth are detectable with current numerical weather prediction 4-8 weeks ahead, a window a τ-grade twin could extend to 10-16 weeks. Highly Pathogenic Avian Influenza (H5N1/H5Nx) affected 100+ countries in 2021-2024, caused 67 million poultry culls in the United States alone (USD 3.3 billion), and continues to threaten a human pandemic event with a 58% case fatality rate in the 463 human cases documented since 2003 — yet current WOAH warnings run 7-14 days behind the wild-bird migration front that drives spread. Vibrio outbreaks in the Baltic and North Sea have increased 10-fold since the 1980 baseline as ocean surface temperatures warm, with shellfish harvest bans currently issued 24-48 hours ahead versus a τ-grade 7-14 day predictive window.

Across all three hazard types, and across the full food-system and interface landscape this paper covers, a τ-grade system could shift prevention from fragmented inspection and episodic outbreak response to a coordinated One Health intelligence layer. That layer would enable earlier detection, better pathway attribution, more targeted and livelihood-preserving interventions, and stronger cross-border coordination.

This is a yellow paper. It is assumption-led, translation-oriented, and public-good framed. It does not claim that the broader scientific or policy community has accepted the τ assumptions. It asks what would follow if those assumptions were true enough to matter operationally.

2 Why This Matters Now

2.1 A burden that has not declined

WHO's food-safety burden estimates have remained stubbornly stable for over a decade. Six hundred million illnesses and 420,000 deaths per year place foodborne disease on a par with malaria and tuberculosis as a leading infectious cause of mortality. The toll falls disproportionately on children — 30% of foodborne deaths occur in children under five, who make up only about 9% of global population [1][2]. Thirty-three million healthy life years are lost annually from foodborne disease [2].

The economic dimension deepens the urgency. The World Bank estimated in 2019 that unsafe food costs LMIC economies USD 110 billion per year in productivity losses and medical expenses — a figure that dwarfs the annual global budget for food-safety capacity building [3]. That same analysis estimated USD 95 billion per year in welfare losses in high-income countries. Total global economic cost exceeds USD 200 billion annually.

These losses fall hardest on households that are already food-insecure. Smallholder farmers who lose access to markets after a contamination event, informal vendors whose livelihoods collapse during a market shutdown, and families who cannot afford to discard food that might be unsafe — these are the populations where the human cost is concentrated and where better intelligence would have the greatest humanitarian leverage.

2.2 The interface problem is structural and worsening

The wildlife-livestock-human interface is not a rare anomaly. It is a standing structural feature of the global food system. More than 40% of all terrestrial land is used for agriculture and pasture. Wild and domestic animals share water points, grazing land, wetlands, and forest edges at scales that are increasing, not decreasing, as agricultural frontier expansion continues in Africa, South Asia, and South America [15].

FAO's 2025 One Health review makes the trajectory explicit: climate change, altered rainfall patterns, wildfires, ecosystem degradation, wildlife displacement, livestock stress, and crop failures are intensifying health risks at the human-animal-plant-environment interface [14]. Droughts push wildlife and livestock toward shared water points. Floods redistribute pathogens across landscape gradients. Temperature anomalies alter the seasonality of pathogen amplification. These are not independent perturbations — they are coupled dynamics that current surveillance and food-safety systems were not designed to track.

HPAI H5N1 and its variants are the most visible current manifestation. The 2021-2024 panzootic affected poultry in over 100 countries, caused USD 3.3 billion in direct US losses alone, and generated the first confirmed human H5N1 fatality in the Americas in 2024 [31]. The wild-bird migration routes that carry HPAI are predictable in principle from atmospheric and migratory ecology models — but current warning systems lag observations by 7-14 days, by which point outbreaks are already seeded in commercial flocks.

2.3 The climate-food-health nexus is accelerating

The three hazard types this paper emphasizes — mycotoxins (climate-driven crop contamination), HPAI and Newcastle Disease Virus (temperature-migratory bird linkage), and Vibrio/harmful algal bloom (HAB) events in coastal systems — all share a common feature: their drivers are physical, ecological, and atmospheric dynamics that are in principle predictable days to weeks ahead of the biological event they trigger.

Aspergillus flavus, the mold that produces aflatoxin, amplifies under specific temperature-humidity-drought stress conditions that are measurable at the field scale. H5N1 travels along bird migration corridors whose timing is governed by temperature cues and atmospheric pressure gradients. Vibrio vulnificus, responsible for the most lethal foodborne bacterial infections in the United States and now spreading rapidly in European coastal waters, proliferates when sea surface temperature exceeds approximately 18°C [35]. Each of these pathways has a physical upstream that is more tractable than the biological downstream.

A τ-grade twin operating on a law-faithful physical substrate could, under the working assumptions this paper adopts, reach further upstream than current statistical models — coupling atmospheric, oceanographic, hydrological, and ecological dynamics into contamination and spillover predictions with longer lead times and better-characterized uncertainty bounds.

2.4 The institutional stack is already asking for this

The direction of travel across WHO, FAO, WOAH, and the national food-safety authorities is clearly toward better intelligence integration — not just better inspection. WHO's Global Strategy for Food Safety calls for stronger microbiological and chemical risk assessment and better preparedness for international foodborne incidents [16]. WOAH's 2026 wildlife-livestock guidance responds to a recognition that information flows between wildlife surveillance, veterinary services, and food-safety authorities are too slow and too siloed [6][7]. FAO's EMPRES animal health program is explicitly built around early warning, early reaction [8].

None of these institutions is asking for better inspection forms. They are asking for better foresight, better pathway attribution, and better cross-sector coordination. That is precisely the capability a τ-grade One Health intelligence layer would provide.

3 Scope and Reader Orientation

3.1 What this paper covers

This is Paper 3 of 4 in the One Health food safety and interface intelligence track of the Panta Rhei Impact portfolio. It focuses specifically on:

- Foodborne disease burden and food-safety intelligence across the full production-to-household chain
- Livestock-wildlife interface risk, including HPAI, ASF, FMD, and emerging zoonotic pathogens
- Community exposure at the human-animal-food-environment interface, including live-animal markets, slaughter points, informal milk chains, and household food handling
- Safe-trade continuity under disease events
- Prevention targeting across farm, market, slaughter, retail, and household layers
- Climate-physical drivers of mycotoxin, avian influenza, and coastal bacterial hazards

Three hazard type clusters receive extended treatment because they illustrate the τ differentiation case most concretely: mycotoxins (aflatoxin/ochratoxin in cereals and groundnuts), highly pathogenic avian influenza, and Vibrio/HAB events in coastal and inland aquatic food systems.

3.2 Who this paper is written for

The primary audience includes ministries of health, agriculture, food safety, and environment; veterinary services and wildlife authorities; public-health institutes with food-safety responsibilities; food regulators and market authorities; local and municipal governments in high-burden food-system contexts; development banks and bilateral donors active in food security and One Health;

humanitarian actors in camp, refugee, and emergency food systems; and One Health implementation partners including FAO, WHO, and WOAH program staff.

Secondary audiences include food systems researchers, climate-health integration teams, and private-sector actors in food processing, cold chains, and agricultural insurance who may see value in τ-grade predictive intelligence.

3.3 What this paper is not

This paper does not cover AMR and wastewater surveillance (addressed in the environmental transmission intelligence paper), health-system resilience and cold chains for clinical facilities (addressed in the facility continuity paper), or vector-borne disease early warning (addressed in the zoonotic spillover paper). It also does not address fisheries management or marine ecosystem services beyond their direct connection to shellfish safety and coastal foodborne hazards.

3.4 How to read the τ assumptions

The τ claims in this paper are working assumptions for planning purposes. Every claim about what a τ-grade system could do is explicitly conditional on those assumptions being operationally valid. The paper does not assert that the broader scientific community has accepted τ or that any fielded τ-grade system currently exists. It asks: if the assumptions hold, what follows for food safety, interface risk management, and community protection?

4 The Opportunity Baseline

4.1 Foodborne disease burden — what the numbers mean in practice

Six hundred million foodborne illnesses and 420,000 deaths per year translate to roughly 1.6 million illnesses and 1,150 deaths every single day. The disease spectrum is wide: norovirus is the leading cause by case count; Salmonella non-typhoidal, Campylobacter, and Shigella are major bacterial contributors; Listeria monocytogenes, though lower in absolute case count, has a 20-30% case fatality rate in high-risk groups; Mycobacterium bovis (bovine TB) transmits through unpasteurized milk; and emerging zoonotic pathogens including hepatitis E virus and various Nipah-related viruses are growing concerns at the livestock-wildlife interface [1][2].

The 33 million DALYs lost to foodborne disease annually — comparable to the burden of HIV/AIDS [2] — reflect not just acute illness and death but long-term sequelae including post-infectious irritable bowel syndrome, reactive arthritis from Salmonella and Campylobacter, haemolytic uraemic syndrome from STEC, and neurological damage from Listeria and certain mycotoxins.

Children bear a grossly disproportionate share: 125,000 deaths annually under age five from foodborne disease [2], concentrated in contexts where food storage is difficult, refrigeration absent, water for food preparation contaminated, and caretaker time for safe preparation constrained.

4.2 The livestock interface — scale and structural importance

FAO's livestock data establishes both the scale of the opportunity and the scale of the risk. Livestock provides livelihoods for 1.3 billion people. It delivers 34% of global food protein [5]. In Sub-Saharan Africa and South Asia, small-scale livestock — chickens, goats, dairy cattle, pigs — are often the primary savings mechanism and nutrition source for households with no other financial reserves.

This makes blunt livestock-disease controls extraordinarily costly in humanitarian terms. USDA's 2022-2023 HPAI response culled 67 million birds and cost USD 3.3 billion in direct losses [31] — in a high-income country with federal compensation programs and industrial production systems. The same outbreak pattern in a context without compensation programs, where a household's 20-bird flock is its primary protein and cash source, is a livelihood-ending event that no indemnity will reach.

The interface between livestock and wildlife is where the structural risk concentrates. WOAH's 2026 guidance identifies ASF (100% fatal in pigs, spread via wild boar), HPAI (multiple strains in wild birds, migratory corridors crossing continents), and FMD (extremely contagious, affecting trade from 65+ countries) as the three paradigmatic transboundary animal diseases at the wildlife-livestock boundary [6][7]. All three are partially or fully driven by wildlife reservoir dynamics that current surveillance systems track with significant lag.

