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From Pacific Warming to Global Economic Stress: El Niño Exposure, Transmission Channels, and an Integrated Agenda for Anticipatory Economic Resilience: A Review

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ABSTRACT

El Niño is commonly described as a climatic disturbance, yet its economic consequences are better understood as a networked shock that travels through food systems, water and energy systems, labor markets, public health, trade, logistics, fiscal accounts, and inflation. This qualitative literature review synthesizes peer-reviewed evidence published since 2020 and uses a ten-economy Asian exposure scorecard as an empirical organizing device. The scorecard highlights large cross-country differences in net food trade, food and staple weights in consumer prices, agricultural value added, agricultural employment, and aggregate structural vulnerability. India, the Philippines, and Indonesia display the highest aggregate exposure in the scorecard, while Singapore, Hong Kong, Taiwan, and South Korea exhibit lower direct agricultural sensitivity but remain exposed through imported food, energy, exchange-rate, and logistics channels. The review shows that realized losses cannot be inferred mechanically from exposure scores because El Niño effects are nonlinear, geographically heterogeneous, and conditioned by event type, forecast uncertainty, stocks, irrigation, trade structure, fiscal space, social protection, and institutional capacity. The central policy implication is that governments should treat forecast lead time as an economic asset. A forecast-to-finance-to-action framework is proposed to connect seasonal climate information with sectoral risk translation, pre-agreed triggers, contingent financing, targeted interventions, and post-event learning. Global resilience therefore requires differentiated national measures combined with regional trade coordination, shared early warning systems, strategic reserves, climate-resilient agriculture, energy-water planning, public-health preparedness, and anticipatory social protection.

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Introduction

The El Niño-Southern Oscillation (ENSO) is the dominant source of interannual climate variability in the tropical Pacific and one of the most consequential mechanisms through which ocean-atmosphere dynamics influence weather far beyond the Pacific basin. During El Niño, anomalous warming of the central and eastern equatorial Pacific alters the Walker circulation and affects rainfall, temperature, drought, flooding, marine conditions, and the probability of certain extremes across multiple continents. The economic significance of these teleconnections is not limited to agriculture. They can affect hydropower, energy demand, wildfire and smoke exposure, fisheries, health, labor productivity, logistics, infrastructure, and commodity markets, ultimately influencing output, inflation, public finances, trade balances, and household welfare [1-3].

Three developments make a renewed economic review especially urgent. First, recent climate research suggests that ENSO characteristics, rainfall variability, and some extreme El Niño risks may change as the climate warms, even though projections vary across models and event types [4]. Second, forecast science is improving in important dimensions, including the possibility of useful ENSO information at seasonal and, under some conditions, multi-year horizons, although the spring predictability barrier and event-type uncertainty remain material [5-7]. Third, recent macroeconomic studies have reopened the debate about persistence, asymmetry, and sign: some research finds large and persistent global economic losses from El Niño, while other work using different samples and global time-series structures finds more limited inflationary effects and, in some specifications, temporary output gains [8-9].

The attached scorecard provides a useful empirical starting point because it compares ten Asian economies along structural dimensions that can amplify or dampen an El Niño shock. Its aggregate z-score is calculated from net food imports as a share of GDP, the food share in the consumer price index (CPI), agriculture's share of GDP, and agriculture's share of employment. Rice and energy CPI weights are reported separately and therefore should be interpreted as complementary transmission indicators rather than components of the aggregate score. India records the highest aggregate score (104.7), followed by the Philippines (103.2) and Indonesia (102.0); Singapore has the lowest score

(96.5). The ranking is analytically revealing because a country can be a net food exporter and still be highly vulnerable through domestic production and livelihoods, while a highly urbanized importer can have little domestic agricultural exposure but remain sensitive to imported prices and supply networks.

This distinction motivates the article's core argument: El Niño economic vulnerability is multidimensional and should be analyzed as the interaction of hazard, exposure, sensitivity, adaptive capacity, and policy response rather than as a single climatic or trade statistic. A structural exposure indicator answers the question, "where are potential transmission channels relatively strong?" It does not answer the separate causal question, "how large will realized GDP or welfare losses be in a specific event?" Realized outcomes depend on event intensity and spatial pattern, the timing of anomalies relative to crop and hydrological calendars, inventories, irrigation, import diversification, exchange rates, fiscal space, public health capacity, and whether institutions act before or after the shock [10-11].

Accordingly, this review addresses five questions. First, through which food and non-food channels do El Niño affect national economies? Second, how do the structural variables in the scorecard help explain cross-country heterogeneity? Third, how can direct climate and sectoral disturbances create second-round effects on prices, growth, trade, employment, health, and fiscal accounts? Fourth, which policy combinations can reduce those losses? Fifth, how can governments and international institutions convert probabilistic ENSO forecasts into anticipatory economic action? The contribution is integrative rather than exhaustive: it connects recent climate science, agricultural and food-security research, macroeconomics, energy-water studies, public health, disaster risk management, and anticipatory action in one qualitative framework.