4.3 The community exposure layer — where risk becomes personal

Even where national food-safety systems are improving, exposure materializes locally in ways that formal systems often cannot reach:

- Live-animal markets in East and Southeast Asia, West Africa, and Central Asia where poultry, waterfowl, and mammals mix in conditions that amplify transmission and contamination risk
- Informal milk chains in South Asia and Sub-Saharan Africa where unpasteurized milk travels from farm to household through ambient-temperature distribution
- Peri-urban slaughter points operating outside formal inspection coverage where contamination from animal intestines is a regular occurrence
- School feeding programs in LMICs where ingredient sourcing and storage practices may not be consistent with HACCP standards
- Pastoral communities with deep integration between livestock handling, raw milk consumption, and household food preparation that creates daily interface exposure
- Informal fish and shellfish markets in coastal communities where storage-chain breaks create Vibrio and HAB exposure risks

These are settings where public inspection capacity is intermittent, refrigeration is absent or unreliable, food-safety messaging is generic rather than targeted, and animal-health and food-safety systems rarely share intelligence. They are also where exposure is most concentrated for the populations least able to bear the consequences — children, pregnant women, elderly, and immunocompromised individuals.

4.4 The climate amplifier

The physical climate system is not a background condition for food safety — it is an active driver. A 2023 Lancet Planetary Health study documented that warming Baltic Sea surface temperatures drove a 10-fold increase in Vibrio vulnificus cases between the 1980 baseline and 2014 [35]. Projections suggest this trend will continue as marine heatwaves intensify and extend geographically.

For mycotoxins, the relationship between climate and contamination is even more direct. Aspergillus flavus, the aflatoxin producer, amplifies under drought-heat stress combinations that are predictable from meteorological data. IFPRI analysis puts the annual economic loss from aflatoxin in Sub-Saharan Africa at USD 670 million [32]. The 2004 Kenya aflatoxin outbreak — 317 cases, 125 deaths — occurred in a region experiencing prolonged drought, and the conditions enabling it were present in meteorological records weeks before the outbreak was detected.

Climate projections suggest that the frequency and geographic reach of all three hazard types — mycotoxin events, HPAI migration-linked outbreaks, and coastal Vibrio/HAB events — will increase over the coming decades. The window to invest in prevention-oriented intelligence systems that can operate at longer lead times is narrowing.

5 Working τ Assumptions

This paper adopts, for planning purposes, a specific set of claims about what the τ framework provides. These are stated explicitly rather than buried in rhetorical hedging. The paper's practical conclusions are conditional on these assumptions.

Assumption 1 — Pathway faithfulness. τ provides a bounded-error, coarse-grainable discrete twin of contamination and transmission pathways across the food chain: from farms, grazing systems, and wildlife corridors through feed and water systems, transport and cold chains, live-animal markets and slaughter points, processors and retailers, institutional food systems, and household handling and storage. The twin is pathway-faithful, meaning that causal structure is preserved at each scale transition, not merely reproduced statistically.

Assumption 2 — Mechanistic cross-domain coupling. τ provides mechanistic coupling across weather and environmental dynamics, water chemistry, surface and aerosol transmission, vector and animal stress physiology, movement ecology, storage and handling conditions, and microbial growth kinetics. This is a much stronger claim than a statistical overlay. It means that an atmospheric drought signal can propagate causally through the model into a mycotoxin risk prediction, rather than being correlated with it via historical patterns.

Assumption 3 — Multiscale integration. τ enables faithful integration across spatial scales (field to continent), temporal scales (hourly to seasonal), and data domains (wildlife surveillance, veterinary data, food testing, wastewater, meteorological, and community exposure data). The integration is governed by the physics rather than by interpolation heuristics.

Assumption 4 — Early-warning capability. Under the mechanistic coupling assumption, τ can generate actionable early warnings for unsafe conditions before outbreaks fully express themselves in human case counts or confirmed animal disease events. The claim is that the physical-ecological upstream is detectable earlier than the biological-clinical downstream.

Assumption 5 — Intervention evaluation. τ can evaluate control options not only for pathogen reduction but for livelihood protection, trade continuity, ecological side-effects, and nutritional consequences. This requires the twin to model human and institutional behavior as well as microbial dynamics — a strong assumption.

Assumption 6 — Valid bounded-error coarse-graining. Decision-makers can act on coarse-grained community, district, or corridor risk models with valid error bounds. The model's uncertainty is honest and calibrated, not suppressed.

These assumptions are much stronger than what mainstream surveillance and food-safety systems currently claim. The paper asks what follows operationally if they hold.

6 What Changes with a Law-Faithful Twin

6.1 From static inspection to pathway intelligence

The current food-safety operational paradigm — standards, inspections, point sampling, reactive recalls, and retrospective epidemiology — was designed for a world where contamination events were relatively slow-moving, relatively localized, and relatively legible to physical inspection. That world no longer describes the global food system in 2026. Food travels faster and farther. Supply chains are longer and more complex. Climate-driven contamination events are more frequent and less predictable from historical patterns alone.

Under τ, the operational shift is from asking "is this product safe right now?" to asking "where in the pathway is contamination most likely to enter and amplify, when, and under what conditions?" The difference is not semantic. A system that can answer the pathway question can:

- Direct sampling and inspection resources to where risk is highest before contamination is confirmed
- Identify the small number of nodes in a supply chain where a targeted intervention would prevent the largest downstream burden
- Issue pre-event advisories to community handlers, school feeding programs, and market operators before contamination windows open rather than after cases are confirmed
- Support safe-trade decisions with probabilistic confidence bounds rather than binary detection results

The same shift applies at the livestock-wildlife interface. Instead of waiting for a confirmed HPAI case in a commercial flock before issuing biosecurity orders, a τ-grade system could identify which farms along a wild-bird migration corridor are at elevated risk during a specific migration window, enabling pre-emptive biosecurity reinforcement rather than reactive culling.

6.2 From blunt biosecurity to interface-aware prevention

Current responses to wildlife-livestock interface events tend toward blunt instruments: mass movement bans, broad culling programs, market closures applied to entire regions, and trade restrictions implemented at the commodity or country level. These instruments protect human and animal health in the short term, but they impose severe collateral costs — livelihood destruction, food-price shocks, erosion of smallholder farmer trust in public health systems, and in some cases perverse incentives to conceal cases.

A τ-grade twin could support much more precise biosecurity actions:

- Risk zoning by corridor, season, and ecological interface type (shared water points vs. shared grazing vs. wetland overlap) rather than by administrative boundary
- Targeted grazing-buffer or water-point interventions at the specific interface locations where transmission probability is highest
- Transport-window changes that reduce exposure during peak-risk atmospheric and migratory periods without shutting down trade entirely
- Market and slaughter workflow redesign based on specific contamination amplification pathways rather than generic HACCP assumptions
- High-confidence safe-trade corridors that can be certified to trade partners with explicit probabilistic bounds rather than asserted based on absence of detected cases

The livelihoods protected by this precision are not trivial. The 2022-2023 HPAI response in the United States permanently closed hundreds of family-scale poultry operations that could not survive the combination of culling, movement restrictions, and market disruption. In Sub-Saharan Africa and South and Southeast Asia, where household poultry is the primary protein and cash reserve for hundreds of millions of families, the humanitarian cost of equivalent blunt responses would be orders of magnitude larger per case prevented.

6.3 From human-case surveillance alone to integrated exposure intelligence

Human cases are a lagging signal. By the time a clinic confirms a foodborne illness cluster or a laboratory confirms a zoonotic spillover event, the contamination or transmission chain has already been propagating for days to weeks. In the case of HPAI, confirmed human cases in regions with limited healthcare access have historically been preceded by weeks of undetected community exposure.

A τ-grade system could fuse leading signals from multiple upstream domains:

- Animal health deterioration in livestock or sentinel wild bird populations before confirmed disease
- Feed and water quality deterioration correlated with temperature-humidity conditions favorable to pathogen amplification
- Storage and transport stress patterns that create cold-chain breaks during high-ambient-temperature periods
- Wildlife movement and behavioral signals (altered migration timing, congregation at stressed water points) that indicate interface intensification
- Slaughter and market process indicators (higher volumes, reduced separation, increased stress-induced fecal contamination) that create contamination-amplification windows
- Community exposure surface indicators (household food handling patterns, informal vendor stock turnover, water quality at community points)

Each of these signals is, on its own, ambiguous. But under the mechanistic coupling assumption of τ, they become jointly interpretable as an integrated picture of exposure pathway status — allowing action earlier in the causal chain, not just after downstream disease is confirmed.

6.4 From siloed institutions to a shared intelligence layer

One of the most structurally consequential changes a τ-grade One Health twin would enable is the creation of a shared intelligence layer across what are currently separate institutional pipelines. Food-safety authorities, veterinary services, wildlife management agencies, environmental health bodies, and public health institutes all collect data that is relevant to the others' decisions — but rarely share it in forms that are causally interpretable across domains.

A τ-grade twin does not require these institutions to merge or to abandon their mandates. It requires them to connect through a common physical model that translates each domain's signals into a shared coordinate system. The institutional analogy is not bureaucratic consolidation — it is weather forecasting, where meteorological observations from dozens of national services are integrated through shared physical models into products that each national service uses for its own purposes.

7 Competitive and Incumbent Landscape

A credible deployment case for τ-grade food safety intelligence requires honest engagement with what current systems do well, where they fall short, and how τ differentiation would apply. This section characterizes six major incumbent systems in detail.

7.1 FAO/WHO INFOSAN — International Food Safety Authorities Network

What it does well. INFOSAN is the global backbone for cross-border food-safety event communication, spanning 189 countries with National Focal Points who can rapidly exchange information during food-safety incidents [10]. Since its launch in 2004, INFOSAN has facilitated information exchange in hundreds of events. Its strength is coverage, speed of notification once an event is recognized, and institutional legitimacy — national food-safety authorities trust INFOSAN communications in ways they do not trust commercial intelligence products.

Where it falls short. INFOSAN is reactive by design. It activates after a food-safety event is recognized and notified. It has no predictive function. It does not model contamination pathways, it does not identify where in a supply chain an event originated, and it does not assess what conditions might cause a similar event at another node in the same supply chain. INFOSAN messages are text-based situational reports, not structured data that can feed into risk models. The system also depends on member states voluntarily notifying events — creating systematic under-reporting in contexts where notification carries trade or reputational consequences.

τ **differentiation.** A τ-grade system would operate upstream of INFOSAN: predicting the conditions under which events are likely to occur, characterizing the supply-chain pathways through which they would propagate, and enabling INFOSAN notifications to be replaced or supplemented by predictive alerts that countries can act on before events are confirmed. INFOSAN would not be replaced — it would receive richer inputs and issue more actionable outputs.

7.2 EU RASFF — Rapid Alert System for Food and Feed

What it does well. RASFF is one of the most operationally mature food-safety alert systems in the world, covering the EU member states plus Norway, Iceland, Liechtenstein, and Switzerland. It operates on a 24-hour notification obligation for serious risks, with a database of tens of thousands of annual notifications covering chemical, microbiological, and allergen hazards. RASFF enables rapid border rejections and market withdrawals. Its traceability function — identifying the supply-chain origins of notified products — is significantly better than most national systems.

Where it falls short. RASFF is a post-detection notification system, not a forecasting system. It does not predict where contamination will emerge. Its traceability is retrospective: it traces events that have already been detected back through supply chains, rather than prospectively mapping which supply chains are at elevated risk. RASFF coverage is also geographically concentrated in high-income Europe, with limited integration with the surveillance systems in the producing countries where most contamination events originate. The system generates high alert volumes (15,000+ notifications per year) that require human prioritization, creating a signal-to-noise challenge.

τ **differentiation.** A τ-grade system would add a prospective risk-mapping function that RASFF lacks: identifying which commodity flows into the EU are at elevated risk under current physical and ecological conditions, enabling targeted enhanced inspection at borders rather than uniform sampling. For mycotoxin events specifically, τ-grade atmospheric-crop stress modeling could identify high-aflatoxin-risk harvests 10-16 weeks before export, enabling import decisions rather than rejection decisions.

7.3 WOAH WAHIS — World Animal Health Information System

What it does well. WAHIS is the authoritative global reference for official animal disease data, covering both domestic and wild animals across 182 WOAH member countries [12]. It provides standardized disease reporting, outbreak mapping, and trade-relevant certification support. WAHIS is the system that enables importing countries to assess animal-health status in exporting countries. Its wild-animal section (WAHIS-Wild) provides a global view of disease in wildlife populations that no other system matches for official legitimacy.

Where it falls short. WAHIS reporting is lagged by weeks to months from the time of actual disease events. Official reports require veterinary investigation, laboratory confirmation, and administrative processing that typically takes two to six weeks after an event is first suspected. In the case of a fast-moving interface disease like HPAI, a lag of two weeks between first case detection and WAHIS notification can represent the difference between a contained outbreak and a regionwide spread event. WAHIS also depends on voluntary reporting and is known to have systematic under-reporting in countries where disease notification carries trade consequences.

τ **differentiation.** A τ-grade system would operate in the detection gap — the period between when ecological and atmospheric conditions first favor transmission and when WAHIS records an official outbreak. By coupling wild-bird migration models, atmospheric dynamics, and interface ecology, a

τ-grade system could extend the warning horizon from the current 7-14 day lag-behind-observation to 21-35 days ahead-of-expected-observation, giving veterinary and biosecurity services actionable lead time.

7.4 FDA Sentinel / CDC PulseNet — US Foodborne Illness Surveillance

What it does well. CDC PulseNet is the world's leading genomic foodborne illness surveillance network, using whole genome sequencing (WGS) to cluster human cases by pathogen strain and trace common-source outbreaks with high specificity [25]. WGS has fundamentally improved source attribution for Salmonella, Listeria, STEC, Vibrio, and Cyclospora outbreaks. FDA's GenomeTrakr network complements PulseNet with pathogen genomics from food and environmental sampling, enabling source-matching between human cases and food production environments. The 2011 Listeria cantaloupe outbreak and the 2018 romaine lettuce STEC outbreak would have taken months to attribute under pre-WGS methods; both were resolved in days.

Where it falls short. PulseNet and FDA Sentinel are retrospective systems. They excel at connecting cases after they occur and tracing them to sources. They do not predict where outbreaks will emerge. They do not model the supply-chain pathways through which a contamination event will spread. They provide no early warning of elevated risk under specific environmental or operational conditions. PulseNet coverage is also geographically limited to the United States, with international partnerships of variable depth. The system does not integrate atmospheric, ecological, or agricultural stress data that drives contamination events upstream of the production environment.

τ differentiation. A τ-grade system would extend the timeline in the opposite direction — upstream from the detection that PulseNet excels at to the conditions that generate contamination in the first place. The combination of τ-grade upstream prediction and PulseNet-grade genomic attribution would create an end-to-end intelligence capability: from prediction of where and when contamination risk is elevated (τ) through rapid source attribution when cases occur (PulseNet). These systems are complementary, not competitive.

7.5 IPBES / WWF Wildlife Trade and Population Monitoring — Observational Frameworks

What it does well. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and major conservation organizations including WWF maintain extensive wildlife population monitoring, trade flow documentation, and ecosystem health assessment frameworks. IPBES's global biodiversity assessments provide the most comprehensive scientific synthesis of wildlife population trends. WWF's TRAFFIC network tracks wildlife trade flows and identifies illegal trade patterns that create zoonotic spillover risk. These frameworks provide the ecological context without which wildlife-livestock interface risk cannot be understood.

Where it falls short. These systems are primarily observational and policy-oriented. They produce assessments and reports, not operational early warnings. They are not designed to generate real-time or near-real-time risk intelligence for veterinary and food-safety authorities. They do not couple ecological observations to atmospheric dynamics, livestock system operations, or human exposure pathways in ways that would enable predictive risk assessment. The disconnect between IPBES/WWF population monitoring and WOAH/FAO animal health systems means that the ecological context for interface risk is not operationally available to the veterinary and food-safety decision-makers who need it.

τ differentiation. A τ-grade system would provide the causal coupling that is missing between wildlife ecology observations and operational food-safety and veterinary risk assessments. By integrating wildlife movement and population dynamics (from existing monitoring systems) with atmospheric conditions, livestock system state, and human exposure geography through a common physical model, τ would create the operational intelligence layer that IPBES/WWF monitoring currently lacks.

7.6 WHO GOARN for Foodborne Events — Coordination Network

What it does well. WHO's Global Outbreak Alert and Response Network (GOARN) can be activated for foodborne disease events of international concern, mobilizing technical experts and laboratory capacity across participating institutions [26]. GOARN provides surge capacity for outbreak investigation that national systems cannot sustain alone. It has been activated for cholera, hepatitis E, botulism, and other foodborne events where national investigation capacity was exceeded. The network's value lies in mobilizing human expertise rapidly.

Where it falls short. GOARN is a coordination mechanism for outbreak response — it activates after events are declared and organizes expert deployment. It has no predictive function. It does not model contamination pathways, does not assess pre-event risk conditions, and does not provide early warning of elevated interface risk. GOARN is also resource-intensive and reserved for events of genuine international concern — it is not a routine food-safety intelligence system.

τ differentiation. A τ-grade system would reduce the frequency with which GOARN-level response is necessary by enabling earlier detection and more targeted pre-event interventions. It would also improve GOARN response quality when activation occurs by providing pathway models that accelerate source attribution and intervention targeting during the outbreak investigation.

8 Structured Opportunity Map

8.1 Opportunity 1 — Mycotoxin Hazard Intelligence: Climate-Coupled Crop Contamination Forecasting

The gap. Current aflatoxin and ochratoxin control relies on post-harvest testing that detects contamination after it has occurred. Pre-harvest agronomic advice exists but is not coupled to real-time atmospheric and soil moisture data at field scale. The result is systematic under-detection before export and market entry, with contaminated maize and groundnuts entering food chains that serve millions of households.

What τ enables. Under the working assumptions, τ could couple atmospheric drought-stress signals, temperature anomalies, soil moisture deficits, crop phenology, and Aspergillus growth kinetics into a pre-harvest contamination risk map updated weekly at field or district scale. For Sub-Saharan Africa — where the burden is greatest and where the 2004 Kenya disaster occurred — this would extend the actionable window from 0-4 weeks (current post-harvest testing) to 10-16 weeks (pre-tasseling risk assessment). That extension enables: pre-harvest drying and storage infrastructure deployment, targeted supplemental irrigation at critical phenological windows, pre-harvest advisory to farmers on biocontrol agents (Aflasafe), and import/export inspection targeting for commodity flows from high-risk production zones.

Scale of opportunity. Sub-Saharan Africa annual aflatoxin economic loss: USD 670 million. Smallholder farmers affected by CGIAR/World Bank aflatoxin programs: 40 million. A 20% reduction in contamination burden through pre-harvest intelligence would represent USD 134 million in annual avoided losses plus avoided mortality in the most exposed child populations.

Institutional entry points. CGIAR's IITA aflatoxin program; World Bank food safety programs in Kenya, Tanzania, Uganda; FAO EMPRES crop health; national grain board surveillance systems.

8.2 Opportunity 2 — HPAI and Transboundary Avian Disease Interface Intelligence

The gap. HPAI early warning is currently based on a combination of wild-bird surveillance (WOAH, national programs), poultry flock surveillance (national veterinary services), and retrospective analysis of migration route data. The typical lag between outbreak seeding in commercial flocks and WOAH WAHIS notification is 2-6 weeks. The lag between first confirmed farm case and regional quarantine decision is 1-3 weeks. By these timepoints, the migration front has moved on and secondary seeding has often already occurred.

What τ enables. Under the working assumptions, τ could couple wild-bird migration phenology models (temperature and pressure-gradient driven), atmospheric transport of viral aerosols, live-poultry market density and trade flow data, farm biosecurity state assessments, and wildlife-livestock overlap geography into an interface risk map updated at weekly or sub-weekly resolution. This could extend the actionable warning window from the current 7-14 day lag-behind-observation to a 21-35 day ahead-of-observation forecast. During the 2021-2024 HPAI panzootic, a 21-day advance warning window for the highest-risk farms along the Atlantic and Mississippi flyways in the United States would have enabled pre-emptive biosecurity reinforcement that could have prevented a significant proportion of the 67 million bird culls. At USD 3.3 billion in direct losses, even a 10% reduction in US exposure would represent USD 330 million in avoided costs, plus avoided losses in trading partner countries and avoided pandemic risk premia.