Literature Review

ENSO as a Climate-Economic Phenomenon

ENSO is not a homogeneous treatment that produces a uniform global response. Eastern-Pacific and Central-Pacific events differ in where sea-surface temperature anomalies peak, in their atmospheric responses, and in the teleconnections that follow. The onset, persistence, and decay of El Niño can also differ across events, and recent work suggests that future warming may alter the timing and persistence of the warm phase. This physical heterogeneity matters economically because the same country may experience different combinations of drought, extreme heat, heavy rainfall, or marine disruption across El Niño episodes. The appropriate economic object is therefore not "El Niño" as a binary variable alone, but a conditional distribution of hazards given event type, strength, season, and location.

Forecastability is equally central. The value of ENSO information is not only scientific; it is operational. Research demonstrates meaningful prediction skill beyond very short weather horizons and, in particular circumstances, enhanced multi-year predictability after strong ENSO states. Yet forecast skill is state-dependent and can deteriorate around the boreal spring, especially for Central-Pacific ENSO under projected warming. Policy systems should therefore use probabilities and calibrated decision thresholds rather than treating an ENSO forecast as a deterministic declaration of future loss.

The economic literature also cautions against assuming linearity. Find nonlinear and persistent macroeconomic damages, with stronger effects for El Niño than for La Niña in their climate-economy specification. using more than 1,100 local food markets in sub-Saharan Africa, similarly identifies asymmetric and spatially heterogeneous food-price responses to ENSO [12]. At the same time, report a different global macroeconomic pattern, in which El Niño is associated with higher output and relatively limited inflation while La Niña generates more pronounced food-inflation effects. These findings are not mutually reducible because they use different data frequencies, samples, identification strategies, ENSO measures, and lag structures. A qualitative review should preserve that disagreement rather than force a single average effect.

Conceptualizing Exposure, Sensitivity, and Adaptive Capacity

A useful analytical distinction separates exposure, sensitivity, and adaptive capacity. Exposure describes the degree to which an economy, sector, or household is connected to a climate-sensitive activity. Sensitivity captures the intensity with which an exposed unit responds: for example, a rainfed crop system is generally more sensitive to rainfall anomalies than a well-managed irrigated system. Adaptive capacity refers to the resources and institutions that reduce losses, including irrigation, storage, trade diversification, financial instruments, health systems, social protection, infrastructure redundancy, and credible public decision-making. These dimensions combine to produce realized vulnerability.

The scorecard mainly captures structural exposure and sensitivity. Agriculture's shares in GDP and employment approximate the economic and livelihood importance of climate-sensitive production; the food share in the CPI approximates consumer exposure to food-price movements; and net food imports capture one aspect of external dependence. Yet the score omits key buffers, including crop insurance, reservoir storage, strategic stocks, the diversity and reliability of suppliers, fiscal space, social protection coverage, and the credibility of macroeconomic institutions. It therefore should be used as a screening device rather than a deterministic damage index.

This conceptual separation is supported by broader climate and food-system research. find large cross-country and cross-crop heterogeneity in temperature-yield relationships and show that irrigation can alleviate some adverse impacts [13]. Demonstrate that climate impacts on global agriculture can emerge earlier in newer crop-model generations, show that warming can reduce output through both yield and cropping-frequency channels. These studies imply that the same climatic anomaly can have materially different economic effects depending on technology, water access, crop choice, and management.

Food-System Transmission Channels

The first and most visible El Niño transmission channel runs from climate anomalies to soil moisture, water availability, crop stress, planting decisions, yields, and livestock conditions. show that ENSO information can forecast a meaningful portion of yield variation for major crops, although predictability varies by crop, region, growing season, and ENSO phase. using cacao production in Sulawesi as a proof of concept, show how ENSO information can be connected to farm management decisions such as fertilizer use [14]. Crop-specific evidence from Colombia likewise finds heterogeneous responses for rice and common beans. The policy implication is not merely to forecast harvest losses; it is to use lead time to adjust planting, irrigation, input use, procurement, storage, and extension services before the shock fully materializes.

A second channel links production to inventories and domestic availability. A modest yield loss can have limited consumer impact if inventories are ample and release mechanisms work; the same physical loss can become inflationary when stocks are thin or procurement and logistics are rigid. Conversely, panic procurement or poorly timed export restrictions can amplify scarcity expectations. Global food systems are especially sensitive to synchronized shocks in major producing regions and to simultaneous disruptions in inputs such as fertilizer, machinery, and fuel [15]. This is one reason that resilience needs to be evaluated across the production-storage-trade chain rather than at the farm gate alone.