Human spillover risk multiplier. The 463 confirmed human H5N1 cases documented between 2003 and 2024, with a 58% case fatality rate [31], represent the clearest current pandemic warning signal in the global food system. Better interface intelligence that reduces the scale and duration of HPAI epizootics directly reduces human exposure opportunities and, by extension, the probability of an adaptive mutation event enabling sustained human-to-human transmission.

8.3 Opportunity 3 — Vibrio and Harmful Algal Bloom Coastal Food Safety Intelligence

The gap. Vibrio vulnificus and V. parahaemolyticus shellfish and wound infection risk is currently managed through sea surface temperature (SST) monitoring and periodic shellfish harvest area closures. The typical harvest closure decision is made 24-72 hours after SST thresholds are exceeded — reactive to physical conditions, not predictive of them. HAB (harmful algal bloom) monitoring similarly relies on chlorophyll and toxin satellite observation, with closure decisions made 24-48 hours after bloom detection.

What τ enables. Under the working assumptions, τ could couple oceanographic dynamics (SST, salinity, stratification), atmospheric forcing (wind stress, upwelling/downwelling), nutrient loading from river basins (linked to upstream land use and rainfall), and Vibrio and algal bloom growth kinetics into a 7-14 day predictive window for shellfish safety conditions along specific coastal segments. This would enable aquaculture operators and coastal food-safety authorities to plan harvest windows, pre-position testing capacity, and issue advance advisories to market operators rather than reactive closures.

Baltic trajectory. The Lancet Planetary Health 2023 study documenting a 10-fold Vibrio increase in the Baltic Sea since 1980 [35] is not an outlier — it is the leading edge of a marine food safety crisis that will expand geographically as global ocean temperatures continue rising. The North Sea, Mediterranean, East China Sea, and Gulf of Mexico are all facing accelerating Vibrio and HAB risk. A τ-grade coastal food safety intelligence system built for the Baltic could serve as the template for deployment in all of these contexts.

8.4 Opportunity 4 — Live-Animal Market and Slaughter Node Intelligence

The gap. Live-animal markets and urban/peri-urban slaughter points are the highest-density interface between wildlife, livestock, and human food exposure pathways. They are also the least well-monitored nodes in most LMICs' food-safety systems. Inspection is intermittent, coverage is incomplete, and data from these nodes rarely reaches veterinary or food-safety authorities in time to inform risk decisions at other points in the chain.

What τ enables. Under the working assumptions, τ could integrate market operation data (volume, species mix, crowding, temperature and humidity), transport history of incoming animals, regional disease intelligence from farms and wildlife monitoring, and local environmental conditions into a real-time or near-real-time risk index for specific markets and slaughter operations. This index could drive targeted inspection deployment, operational advisory to market managers, and community-level exposure warnings that are specific to the current risk window rather than generic hygiene messages.

Paradigmatic case: wet markets in Southeast Asia. The ecological conditions at wet markets in Thailand, Vietnam, Indonesia, and Malaysia have been associated with HPAI transmission to humans, novel coronavirus events, and multiple other spillover events. A τ-grade system coupling atmospheric conditions, wildlife trade flow data, farm epidemiology, and market operation parameters could provide the first genuinely predictive intelligence layer for these settings.

8.5 Opportunity 5 — Community Food and Animal Exposure Advisories in Vulnerable Settings

The gap. Community-level food-safety advisories in LMICs are overwhelmingly generic. "Wash your hands. Cook meat thoroughly. Refrigerate perishables." These messages are not wrong, but they do not target the specific exposure windows, specific hazards, and specific community practices that drive actual disease burden in specific places and seasons. They cannot be targeted because the risk intelligence needed to target them does not exist.

What τ enables. Under the working assumptions, τ could generate community-level, seasonal, and hazard-specific exposure advisories driven by the real-time state of the food and interface environment in each community's context. During a pre-harvest aflatoxin risk window, advisories could specifically address maize drying and storage. During a peak HPAI interface risk period, advisories could specifically address backyard poultry handling and live-market visits. During a Vibrio risk window, advisories could specifically address shellfish sourcing and preparation. This is the difference between public health communication and public health intelligence.

Gender and equity intersection. Women in smallholder agricultural systems and in informal food markets are disproportionately exposed to foodborne hazards through their roles as food preparers, sellers of fresh produce and animal products, and caregivers for children most vulnerable to foodborne illness. Targeted community advisories that reach women in these roles — through mobile health platforms, community health worker networks, and school feeding program channels — have a much higher expected impact per advisory than broadcast messaging.

8.6 Opportunity 6 — Cross-Border Safe-Trade Continuity Intelligence

The gap. Trade restrictions following animal disease events are one of the largest economic channels through which disease burden is transmitted from producing to non-producing countries. Trade bans are typically applied at the country or commodity level, are slow to lift even after the underlying risk has passed, and do not distinguish between high-risk and low-risk production zones within the same country.

What τ enables. Under the working assumptions, τ could provide importing countries with probabilistic risk assessments for specific production zones within exporting countries, enabling zone-based rather than country-level trade decisions. This is already the conceptual standard under the WOAH terrestrial animal health code — but implementation depends on intelligence that current systems rarely provide. A τ-grade system could support regionalization decisions with bounded-error probabilistic certification that is both more scientifically defensible and more politically durable than binary presence/absence certification.

9 Geographic Case Studies

9.1 Case Study 1 — Aflatoxin Crisis, East and West Africa (Recurrent, Reference Event: Kenya 2004)

Background. Aflatoxin contamination of maize and groundnuts is a recurrent food-safety crisis across Sub-Saharan Africa, with particularly severe events in Kenya, Tanzania, Uganda, Malawi, and Zambia. Aflatoxins are secondary metabolites of Aspergillus flavus and A. parasiticus molds, which colonize pre-harvest maize and groundnuts under specific conditions: drought stress combined with high temperatures (optimal range 25-40°C), plant tissue damage from insects, and delayed harvest or improper drying. All of these conditions are physically measurable and, under working τ assumptions, causally modifiable in their downstream effects through targeted pre-harvest interventions.

The 2004 Kenya outbreak. The 2004 Kenya aflatoxin outbreak remains the worst recorded aflatoxicosis event in history. In Eastern Province, a prolonged drought in 2003-2004 created ideal Aspergillus growth conditions. Maize was the primary dietary staple. Affected communities were food-insecure and dependent on local stocks, making household sampling and avoidance impossible. The outbreak resulted in 317 confirmed cases of acute aflatoxicosis and 125 deaths — a case fatality rate of approximately 39% [32]. Post-event analysis confirmed that the temperature-moisture conditions enabling the outbreak were detectable in meteorological records 6-8 weeks before peak clinical presentations. With current NWP systems, those conditions could have been identified 4-8 weeks in advance. Under τ assumptions, the coupled atmospheric-crop stress-fungal growth model could extend that window to 10-16 weeks — sufficient to mobilize Aflasafe biocontrol agent distribution, pre-position drying infrastructure, and issue targeted market advisory to prohibit sale of high-risk stocks.

Annual burden and economic context. IFPRI analysis estimates annual economic losses from aflatoxin in Sub-Saharan Africa at USD 670 million, accounting for direct crop losses, food waste, trade exclusions, and livestock illness from contaminated feed [32]. World Bank-CGIAR aflatoxin programs in East and West Africa currently reach approximately 40 million smallholder farmers — but these programs operate on agronomic advisory timescales, not real-time risk intelligence. Integrating τ-grade atmospheric-crop stress forecasting into CGIAR's delivery channels would add a predictive risk layer to existing program infrastructure at marginal deployment cost.

τ differentiation — specific. A τ-grade system would couple: (a) ERA5 or equivalent atmospheric reanalysis and forecast data (temperature, precipitation, humidity at 1-10km resolution), (b) soil moisture satellite retrievals (Sentinel-1 SAR, SMAP), (c) crop phenology data (NDVI from Sentinel-2 or MODIS), (d) Aspergillus growth kinetics (temperature-humidity response curves from mycology literature), and (e) harvest calendar and market flow data. The mechanistic coupling of these inputs into a spatially explicit, temporally evolving aflatoxin risk map — updated weekly at district scale — would extend the actionable window to 10-16 weeks before harvest. Farmers, extension services, commodity aggregators, and border inspection authorities would all receive risk-calibrated information appropriate to their decision windows.

Climate trajectory. IPCC AR6 projections for East and West Africa indicate increasing drought frequency and intensity across the maize and groundnut production zones where aflatoxin risk is currently highest. Without improved intelligence systems, the recurrence frequency of Kenya 2004-scale events will increase.

9.2 Case Study 2 — H5N1 Highly Pathogenic Avian Influenza, Global 2021–2024

Background. The 2021-2024 HPAI H5N1 clade 2.3.4.4b panzootic is the largest avian influenza event in recorded history. As of early 2024, outbreaks had been confirmed in poultry in over 100 countries across Europe, Asia, Africa, and the Americas. In the United States, the USDA reported 67 million poultry culled in the 2022-2023 season alone, with direct production and control costs of USD 3.3 billion [31]. In Europe, over 50 million birds were affected in 2022-2023. In Canada, 7.5 million birds were culled.

Wild-bird migration mechanics. HPAI H5N1 is maintained in wild waterfowl and shorebird populations, with domestic poultry exposed primarily through shared water points, wild-bird overflights, contaminated water sources, and fomite transmission in areas of overlap. The spread of HPAI across continents is driven by the autumn southward and spring northward migrations of the Atlantic, Pacific, East Asian-Australasian, and Central Asian flyway populations. These migrations are governed by atmospheric temperature gradients and photoperiod cues — they are, in principle, predictable from atmospheric and ecological models with 3-6 week lead times.

Current warning lag. WOAH WAHIS notifications for HPAI outbreaks typically lag the first confirmed farm case by 2-4 weeks. The first confirmed farm case itself often lags the initial wild-bird exposure event by 5-10 days (incubation period). Practical warning time from initial exposure to regional biosecurity orders is therefore typically 3-6 weeks — by which time, wild-bird migration has advanced several hundred kilometers and secondary poultry exposure events are already occurring. During the 2022-2023 outbreak in the US Midwest, the first Minnesota turkey farm confirmation was followed by a cascade of outbreaks across 47 US states within 8 weeks, despite rapid federal response.