Third, trade can function as both insurance and transmission. Janssens et al. (2020) show that international trade can reduce hunger risks associated with geographically uneven climate impacts by allowing production shortfalls in one region to be offset by supplies from another. However, the same integration exposes importers to global price spikes, currency depreciation, shipping disruptions, and policy responses in exporting countries. Friel, Schram, and emphasize that trade rules shape the policy space available to governments, and highlight the global competition among crop uses that constrains the food available for direct consumption. Thus, trade diversification and predictable rules are more defensible resilience strategies than either autarky or unconstrained dependence on a narrow supplier base [16-17].

Fourth, international commodity shocks must pass through domestic markets before they affect household welfare. The magnitude and persistence of pass-through depend on exchange rates, taxes, subsidies, administered prices, market concentration, transport costs, and the commodity composition of consumption. document nonlinear El Niño-food price relationships in Colombia, while finds that ENSO affects roughly half of the local food-price series analyzed in sub-Saharan Africa, with significant commodity and geographic differences. This evidence supports the scorecard's emphasis on the food share in the CPI and its supplementary rice weight: a staple-price shock is more macroeconomically salient when the affected item has a large consumer budget share [18].

Finally, food-price shocks have distributional and nutritional consequences. Households near subsistence allocate a larger fraction of expenditure to food and have less capacity to smooth shocks [19]. show that macroeconomic downturns are associated with higher child wasting in low- and middle-income countries, while demonstrate that extreme climate events can increase global food-insecurity risks and adaptation requirements [20]. further illustrate the structural fragility of food security in small island developing states, where remoteness and import dependence compound nutritional risk. Food inflation is therefore not only a CPI issue; it can be a human-capital and inequality shock [21].

Non-Food Transmission Channels

A comprehensive economic assessment must move beyond food. Water and energy are a first major non-food channel because El Niño-associated drought can reduce river flows and reservoir levels, impair hydropower production, and alter electricity system costs. show that ENSO-modulated drought in the Greater Mekong can reduce hydropower availability and increase reliance on thermal generation, raising both costs and emissions. At global scale demonstrate that streamflow drought can generate substantial hydropower reductions in many countries. This water-energy interaction can feed back into food through irrigation costs, fertilizer production, refrigeration, and transport [22].

Heat and labor constitute a second non-food pathway. El Niño can raise regional temperatures and the probability of record-breaking heat in some locations, with implications for occupational exposure and productivity review evidence that occupational heat stress creates a material economic burden through reduced work capacity, synthesize evidence on heat-related labor productivity losses. For economies with large outdoor workforces, the labor channel can operate simultaneously with agricultural yield losses, reinforcing income and output effects [23].

Health is a third pathway. ENSO can influence heat exposure, rainfall-sensitive infectious disease conditions, water quality, smoke, and nutrition. associate ENSO-related climate variability with excess mortality and medical costs among older adults in China [24]. Report higher risks of child mortality following maternal exposure to El Niño-like conditions across multiple low- and middle-income countries, and identify persistent effects on mortality improvement and life expectancy in Pacific Rim populations [25-26]. consequently, argue that El Niño deserves explicit attention in public-health emergency preparedness. These studies imply that a narrow focus on farm output can understate both welfare and fiscal costs.

Wildfire, smoke, and land hazards provide additional channels. document substantial El Niño-driven changes in global fire during the 2015-16 event, while show how ENSO and climate change can combine to produce extreme fire weather. In Southeast Asia, El Niño-related dry conditions have long interacted with land use to intensify haze; recent evidence from Malaysia and Borneo documents the air-quality consequences of this mechanism. Rahman, further show the economic-development context in which forest fires affect Indonesian regional air quality. Landslides constitute a contrasting precipitation-related risk: demonstrate strong global links between El Niño and landslide exposure, especially in parts of Southeast Asia and Latin America [27].

Marine ecosystems and fisheries also matter economically. Review social-ecological impacts of ENSO on Galapagos small-scale fisheries, including changes in landings, costs, and livelihood security [28]. Marshak and Link connect marine primary production to fisheries economic performance more generally. These pathways can affect food supply, export earnings, employment, and coastal livelihoods, illustrating again why the economic footprint of El Niño is broader than terrestrial agriculture.

From Sectoral Shocks to Macroeconomic Outcomes

Sectoral disturbances become macroeconomic when they are large, persistent, synchronized, or propagated through prices and networks. estimate that historical El Niño events can generate persistent country-level growth effects that accumulate into very large global losses. similarly estimate nonlinear economic damages that continue after the initial climatic shock. The mechanism can include lost agricultural and fisheries output, lower labor productivity, damage to infrastructure, foregone investment, health burdens, and supply-chain disruption. These findings motivate attention to dynamic effects rather than treating El Niño as a one-year deviation.