Human spillover risk. HPAI H5N1 has caused 463 confirmed human infections since 2003, with a case fatality rate of approximately 58% [31]. Sporadic human cases have been confirmed in Asia, Africa, and — for the first time in 2024 — in the Americas, following direct contact with infected poultry or wild birds. Influenza virologists assess the pandemic risk from an H5N1 variant acquiring sustained human-to-human transmission capacity as the most significant current pandemic threat after SARS-CoV-2. Reducing the global burden and duration of HPAI epizootics reduces human exposure opportunities and, by extension, the probability of the adaptive mutation pathway.

τ differentiation — specific. A τ-grade HPAI interface intelligence system would integrate: (a) wild-bird migration phenology models driven by atmospheric temperature gradients (coupling ECMWF ensemble forecasts to established migration ecology models for the 12 major flyway populations), (b) aerosol transport models for HPAI-contaminated fomites in high-wind events (coupling atmospheric turbulence dynamics to viral decay kinetics), (c) live-poultry market trade flow networks (coupling USDA, EU, and FAO trade data to market-location databases), (d) farm biosecurity assessment data (coupling WOAH WAHIS event history to farm-level biosecurity status surveys), and (e) wild-bird surveillance data from national programs and eBird/GBIF platforms. The output would be a weekly interface risk map at county or equivalent scale, updated to reflect current atmospheric conditions and migration front position, with explicit uncertainty bounds.

Under this system, the 2022-2023 US HPAI outbreak would have had a 21-35 day advance warning for the highest-risk farms in the Great Plains and Mississippi flyway intersection. Pre-emptive biosecurity reinforcement (enhanced biosaucer barrier systems, reduced outdoor access, augmented cleaning protocols, pre-positioned personal protective equipment for workers) at the 5,000 highest-risk farms, costing approximately USD 50 million, could have reduced the overall cull count significantly. At a 10% reduction in culled birds (6.7 million fewer birds), the value preservation would be approximately USD 330 million in a single US season.

Global extrapolation. In countries without federal compensation programs — across South and Southeast Asia, West Africa, and the Andean region — equivalent intelligence and pre-emptive biosecurity would prevent livelihood losses for which no recovery mechanism exists. The humanitarian value of reducing HPAI burden in these settings is not captured in direct production cost estimates.

9.3 Case Study 3 (Optional) — Vibrio Outbreaks in Baltic and North Sea Coastal Waters

Background. Vibrio vulnificus and V. parahaemolyticus are halophilic bacteria that amplify rapidly in warm, low-to-moderate salinity coastal waters. V. vulnificus is the most lethal foodborne pathogen in the United States by case fatality rate (approximately 25-35% for primary septicemia cases), with oyster and shellfish consumption the primary exposure route. V. parahaemolyticus causes the largest global burden of seafood-associated gastroenteritis.

The Baltic warming signal. A landmark 2023 Lancet Planetary Health study documented a 10-fold increase in V. vulnificus clinical cases in the Baltic Sea region between the 1980 baseline and 2014, driven directly by rising Baltic Sea surface temperatures [35]. The Baltic has warmed approximately 1.5°C since 1980 — faster than the global ocean average — due to a combination of reduced ice cover and increased river runoff. The study projected continued increases in Vibrio incidence as warming continues, with geographic range expansion into previously unaffected North Sea and Norwegian coastal waters already observed.

Current management gap. Baltic and North Sea shellfish harvest area closures are triggered by SST threshold exceedance — typically when SST exceeds 18-20°C at designated monitoring stations. This trigger-response system issues closures with 24-72 hours of lead time — sufficient for immediate market withdrawal but insufficient for aquaculture operators to plan harvest timing, for fishing fleet operators to redirect effort, or for food service distributors to pre-adjust sourcing chains. The absence of predictive capability creates a binary shutdown dynamic that imposes costs disproportionate to the actual risk, particularly when temporary temperature anomalies do not translate into bloom-level Vibrio concentrations.

τ differentiation — specific. A τ-grade coastal food safety system would couple: (a) coupled ocean-atmosphere model forecasts (CMEMS or equivalent at 1-5km coastal resolution) providing SST, salinity, and stratification forecasts at 7-14 day range, (b) nutrient loading estimates from upstream river basins (linking precipitation and land-use data to dissolved nitrogen and phosphorus flux), (c) Vibrio growth kinetics (temperature-salinity growth rate models from the environmental microbiology literature), and (d) shellfish physiology and bioaccumulation dynamics (filter-feeder tissue concentration models). The output would be a 7-14 day risk forecast for specific shellfish harvest zones, enabling operators to plan harvest windows when risk is lowest, pre-position test capacity, and communicate to downstream food service with sufficient lead time to avoid emergency shutdowns.

10 Finance, ROI, and Climate-Finance Eligibility

10.1 The economic case — stated as precisely as possible

The humanitarian and economic case for investment in τ-grade food safety and interface intelligence rests on three independently documentable cost streams:

Stream 1 — Foodborne disease economic burden. World Bank 2019 analysis: USD 110 billion/year in productivity and medical losses in LMICs from unsafe food [3]; additional USD 95 billion/year in welfare losses in high-income countries. Total global economic cost exceeds USD 200 billion annually. A 1% reduction in global foodborne burden through better prevention, earlier attribution, and more targeted controls represents USD 2 billion in annual avoided losses. Even at modest investment-to-impact ratios, a system costing USD 5-25 million to build and operate at national or regional scale generates returns orders of magnitude above investment cost if it achieves 0.1-0.5% burden reduction in the served geography.

Stream 2 — HPAI and transboundary animal disease losses. The 2022-2023 US HPAI response cost USD 3.3 billion [31]. The 2001 UK FMD epidemic cost an estimated GBP 8 billion in direct and indirect losses. The 2019-present ASF pandemic in East Asia caused estimated losses of USD 55-130 billion in the Chinese pig sector alone, with global pork price effects persisting for three years. Intelligence that reduces response costs by 10% in a single HPAI outbreak season in a major production country recovers many multiples of the intelligence system's capital cost.

Stream 3 — Avoided pandemic risk premia. The COVID-19 pandemic is estimated to have cost the global economy USD 12-20 trillion over 2020-2022. The probability-weighted expected cost of an H5N1 pandemic, given current spillover rates and the documented evolutionary pathway, is not zero. Intelligence systems that measurably reduce HPAI epizootic burden reduce human exposure opportunities and, through that channel, reduce pandemic probability. The economic value of even a 0.01% reduction in pandemic probability — roughly USD 1 billion in expectation over a five-year horizon — dwarfs the capital cost of any national food-safety intelligence system.

10.2 Scenario A — National Foodborne Hazard Climate Intelligence Platform

Scope. A national-scale platform for a middle-income country with significant agricultural sector, combining mycotoxin risk forecasting, HPAI interface intelligence, and coastal Vibrio/shellfish safety forecasting. Target countries: Kenya, Thailand, Vietnam, Nigeria, Peru, or Bangladesh — all with significant food-safety burden and existing food-safety authority infrastructure.

Capital cost estimate. USD 2-5 million for platform development, data integration, institutional connectivity, and first two years of operation. Annual operating cost: USD 0.5-1 million.

ROI framing. Against Kenya's approximate USD 670 million annual aflatoxin burden alone, a 10% reduction in contamination events through pre-harvest intelligence represents USD 67 million in annual avoided losses. Against Thailand's HPAI-related trade disruption costs (estimated USD 150-400 million in the 2004-2006 outbreak), a 15% reduction represents USD 22-60 million. Platform breakeven at the lower bound occurs within the first year of effective operation.

Reference cost benchmark. World Bank One Health HSES (Human and Social Environmental Standards) programs in Kenya and Tanzania have funded food-safety capacity building at USD 5-15 million scale [27]. A τ-grade intelligence system would deliver significantly more predictive and pathway-attribution capability at comparable cost.

10.3 Scenario B — Regional Livestock-Wildlife Interface Surveillance Network

Scope. A multi-country regional network for a transboundary wildlife-livestock interface zone, such as the Greater Mekong region (Thailand, Vietnam, Laos, Cambodia, Myanmar), the East African Community (Kenya, Tanzania, Uganda, Ethiopia, Rwanda), or the Sahel-savanna interface (Sahel HPAI migration corridor). The platform would combine HPAI interface intelligence, ASF/wild boar interface monitoring, FMD zone management support, and community exposure advisory.

Capital cost estimate. USD 10-25 million for platform development, regional data integration, institutional governance establishment, field data collection network, and three years of operation. Annual operating cost: USD 2-4 million.

ROI framing. Against the USDA's USD 3.3 billion 2022-2023 HPAI cost, the equivalent burden for Southeast Asia — with much lower compensation programs and much higher small-holder exposure — cannot be quantified with the same precision but is likely comparable in absolute terms and far larger in per-capita humanitarian impact. Regional pandemic prevention framing: the Mekong region has been the origin of multiple novel influenza variants. A regional interface surveillance network that reduces HPAI epizootic burden and human spillover exposure has measurable pandemic prevention value that development banks and global health funders can model explicitly.

Pandemic prevention cost framing. The World Bank's One Health HSES program has estimated that strengthening animal-human interface surveillance in high-risk regions at USD 500 million annually would reduce pandemic risk by 50% relative to baseline [27]. A τ-grade regional platform would represent a concentrated investment in one of the highest-risk interface geographies at approximately 2-5% of that global annual estimate.

10.4 Named Climate Finance Windows

World Bank One Health HSES (Human and Social Environmental Standards). The World Bank's One Health framework has supported food-safety and animal-health capacity building in Kenya, Tanzania, Nigeria, Vietnam, Cambodia, and Bangladesh at USD 5-30 million project scale [27]. τ-grade intelligence systems are well-scoped for these funding windows, particularly under the "pandemic prevention" and "food security" cross-cutting themes that have been priorities since COVID-19.

FAO EMPRES (Emergency Prevention System for Animal Health). FAO's Emergency Prevention System for Animal Health has funded early warning and rapid response capacity for HPAI, ASF, and FMD across Africa and Asia at USD 5-20 million per program cycle [8]. A τ-grade HPAI interface intelligence system is a direct enhancement to EMPRES's core mission and would be eligible for EMPRES funding as a capacity-building and early-warning program.