Inflation is a parallel transmission mechanism. A climate-related food shock raises headline inflation directly when food has a high CPI weight, and it can generate second-round effects if wages, expectations, services, or transport costs adjust. The scorecard indicates particularly high food weights in India and the Philippines, increasing the macroeconomic salience of food disturbances. The rice weight is especially notable in the Philippines, where a rice shock can be visible in both household

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welfare and the headline price index. Energy-price effects can reinforce this process if drought reduces hydropower or heat changes electricity demand. The resulting policy problem is difficult because central banks cannot create food or water, yet persistent supply shocks can still destabilize expectations and real incomes.

External accounts can move through both quantities and prices. Net food importers may face a larger import bill when global food prices rise, while exporters can benefit from higher prices but lose volumes if domestic harvests deteriorate. Exchange-rate depreciation can amplify imported inflation. Fiscal balances may also weaken through emergency food programs, targeted subsidies, disaster reconstruction, health expenditure, public utility losses, and lower tax receipts. These channels are one reason exposure scores should be complemented by fiscal-space and institutional indicators in future versions.

Integrated Transmission Framework

Figure 1 summarizes the central analytical proposition of this review. The reader should focus on the sequence rather than any single arrow: ENSO first changes the probability of regional hazards; those hazards affect sectoral production and capacity; sectoral shocks then travel through prices, trade, employment, finance, and supply chains; and only after these stages do they become macroeconomic and distributional outcomes. The lower band is equally important because exposure, sensitivity, adaptive capacity, policy response, and international spillovers condition every stage.

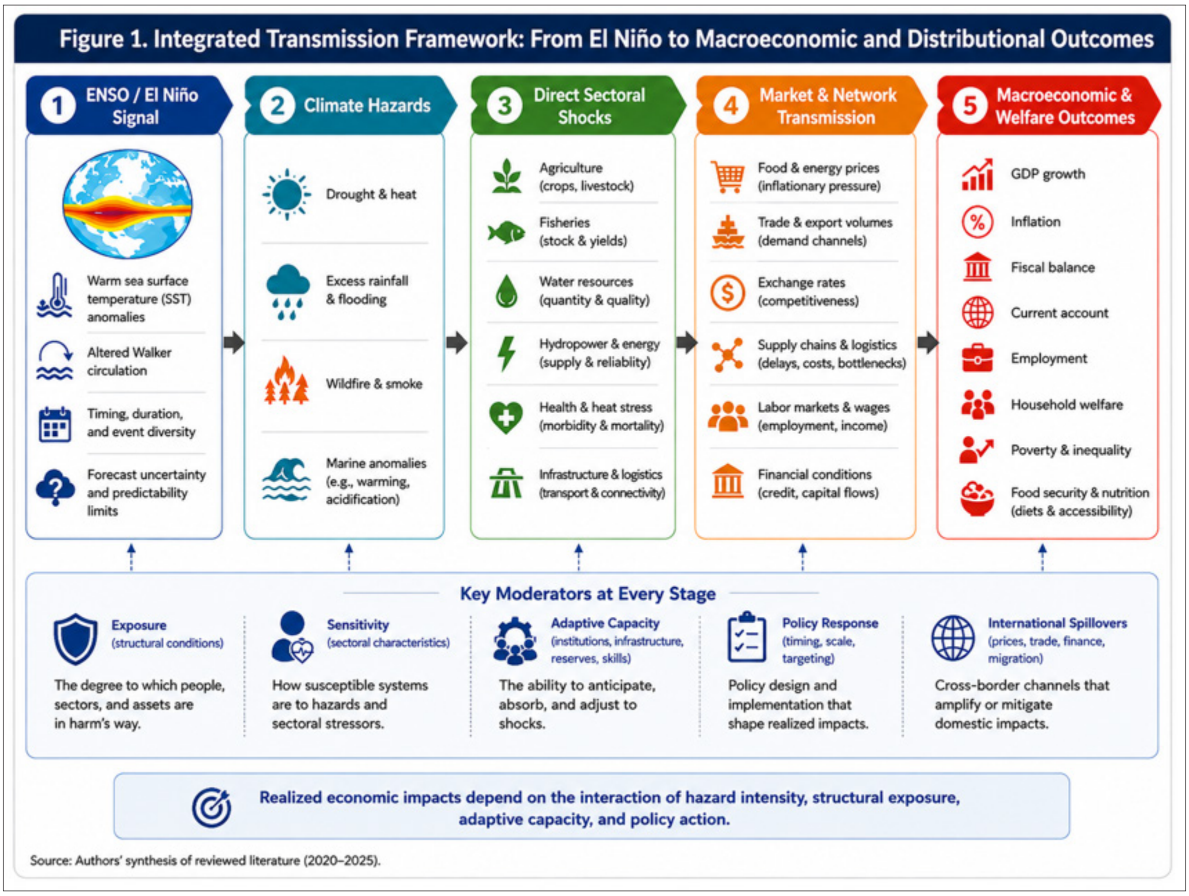

Figure 1: Integrated transmission framework from El Niño to macroeconomic and distributional outcomes.
Source: Author's synthesis of the reviewed literature.

The framework clarifies why two countries exposed to the same El Niño can experience different outcomes. A drought can generate a small macroeconomic loss where irrigation, crop insurance, inventories, diversified imports, and social protection are strong, but a much larger loss where rainfed agriculture dominates employment, and households devote a large share of income to food. The same logic applies to non-food channels: resilient electricity systems, robust hospitals, heat-action plans, and redundant transport networks can prevent a climatic disturbance from cascading into a generalized economic shock. The conceptual model therefore rejects both climate determinism and purely sectoral analysis.

Method

Research Design

This study employs a qualitative, narrative-integrative literature review rather than a systematic literature review (SLR). The purpose is explanatory and synthetic: to connect mechanisms and policy implications across disciplines that use different methods, units of analysis, and outcome variables. The review does not claim exhaustive retrieval, does not use PRISMA as an organizing protocol, and does not estimate a pooled effect size. This design follows contemporary guidance that literature reviews can constitute independent scholarly studies with different legitimate aims and degrees of structure, and that qualitative analysis can be used to organize heterogeneous evidence into a coherent interpretive account [29-30].

The design is deliberately distinct from qualitative evidence synthesis as a formal systematic-review family. show that qualitative evidence synthesis generally retains systematic procedures for identifying and appraising primary qualitative studies [31]. By contrast, the present study adopts purposive and iterative selection to answer a multidisciplinary economic question: how El Niño propagates across food and non-food systems, how structural characteristics influence cross-country exposure, and which anticipatory policy combinations are most defensible.

Literature Identification and Selection

Peer-reviewed journal literature published from January 2020 through August 2026 was prioritized. Searches were conducted iteratively across scholarly search engines and publisher platforms using combinations of terms related to El Niño, ENSO, economic growth, food prices, inflation, crop yields, food security, hydropower, drought, heat stress, health, wildfire, landslides, fisheries, climate services, early warning, anticipatory action, and forecast-based financing. The temporal boundary was chosen to emphasize contemporary evidence and recent improvements in climate prediction and impact modeling.

Selection was purposive rather than exhaustive. Studies were retained when they contributed at least one of four elements: a causal or empirical estimate of an ENSO-related impact; evidence on a relevant climate-economic transmission channel; evidence on adaptation or anticipatory action; or methodological guidance for qualitative literature review. Priority was given to established peer-reviewed journals, studies with transparent methods, multi-country or global analyses, and country studies that illuminate mechanisms relevant to the scorecard economies. The final reference set contains more than fifty peer-reviewed journal articles from 2020 onward, complemented by the attached scorecard as the cross-country empirical anchor.

Thematic Analysis and Cross-Country Interpretation

The literature was coded conceptually around six thematic families: (1) ENSO dynamics and predictability; (2) agriculture, food production, and food prices; (3) water, energy, labor, health, hazards, and fisheries; (4) macroeconomic transmission; (5) cross-country structural exposure; and (6) anticipatory and resilience policies. Within each theme, attention was paid to mechanisms, direction of effect, lag structure, nonlinearities, heterogeneity, and policy moderators. Conflicting findings were treated as substantive evidence about model dependence and context rather than as noise to be discarded.

The scorecard was then used for comparative interpretation. No new causal econometric estimation was performed. Instead, the values were read as structural indicators that help organize country archetypes. For Figure 3, two illustrative normalized composites were constructed solely for visualization: domestic agricultural sensitivity averages min-max normalized agriculture-GDP and agricultural-employment shares, while external/consumer exposure averages normalized net food imports and food, rice, and energy CPI weights. These composites are not official Nomura indicators and should not be used as rankings; they are a heuristic map for comparing transmission structures.

Limitations

The method has four limitations. First, a qualitative review cannot guarantee exhaustive coverage and is more exposed than an SLR to author judgment in study selection and emphasis. Second, the scorecard is cross-sectional and does not represent event-specific hazards or adaptive capacity. Third, ENSO teleconnections vary in space and time, so structural exposure alone cannot predict realized losses. Fourth, the literature is uneven across sectors: agriculture and climate dynamics are comparatively mature, whereas integrated evidence connecting ENSO to fiscal, monetary, health, and network outcomes remains thinner. These limitations are addressed by triangulation, explicit preservation of conflicting findings, and cautious language that distinguishes exposure from causally identified damage.

Results

Cross-Country Structural Exposure in the Scorecard

The scorecard as illustrated in Figure 2 reveals three broad patterns. First, the highest aggregate vulnerability scores occur in India (104.7), the Philippines (103.2), and Indonesia (102.0), economies where food expenditure and agricultural production or employment remain economically significant. Second, China and Malaysia sit near the center of the distribution (100.2 each), reflecting mixed domestic and external channels. Third, Singapore (96.5), Hong Kong (97.9), Taiwan (98.0), and South Korea (98.3) have relatively low aggregate structural scores because agriculture contributes little to GDP and employment, despite their exposure to international food and energy markets.