USAID Bureau for Humanitarian Assistance — Food Safety Component. USAID's Bureau for Humanitarian Assistance (BHA) funds food-safety programs in emergency and early recovery contexts where foodborne disease burden is acute. Food safety in camp and displacement settings, school feeding program food safety, and informal market safety in fragile states are all within BHA's mandate. A τ-grade community exposure advisory system would fit within this window as a public-good intelligence tool for high-vulnerability populations.

Green Climate Fund (GCF) — Agriculture-Health-Climate Nexus. GCF has funded programs at the intersection of climate adaptation and agriculture in developing countries, including crop disease and pest management programs that have climate-intelligence components. The mycotoxin use case — where climate-driven crop contamination has direct food safety, nutrition, and livelihood consequences — is well-positioned for GCF agricultural resilience funding, particularly under the food security and nutrition outcome area. Project size: USD 15-40 million range typical for GCF agricultural adaptation grants.

Wellcome Trust / CEPI Pandemic Preparedness. The Coalition for Epidemic Preparedness Innovations (CEPI) and Wellcome Trust both fund pandemic preparedness infrastructure at the animal-human interface. A τ-grade HPAI and zoonotic interface intelligence system is fundable under pandemic preparedness framing, particularly given the documented H5N1 pandemic risk and the 2022-2024 panzootic event.

11 Evidence and Translation Ladder

Successful deployment of τ-grade food safety and interface intelligence follows a staged ladder that manages institutional trust, data integration complexity, and operational adoption in a realistic sequence.

11.1 Phase 1 — Shadow Mode and Benchmark Pilots (Months 0–18)

What happens. Deploy τ alongside existing systems in shadow mode — generating predictions and risk assessments that are visible to technical teams but not yet used in operational decisions. The primary goal is benchmarking: does τ predict contamination events, interface risk windows, and community exposure conditions earlier, more accurately, and with better-calibrated uncertainty than current systems?

Specific shadow targets: - INFOSAN events: does τ predict the supply-chain pathways that appear in INFOSAN notifications before notifications are issued? - WAHIS HPAI events: does τ predict interface-risk windows that precede confirmed outbreaks by 21+ days? - Mycotoxin testing results: does τ predict district-level aflatoxin risk before harvest testing confirms contamination? - SST-triggered shellfish closures: does τ predict closures 7+ days before SST threshold exceedance triggers them?

Institutional partners. National food-safety authorities; WOAH regional laboratories; FAO EMPRES country teams; national veterinary services; national meteorological services (for atmospheric data integration).

Output. Benchmark report with false-positive, false-negative, lead-time, and attribution-accuracy metrics. Institutional trust-building scorecard. Foundation for Phase 2 go/no-go decision.

11.2 Phase 2 — Corridor Pilots (Months 12–36)

What happens. Run τ operationally in two to three selected high-value, high-risk corridors where the shadow-mode benchmark demonstrates performance sufficient to support advisory use.

Candidate corridors: - Poultry-wild bird-live market corridor in one Southeast Asian country (Thailand or Vietnam recommended given existing HPAI program infrastructure) - Maize aflatoxin risk corridor in Kenya and Tanzania (building on existing World Bank/CGIAR program infrastructure) - Baltic shellfish safety corridor in one EU member state (Estonia or Finland recommended given Baltic warming signal)

Operational outputs. Weekly risk advisories to corridor participants (farmers, market operators, veterinary services, food-safety inspectors). Monthly attribution reports linking risk predictions to confirmed events. Intervention record tracking (did advisory recipients act on advisories, and what outcomes followed?).

Evaluation metrics. Detection lead time improvement vs. current systems. False positive rate (critical for maintaining trust with market operators and smallholders). Intervention uptake rate. Livelihood impact of advisory-driven interventions vs. reactive closures.

11.3 Phase 3 — National Integration (Months 30–60)

What happens. Integrate τ-grade risk products into national food-safety, veterinary, and wildlife management decision systems. Key integrations:

- INFOSAN national focal point workflows: τ risk products as inputs to notification decisions
- WAHIS national reporting: τ predicted events as triggers for enhanced surveillance rather than waiting for passive detection
- National food-safety authority inspection planning: τ supply-chain risk maps as inspection resource allocation inputs
- National veterinary service biosecurity orders: τ interface risk assessments as zone-risk classification inputs

Institutional governance. By Phase 3, the deployment requires a formal institutional home — either within an existing national agency (food-safety authority, veterinary directorate) or as a joint inter-agency platform. Governance frameworks need to address: data ownership and access; liability for missed predictions; decision authority (τ informs, humans decide); and public communication protocols for risk advisories.

11.4 Phase 4 — Regional and Cross-Border Integration (Months 48–84)

What happens. Extend τ to regional and cross-border applications: transboundary animal disease management, cross-border safe-trade corridor certification, regional HPAI interface surveillance networks, and continental-scale mycotoxin risk mapping.

Key regional frameworks. East African Community agricultural health system; ASEAN Animal Health and Zoonoses Division; EU RASFF integration (τ as upstream risk input to RASFF notification prioritization); African Union Inter-African Bureau for Animal Resources (AU-IBAR).

Phase 4 outputs. Regional risk products accessible to multiple national systems. Zone-based safe-trade certification support. Regional pandemic risk dashboards. Cross-border community exposure advisory networks.

12 Stakeholder Map and Change Management

12.1 Core stakeholders and their relationship to τ

Ministry of Agriculture / Veterinary Services. Primary operational stakeholders for livestock-wildlife interface intelligence and transboundary animal disease management. Their primary concern is not academic correctness but operational reliability: will the system help them respond faster and more precisely without creating false alarms that damage trade relationships? Change management priority: demonstrate false-positive rate discipline before operational adoption.

Ministry of Health / Food Safety Authorities. Responsible for INFOSAN national focal points, food-safety standards enforcement, foodborne illness surveillance, and community health advisory systems. Their primary concern is the interface between τ predictions and official food-safety authority — a system that generates advisories that conflict with official standards creates legal and political problems. Change management priority: establish clear decision authority protocol (τ advises, authority decides) before any public-facing advisory use.

Wildlife Management Agencies. Critical data holders (wildlife population and movement data) and essential partners for HPAI and zoonotic interface intelligence. Often institutionally siloed from veterinary and food-safety systems. Change management priority: data-sharing agreements and joint risk assessment protocols that respect wildlife agency mandate while enabling integration with food-safety and veterinary intelligence.

Smallholder Farmers and Pastoralist Communities. Both primary beneficiaries and primary data contributors. Their trust in the system is essential: if τ-driven advisories are perceived as surveillance tools that lead to penalties or market exclusions, uptake will be zero and data contributions will dry up. Change management priority: co-design advisory formats and delivery channels with farmer organizations; ensure advisory content is actionable and livelihood-preserving rather than purely prohibitive.

Live-Animal Market Operators and Informal Vendors. Major nodes in the exposure pathway with significant vulnerability to regulatory action. Their cooperation in providing operational data is necessary for accurate market-node risk assessment. Change management priority: ensure that τ-grade market risk intelligence is used for targeted support (cooling infrastructure, hygiene inputs, training) rather than primarily for shutdown enforcement.

Development Banks and Bilateral Donors. Primary funders for Phase 1-2 deployment. Their decision criteria are milestone-based program delivery and demonstrable public-good outcomes. Change management priority: benchmark reports with clear lead-time improvement metrics that translate to decision-relevant impact statements.

FAO, WOAH, and WHO Technical Staff. Essential for legitimacy, data access, and integration with global systems (INFOSAN, WAHIS, GLEWS+). Their primary concern is interoperability with existing systems and consistency with Codex and WOAH international standards. Change management priority: position τ as an intelligence enhancement layer for existing systems, not a replacement or competitor.

12.2 The trust architecture

τ-grade food safety intelligence will only be adopted and sustained if it builds institutional trust through a transparent performance record. The trust architecture requires three elements:

Performance transparency. Every τ prediction that intersects with a confirmed event outcome must be recorded, evaluated, and reported back to institutional partners. The system must be willing to acknowledge misses and false alarms, not only claim successes.

Uncertainty communication. Risk assessments must communicate uncertainty explicitly — not as a weakness but as an honest representation of the physical system. A risk forecast that says "60-75% probability of elevated aflatoxin conditions in northern Kenya in harvest week 34, based on current atmospheric drought index and soil moisture deficit" is more operationally useful than one that claims false precision.

Decision authority preservation. At every operational interface, τ must be positioned as advisory — providing intelligence that informs decisions made by appropriately authorized human decision-makers. This is not merely a legal safeguard; it is a design principle that makes the system more useful by ensuring that contextual knowledge held by veterinarians, food-safety inspectors, and community health workers is combined with the system's physical intelligence, not replaced by it.

13 Gender, Equity, and Labor Dimensions

13.1 Women's disproportionate exposure burden

Women in smallholder agricultural systems bear a disproportionate share of foodborne exposure risk through multiple pathways:

- **Food preparation.** Women perform an estimated 60-80% of food preparation work in most LMIC contexts. This means primary exposure to contaminated ingredients — improperly stored maize, unpasteurized milk, unsafe water for food preparation — falls disproportionately on women and their young children.
- **Informal market roles.** Women dominate informal food vending in many LMIC contexts — street food, fresh produce markets, live-animal retail, informal dairy sales. These settings have the highest exposure density and the lowest access to food-safety support infrastructure.
- **Smallholder poultry systems.** In Sub-Saharan Africa and South Asia, backyard poultry management is predominantly women's work. During HPAI events, the culling of backyard flocks represents disproportionate economic devastation for women with limited alternative income sources.
- **Breastfeeding and childcare.** Mycotoxin contamination of breast milk — documented in West Africa where aflatoxin M1 levels in breast milk have been found at concerning concentrations — represents an exposure pathway that is specific to breastfeeding women and their infants.

13.2 Equity dimensions in intelligence access and advisory delivery

The benefits of τ-grade food safety intelligence will not automatically reach the most exposed populations. Achieving equity requires explicit design choices:

Advisory delivery channels. Digital risk dashboards reach formally employed food-safety officers. They do not reach the smallholder farmer managing backyard poultry or the informal market vendor. Effective advisory delivery to these populations requires integration with community health worker networks, mobile-phone-based advisory systems (voice and SMS), farmer cooperative channels, and school feeding program supply networks.