The score also produces an important paradox. India is a small net food exporter in the table (-0.3 percent of GDP) but records the highest aggregate vulnerability because food represents 34.8 percent of the CPI basket, agriculture contributes 16.2 percent of GDP, and 41.6 percent of employment is agricultural. Thailand is an even larger net food exporter (-3.9 percent of GDP), yet 28.6 percent of its workforce is in agriculture. Export status can therefore buffer an external supply problem while leaving domestic production and rural incomes highly sensitive to climate anomalies.

Conversely, Hong Kong and Singapore have extremely small domestic agricultural sectors, but this does not imply zero El Niño exposure. Their vulnerability is shifted toward import prices, supplier concentration, shipping and logistics, energy costs, and exchange-rate conditions. South Korea and Taiwan occupy a similar but somewhat less import-centric position. The crucial analytical move is to distinguish the location of the shock: in agrarian economies it can start inside domestic production and livelihoods, whereas in urbanized economies it can enter through border prices and network dependencies.

Figure 2 visualizes the scorecard using within-indicator normalization. Colors indicate relative position within each column; rice and energy CPI weights are supplementary and are not included in the aggregate z-score.

Figure 2. Cross-Country El Niño Economic Exposure Indicators

Country	Net Food Imports (% GDP)	Food CPI Share (%)	Rice CPI Share (%)	Energy CPI Share (%)	Agriculture in GDP (%)	Agricultural Workforce Share (%)	Aggregate z-score (Higher = More Vulnerable)
India	-0.3	34.8	2.0	10.2	16.2	41.6	104.7
Philippines	2.0	34.8	8.9	9.1	8.6	20.5	103.2
Indonesia	-0.2	22.5	3.4	11.5	13.1	27.3	102.0
China	0.2	18.2	0.6	7.0	6.7	21.7	100.2
Malaysia	1.7	15.6	0.8	9.0	8.2	9.2	100.2
Thailand	-3.9	19.3	3.4	11.8	8.7	28.6	99.0
South Korea	1.4	13.2	0.5	7.6	1.5	5.1	98.3
Taiwan	1.0	13.2	0.4	3.7	1.5	4.1	98.0
Hong Kong	2.6	8.5	0.2	3.2	0.04	0.2	97.9
Singapore	0.6	6.1	0.1	3.7	0.00	0.1	96.5

Relative Exposure (Within Each Indicator)

Lower Exposure — Higher Exposure

Note: Aggregate z-score is calculated using four indicators: net food imports, food CPI share, agriculture share in GDP, and agricultural workforce share. Rice and energy CPI shares are supplementary indicators and are not included in the aggregate z-score.

Source: scorecard (CEIC, World Bank, ILO, and Nomura Global Economics).

Figure 2: Cross-country El Niño economic exposure indicators from the scorecard. Colors are normalized within columns; rice and energy CPI shares are supplementary and excluded from the aggregate z-score.
Source: scorecard (CEIC, World Bank, ILO, and Nomura Global Economics).

The heatmap makes the heterogeneity visible. The Philippines combines high food and rice CPI weights with net food import dependence; India combines high food CPI weight with the largest agricultural GDP and workforce shares; Indonesia combines substantial agricultural dependence with a relatively high energy weight; and Thailand combines strong agricultural employment with the highest energy CPI share while remaining a large net food exporter. These different structures imply that a single regional El Niño policy template would be inefficient.

Country Archetypes and Distinct Transmission Structures

Figure 3 translates the scorecard into four heuristic country archetypes rather than a new vulnerability ranking. The vertical axis represents domestic agricultural sensitivity, whereas the horizontal axis represents external, consumer-price, and network exposure. This two-dimensional representation is useful because climate risk is generated by interacting chains of hazard, exposure, sensitivity, and adaptive capacity, and because shocks can cascade between sectors rather than remain confined to their point of origin [32-33]. Accordingly, the figure is intended to identify dominant transmission structures and the corresponding policy emphasis, not to predict realized losses from a particular El Niño event.

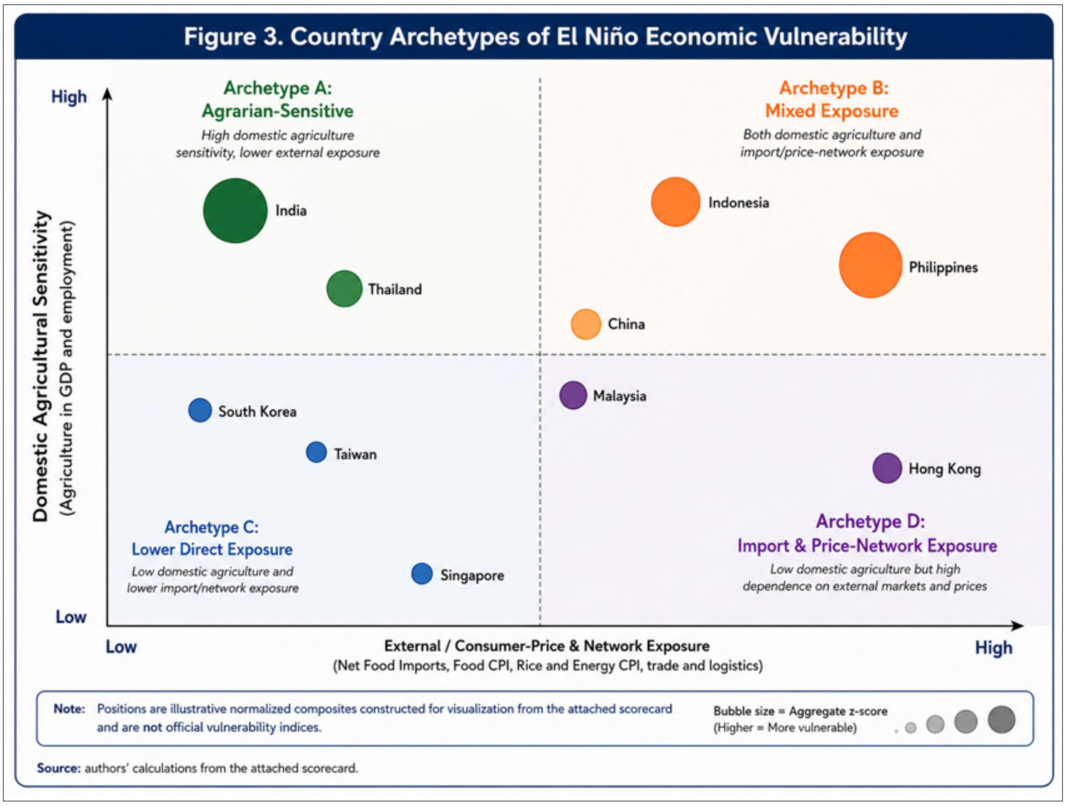

Figure 3: Illustrative country archetypes. The two axes are normalized composites created for visualization from the attached scorecard and are not official vulnerability indices. Bubble size reflects the relative aggregate z-score. Source: authors calculations from the attached scorecard.

The location of countries across the four quadrants makes an important conceptual distinction visible. Economies in the upper-left agrarian-sensitive quadrant are primarily exposed through domestic production, agricultural employment, farm income, and water availability. Economies toward the upper-right combine those domestic channels with stronger consumer-price and external-market exposure, so climatic disturbances can affect both producers and consumers at the same time. By contrast, economies in the lower part of the figure have smaller direct agricultural sectors; their vulnerability is more likely to be transmitted through imported food and energy prices, shipping, supplier concentration, inventories, exchange rates, and logistics. Research on food supply chains supports this distinction: environmental shocks can be propagated or attenuated by infrastructure, market organization, connectivity, and sourcing diversity, while greater supply-chain diversity can materially buffer exposure to food shocks [34].

The quadrant positions should nevertheless be interpreted as structural snapshots rather than fixed country identities. Actual vulnerability can change with the geography and timing of a specific El Niño, the crops and river basins affected, available inventories, irrigation and reservoir conditions, exchange-rate movements, and the ability of institutions to act before losses propagate. The bubble size adds information on the scorecard aggregate z-score, but it does not convert the map into a causal damage function. This caution is consistent with the wider literature on cascading climate impacts, which shows that indirect effects can travel across regions and sectors and that the severity of the final outcome depends on interdependencies and response capacity as much as on the initiating physical shock [35].

India and Indonesia sit high on domestic agricultural sensitivity, though their external-price structures differ. The Philippines combines both types of exposure and therefore warrants a particularly integrated package spanning rice production, import diversification, buffer stocks, consumer protection, and inflation surveillance. China and Malaysia display mixed structures in which national aggregates can hide substantial subnational differences. Thailand's export position is protective on one dimension but does not remove risks to farm incomes, water, or energy. Singapore and Hong Kong, by contrast, illustrate the need for resilience through diversified sourcing, inventories, port and logistics continuity, and credible price and social-protection systems rather than through domestic agricultural expansion. These differentiated strategies are consistent with evidence that resilience is strengthened by diversification across production, livelihoods, markets, and supply relationships and by directing investment toward the most vulnerable parts of food systems [35-38].

Thematic Findings on Food-Related Impacts

The literature supports a five-stage food pathway: climate anomaly, farm production, stocks and trade, consumer prices, and welfare. Evidence is strongest for the first and fourth stages. ENSO indices can provide useful advance information about crop outcomes in some regions, with crop- and season-specific skill [39]. However, yield effects are not universal. The same ENSO phase can benefit one crop or region and harm another, which means national food-security planning should be crop-specific and geographically disaggregated rather than based on a single national rainfall assumption.