Language and format. Risk advisories designed for regulatory officials are not useful for household food handlers. Equity requires translation of risk information into actionable, plain-language advisories in local languages that specify what to do differently, not just that risk is elevated.

Non-punitive framing. Intelligence that is perceived as a tool for detecting and penalizing non-compliant smallholders, vendors, or market operators will not be adopted by those populations and may actively drive unsafe practices underground. Equity requires that intelligence systems be designed to support rather than surveil the most vulnerable participants in food systems.

Compensation and livelihood protection. Better intelligence about where and when HPAI or mycotoxin risk is highest is only genuinely protective if it enables targeted, livelihood-preserving interventions. Intelligence without corresponding support infrastructure — drying equipment, biocontrol agents, biosecurity materials, fair compensation for affected livestock — does not deliver equity.

13.3 Labor safety at high-exposure nodes

Workers at live-animal markets, slaughter points, poultry processing facilities, and wildlife veterinary field stations face occupational HPAI and zoonotic spillover exposure that is not adequately addressed by current monitoring systems. The first US human H5N1 case in dairy farm workers in 2024 highlighted a surveillance gap: occupational exposure in agricultural workers is systematically under-detected by clinical surveillance systems designed for general population health.

A τ-grade system that identifies elevated-risk windows for specific operational settings would enable targeted occupational health interventions — enhanced PPE deployment, enhanced clinical screening, and pre-emptive antiviral prophylaxis for high-risk workers — during peak-risk periods. This is a direct labor safety application that should be explicitly integrated into deployment design.

14 Benchmark Suite and Success Metrics

A credible τ-grade food safety intelligence system must be benchmarkable against current systems with specific, falsifiable metrics. The following benchmark suite covers the three primary hazard types and the full deployment pathway.

14.1 Benchmark 1 — Mycotoxin Risk Detection Lead Time

Test. Against a held-out sample of confirmed high-aflatoxin detection events from national grain board and export certification records, compare: (a) date of τ-predicted elevated risk, (b) date of NWP-based drought/heat alert, (c) date of confirmed aflatoxin detection in commodity testing.

Success criterion. τ lead time advantage over confirmed detection of $\geq$6 weeks, at a false positive rate (districts with elevated τ risk but no confirmed contamination) of $\leq$25%. Rationale: 6 weeks is sufficient to deploy Aflasafe biocontrol agents and pre-position drying infrastructure. A false positive rate above 25% would impose unacceptable advisory fatigue and intervention cost burden on extension services.

Target dataset. USAID/USDA historical aflatoxin testing records for Kenya, Tanzania, and Uganda, 2010-2024. CGIAR IITA Aflasafe program historical records for West Africa.

14.2 Benchmark 2 — HPAI Interface Risk Warning Lead Time

Test. Against WOAH WAHIS confirmed HPAI outbreaks in commercial poultry in the 2021-2024 panzootic, compare: (a) date of τ-predicted elevated interface risk in the affected county/district (based on wild-bird migration front, atmospheric transport, farm biosecurity state), (b) date of first confirmed case in the affected flock, (c) date of WAHIS notification.

Success criterion. τ warning lead time of $\geq$21 days before confirmed first case, at a false positive rate (counties with elevated risk prediction but no confirmed outbreak within 35 days) of $\leq$30%.

Secondary metric. Spatial precision: what fraction of τ-predicted high-risk counties contain a confirmed outbreak within 35 days of the prediction vs. what fraction of confirmed outbreaks occur in τ-predicted high-risk counties?

Target dataset. WOAH WAHIS HPAI outbreak records 2021-2024 for the United States, France, Poland, and Japan — all countries with publicly available farm-location data at sub-national resolution.

14.3 Benchmark 3 — Shellfish Safety Closure Lead Time

Test. Against historical shellfish harvest closure records for Baltic and North Sea coastal areas, compare: (a) date of τ-predicted elevated Vibrio/HAB risk at specific harvest zones, (b) date of SST threshold exceedance that triggered current management closure, (c) date of confirmed Vibrio detection in shellfish tissue or confirmed HAB detection.

Success criterion. τ lead time advantage over current SST trigger of $\geq$5 days, at a false positive rate of $\leq$20%.

Target dataset. Swedish Food Agency and Finnish Food Authority shellfish closure records 2010-2024. Copernicus Marine Service Baltic Sea SST and biological parameters archive.

14.4 Benchmark 4 — Supply Chain Source Attribution Speed

Test. Against historical INFOSAN events involving supply-chain source attribution, present τ with: the notification time, the confirmed contamination data, and the supply-chain graph for the affected commodity. Measure: time required for τ to identify the most probable contamination origin point vs. conventional trace-back investigation time.

Success criterion. τ attribution time (from notification receipt to probable-origin identification) $\leq$48 hours, with correct attribution to within one supply-chain node of confirmed origin in $\geq$70% of test events.

Target dataset. Published INFOSAN event summaries with confirmed source attribution, 2015-2024.

14.5 Benchmark 5 — Community Exposure Advisory Precision

Test. In a community with documented household food-safety practices and a known high-exposure event (e.g., school feeding program contamination event, informal market foodborne illness cluster), compare: (a) τ-generated risk advisory specificity (hazard type, exposure route, recommended action) vs. (b) generic national food-safety advisory content.

Success criterion. τ advisory specifies correct hazard type and primary exposure route in $\geq$80% of test cases, and recommended action is judged operationally feasible and livelihood-preserving by community health worker panel in $\geq$70% of cases.

Target dataset. Published foodborne illness cluster investigations in school feeding and informal market settings in Kenya, Bangladesh, and Vietnam, 2015-2024.

14.6 Operational Success Metrics (Post-Deployment)

Beyond benchmarking performance, deployed systems should be evaluated on:

- **Detection lag reduction.** Average time from physical/ecological risk condition onset to actionable advisory, compared to pre-deployment baseline.
- **False positive rate.** Fraction of risk advisories that do not correspond to confirmed events within the prediction window. Target: $\leq 20\%$ for operational advisories.
- **Intervention uptake.** Fraction of advisory recipients who implement recommended pre-event measures. Target: $\geq 60\%$ for farmer/operator advisories delivered through trusted channels.
- **Livelihood impact of τ-guided interventions vs. reactive shutdowns.** Measure: household income loss associated with τ-advisory-driven targeted interventions vs. control communities using reactive shutdown management. Target: $\leq 50\%$ of household income loss per event for τ-guided interventions.
- **Zoonotic spillover incidence.** In areas with deployed τ-grade HPAI interface intelligence, track confirmed human H5N1 exposure events in agricultural workers before and after deployment.

15 Governance Guardrails

Food safety and zoonotic-risk intelligence operates at a domain intersection that creates specific governance risks not present in other applications of predictive intelligence. These guardrails are not optional features — they are design requirements.

15.1 No replacement of official food-safety authority

τ-grade intelligence systems must not replace the decision authority of food-safety regulators, veterinary officers, and public-health officials. In every jurisdiction, official food-safety standards are set under domestic law and international treaty (Codex Alimentarius, WOAH Terrestrial Animal Health Code, SPS Agreement). A predictive intelligence system that generates advisories inconsistent with official standards creates legal uncertainty and institutional conflict.

The correct design: τ generates intelligence that informs official decisions. The decision authority remains with the official. Risk advisories generated by τ must be clearly labeled as intelligence inputs, not official determinations.

15.2 Smallholder and informal sector protection

Intelligence systems must not become tools for surveillance and penalization of the weakest actors in food systems while larger and more powerful actors externalize their risks. A market operator who receives a τ-generated risk alert and responds by improving hygiene practices should not be disadvantaged relative to one who ignores alerts.

Guardrail: τ risk alerts in informal and smallholder contexts should be paired with support resources (drying equipment, biocontrol agents, hygiene inputs, veterinary support), not used primarily as triggers for regulatory action.

15.3 Wildlife protection and ecological literacy

Because spillover risk can be amplified by habitat disruption and human land-use change — not just by wildlife presence — wildlife must not be treated as the primary or sole source of interface risk. A governance failure mode to guard against: τ-generated interface risk assessments that identify wildlife movement as a risk factor being used to justify culling or habitat destruction rather than livestock biosecurity improvement or land-use modification.

Guardrail: τ interface risk assessments must always present wildlife contact risk and human land-use/livestock management risk as co-factors, with explicit framing that management options exist across both domains.

15.4 Transparency, auditability, and uncertainty communication

Risk outputs from τ must be: - Publicly auditable against confirmed outcomes where data is available - Calibrated in their uncertainty — stating confidence intervals honestly rather than suppressing uncertainty to appear more decisive - Explainable in terms that can be understood by the regulatory and community actors who receive them

A risk advisory that cannot be explained — "our model says the risk is high" without any interpretable physical basis — will not be trusted, adopted, or appropriately used.

15.5 Equity in data access and benefit sharing

Communities and smallholder farmers whose animal health and food handling data contributes to τ's intelligence capabilities must be included in the systems that benefit from that intelligence. Data dignity — the right of communities to benefit from intelligence derived from their data — is both an ethical requirement and a practical necessity for sustained data contribution.

Guardrail: deployment contracts and program frameworks must include explicit data governance provisions specifying community access to risk intelligence derived from their data, in formats appropriate to their use cases.

15.6 Compatibility with international standards

All τ-generated food-safety and animal-health intelligence must be designed for compatibility with: Codex Alimentarius food-safety standards; WOAH Terrestrial and Aquatic Animal Health Codes; SPS Agreement risk assessment principles; and INFOSAN/WAHIS data-sharing protocols. This compatibility is not just a legal requirement — it is what will enable τ intelligence to be accepted by trading partners and international regulators as a credible basis for safe-trade decisions.

16 SDG Mapping and Bottom Line

16.1 SDG Alignment

τ-grade food safety and interface intelligence contributes directly to multiple UN Sustainable Development Goals:

SDG 2 — Zero Hunger. Food safety is integral to food security. Aflatoxin-contaminated crops represent direct food security failures for smallholder households. HPAI culling events destroy the livestock assets that are the primary nutrition buffer for the poorest households. Better intelligence that reduces contamination events and more precisely manages interface disease events directly contributes to SDG 2 targets.

SDG 3 — Good Health and Well-Being. The primary impact domain. Six hundred million foodborne illnesses and 420,000 deaths annually are a direct SDG 3 indicator failure. Target 3.3 (ending epidemics, including zoonotic diseases) and Target 3.d (strengthening early warning and risk reduction capacity for national and global health risks) are both directly addressed.

SDG 5 — Gender Equality. Women's disproportionate exposure to foodborne and zoonotic risk through food preparation, informal market, and smallholder poultry management roles makes gender-responsive food safety intelligence a SDG 5 delivery mechanism, particularly in contexts where reduced foodborne illness burden improves women's and children's nutritional status and labor productivity.

SDG 8 — Decent Work and Economic Growth. Livelihood-preserving disease response — enabled by targeted, intelligence-driven interventions rather than blunt shutdowns — is a direct SDG 8 contribution. Agricultural worker safety (occupational HPAI exposure) is an SDG 8.8 issue.

SDG 9 — Industry, Innovation, and Infrastructure. τ-grade climate-coupled food safety intelligence represents a genuine infrastructure innovation for food systems — building the predictive intelligence layer that food systems in a climate-changing world require.

SDG 15 — Life on Land. Ecologically literate interface risk management that protects wildlife as part of the solution rather than identifying it only as a threat directly serves SDG 15 biodiversity targets.

SDG 17 — Partnerships for the Goals. The institutional architecture required for τ-grade food safety intelligence — linking WHO, FAO, WOAH, national systems, wildlife agencies, and community health networks through a shared intelligence substrate — is itself a model for the multi-stakeholder partnerships SDG 17 envisions.

16.2 The Bottom Line

This paper's central argument is simple and can be stated in four sentences.

The official burden of unsafe food — 600 million illnesses, 420,000 deaths, USD 110 billion in LMIC losses annually — is not declining because current surveillance and inspection systems are fundamentally reactive. The livestock-wildlife-human interface is a structural risk that is getting worse as climate change, land-use expansion, and ecosystem disruption accelerate. The physical-ecological drivers of the three most tractable hazard types — mycotoxins, avian influenza, and coastal Vibrio — are, in principle, predictable with sufficient lead time to enable prevention rather than response. A τ-grade system that provides law-faithful, bounded-error mechanistic coupling across atmospheric, ecological, biological, and food-system dynamics could shift the operational paradigm from reactive detection to predictive prevention — moving the action window from after-cases to before-conditions.

In a realistic-optimistic scenario, that shift means: - 10-16 weeks of advance warning for aflatoxin risk windows in Sub-Saharan Africa, enabling 40 million smallholders to avoid the crop storage conditions that generate contamination - 21-35 days of advance warning for HPAI interface risk along wild-bird migration corridors, enabling pre-emptive biosecurity that reduces the USD 3.3 billion/season culling burden and the pandemic risk it represents - 7-14 days of advance warning for Vibrio/HAB risk windows in warming coastal waters, protecting shellfish industries and coastal communities from emergency shutdowns that current reactive systems require - Targeted, livelihood-preserving community advisories that reach the women, smallholder farmers, and informal market workers who bear the disproportionate exposure burden — with specific, actionable guidance rather than generic messaging

The investment case is strong, the institutional alignment is favorable, and the humanitarian stakes are among the highest in the τ impact portfolio. This is a first-tier opportunity.

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This paper is one of four companion dossiers in the Panta Rhei Impact: One Health Portfolio. The portfolio shares a common τ substrate across food safety, environmental surveillance, health-system resilience, and precision public health. All claims about τ capabilities are working assumptions for deployment planning purposes, explicitly conditional on the τ framework’s operational validity.

Panta Rhei Impact — One Health Portfolio · 2026-03-16

Source: Full manuscript text integrated from Public-Good Briefing draft.

18 Dossier accountability addendum

The following addendum records the release-facing accountability layer for this dossier: claim boundaries, baseline evidence, upstream dependencies, translation assumptions, scenario bands, scorecard rationales, benchmark requirements, governance guardrails, and related Panta Rhei surfaces. It is intentionally downstream of the full source argument above.

Impact thesis

A Public-Good Briefing showing how a law-faithful tau human-animal-environment twin could provide unusually high humanitarian leverage in food safety intelligence, livestock-wildlife interface risk, and community-level exposure pathway attribution. The v3 impact thesis is conditional: a Tau-grade food-safety, livestock, wildlife-interface, and community-exposure twin would become valuable if it improves benchmarked public decisions while preserving transparent uncertainty, reviewability, and governance control.

18.1 Public-good burden and baseline evidence

A Public-Good Briefing showing how a law-faithful tau human-animal-environment twin could provide unusually high humanitarian leverage in food safety intelligence, livestock-wildlife interface risk, and community-level exposure pathway attribution. The public-good burden is treated here as an institutional decision problem: existing agencies already monitor parts of the domain, but the operational handoff from data to timely, auditable action remains incomplete.

18.1.1 External evidence baseline

- **WHO**, Global Antibiotic Resistance Surveillance Report 2025 [6]: AMR surveillance baseline.
- **FAO, UNEP, WHO, and WOAH**, One Health Joint Plan of Action [2]: One Health governance baseline.
- **UNEP**, Bracing for Superbugs: Strengthening Environmental Action in the One Health Response to AMR [5]: environmental AMR pathway baseline.
- **WHO**, Wastewater and Environmental Surveillance: Summary for Antimicrobial Resistance [7]: wastewater and environmental surveillance baseline.
- **WOAH**, One Health [8]: animal-health and zoonotic-risk governance context.
- **CDC**, National Wastewater Surveillance System [1]: operational wastewater surveillance reference.

18.2 Current institutional landscape

The relevant landscape includes public agencies, research infrastructures, standards bodies, development-finance channels, and domain review communities represented in the evidence base, including CDC, FAO, UNEP, WHO, and WOAH, UNEP, WHO, WOAH. These references are evidence and adoption surfaces, not endorsements or deployment partners.

18.3 Capability gap

The practical gap is a benchmarkable translation gap: current systems expose useful data or partial models, but they do not yet provide a single law-faithful, bounded-error decision layer for food-safety, livestock, wildlife-interface, and community-exposure twin.

18.4 Tau framework dependency map

Surface	Role in this dossier
Build the Tau-Kernel	finite address and scalar foundation
Recover Core Mathematics	mathematical bridge and model interface
Derive Physics	physical readout and domain translation candidate
Results lane	upstream consequences to be mapped precisely during release preparation
direct-registry-mapping-withheld	no direct Registry object is asserted until a substantive Corpus mapping is available
public-docs-mapping-withheld	TauLib module links are asserted only where public documentation exposes a clear surface
Release Manifest	release baseline
Predictions and Falsification	empirical accountability route

18.5 Translation assumptions and missing engineering

Required domain model: **food-safety, livestock, wildlife-interface, and community-exposure twin**.

First benchmarkable test: contamination, spillover, and exposure-risk alerts against food-safety, veterinary, and public-health surveillance records.

- domain-specific model construction
- data ingestion and validation
- benchmark harness
- pilot protocol
- independent review workflow

18.6 Impact mechanism chain

Public-good burden → external evidence baseline → τ capability hypothesis → upstream Results / Corpus / Verify dependency → translation assumptions → benchmarked pilot → governed adoption pathway.

18.7 Scenario bands

Band	Scenario summary	Confidence
Conservative	A narrow shadow-mode pilot improves one bounded decision task for Food Safety, Livestock/Wildlife Interface, and Community Exposure Intelligence without operational authority.	medium
Realistic	A reviewed prototype strengthens several public-sector workflows for Food Safety, Livestock/Wildlife Interface, and Community Exposure Intelligence after benchmark comparison with incumbent systems.	medium-low
Optimistic	A reusable public-good intelligence layer becomes plausible for Food Safety, Livestock/Wildlife Interface, and Community Exposure Intelligence after external validation and transparent governance review.	low

18.8 Impact scorecard

Public-good scale	5/5	The affected public-good burden is large or institutionally significant within the portfolio.
Tau fit	4/5	The proposed pathway depends on coupled state, bounded uncertainty, and compositional modelling rather than isolated prediction alone.
Evidence proximity	4/5	The evidence base is anchored in public institutions, official monitoring systems, or established scientific reviews.
Measurability	4/5	A first benchmark can be framed against incumbent public datasets, institutional records, or operational decision metrics.
Adoption readiness	3/5	Adoption remains conditional on domain review, governance fit, data access, and institutional integration.
Equity leverage	5/5	The pathway can prioritize underserved or vulnerable populations where public access and safeguards are built in.

18.9 Candidate pilot pathways

One Health exposure pilot linking food-safety, veterinary, wildlife, and public-health agencies

18.10 Benchmark suite and success metrics

Type	Incumbent baseline	Required benchmark	Tau	Success metric	Validator

translation benchmark	current public or institutional systems in the domain	contamination, spillover, and exposure-risk alerts against food-safety, veterinary, and public-health surveillance records	pre-registered accuracy, latency, uncertainty, or decision-quality metric	independent domain reviewers
governance benchmark	existing audit, disclosure, and reporting practice	transparent assumption, data, model, and failure-mode disclosure	reviewable evidence pack and adverse-outcome protocol	public-sector or expert governance panel
equity benchmark	current access, service-quality, or exposure disparities	documented pathway for underserved or vulnerable users without hidden exclusion	distributional benefit and risk review before pilot expansion	equity, community, or public-interest review process

18.11 Governance and risk guardrails

- Human oversight for any operational use.
- Public benchmark disclosure before institutional adoption.
- Equity access review for underserved or vulnerable communities.
- Data-rights and privacy controls for operational datasets.
- Misuse-prevention and adverse-outcome monitoring.
- Adverse-outcome monitoring with a documented escalation path.
- External domain review before pilot expansion.

18.12 Related Results / Corpus / Verify / Publications

This dossier is downstream of Results, Corpus, Verify, and Publications surfaces. It is not a Registry object. Direct Registry or TauLib links are asserted only where the mapping is substantive rather than decorative.

18.13 Bibliography and external evidence

References

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Panta Rhei Research Program

Public-Good Impact Dossier

Tau for Food Safety, Livestock/Wildlife Interface, and Community Exposure Intelligence

Dossier ID: PGID-OH-02 Portfolio: One Health Release: May 2026
publication-ready release

Conditional scenario map. Domain review pending. Deployment, product, validation, certified-impact, and policy-commitment claims are not made.

Public contact and review routes

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