For Asian economies, rice deserves special attention because it is simultaneously a staple, a politically salient price, and a heavily managed commodity in several countries. The Philippines' rice CPI weight of 8.9 percent in the scorecard is unusually high, meaning that rice disruptions can move both food inflation and real household purchasing power. Indonesia and Thailand also have meaningful rice weights. The correct policy inference is not that high rice weight automatically causes high aggregate vulnerability, but that rice is a potentially powerful pass-through channel when production or import prices are disturbed.

The food-trade literature points toward diversification rather than self-sufficiency as the most general resilience principle. find that trade can materially reduce the food-security consequences of uneven climate impacts by reallocating supply across space. At the same time, highly concentrated import structures can create tail risk when several suppliers experience concurrent shocks or impose restrictions. similarly show that international trade can increase supply diversity while simultaneously increasing import dependence, illustrating why connectivity is both a buffer and a potential transmission channel. At the city and supply-chain levels, diversity in sourcing can increase resistance to food shocks, while infrastructure and network design determine whether disturbances are absorbed or add that global crop allocation among direct food, feed, processing, and exports constrains the calories available for direct consumption. Resilience therefore depends on supplier diversity, storage, transparent trade rules, and domestic logistics as a package.

Input markets also matter. show that shocks to agricultural inputs can substantially reduce yields, especially in high-yielding areas. An El Niño shock that coincides with expensive fertilizer, energy, or credit can therefore create compound stress larger than the climate signal alone would suggest. This supports a broader view of anticipatory agriculture in which governments monitor water, seeds, fertilizer, farm finance, and logistics together.

At the household level, the food-CPI share in the scorecard captures one reason identical commodity shocks create unequal welfare losses across countries. A high food weight implies that households and the headline inflation index are more responsive to food prices. Food affordability can deteriorate even when aggregate supply is adequate if incomes fall or prices rise faster than wages. The link from economic contraction to child wasting documented by underscores the importance of protecting real purchasing power and nutrition, not merely stabilizing aggregate tonnage.

Thematic Findings on Non-Food Impacts

The non-food evidence identifies several interacting channels. Water scarcity can reduce hydropower, raise thermal generation, and compete with irrigation. Heat can simultaneously depress labor productivity, increase electricity demand for cooling, and raise health risks. Wildfire can damage assets and create cross-border smoke externalities. Heavy rainfall can disrupt transport through floods and landslides. Marine anomalies can reduce fishery income or shift catches geographically. Because these hazards can occur in different places during the same El Niño, the economic system can face simultaneous domestic and imported disturbances.

The Greater Mekong evidence is especially relevant to Southeast Asia. Show that ENSO-linked drought can affect hydropower trade between Laos and Thailand, increasing costs and emissions when thermal generation substitutes for hydropower. For Thailand, the scorecard's relatively high energy CPI weight therefore matters alongside its agricultural employment share. For Singapore and Hong Kong, energy and shipping price transmission may be more important than direct domestic production losses. This is an example of why non-food indicators should complement agriculture-centered exposure scores.

Heat-health-labor interactions are another underappreciated macroeconomic pathway. Occupational heat can reduce effective labor supply even without physical destruction of capital [40]. Health burdens can also persist beyond the event itself, as suggested by emerging ENSO mortality research. These mechanisms matter for fiscal analysis because medical expenditure, lost productivity, and social assistance can continue after rainfall or temperature anomalies have normalized.

Fire and smoke demonstrate the importance of cross-border externalities. El Niño-related dryness can increase fire activity in susceptible regions, while smoke can travel far beyond the burning area [41]. In maritime Southeast Asia, this mechanism can affect transportation, tourism, schools, and health systems in multiple jurisdictions. The optimal policy is therefore not purely national: land management, fire prevention, air-quality monitoring, and regional coordination have shared benefits.

Thematic Findings on Mitigation and Anticipatory Action

The mitigation literature converges on the value of moving from hazard forecasts to impact-based decision systems. In agriculture, preseason crop forecasts can provide six-to-twelve-month information in some regions, creating time for input planning, procurement, and food-security preparation. In humanitarian and disaster management, forecast-based financing links probabilistic forecasts to pre-agreed triggers and actions. demonstrate this logic for heatwaves in develop drought triggers for Mozambique [42-44]. Caution that the economic value of seasonal forecast systems can require repeated use over long horizons, particularly when false alarms and forecast uncertainty are considered. Disaster-risk-finance research reaches a similar conclusion: ex-ante financing can accelerate action, but trigger design, institutional mandates, and uncertainty management determine whether resources arrive at the right time and for the right purpose [45].

Anticipatory action is therefore not simply an earlier version of emergency response. It requires institutional precommitment. Show that anticipatory systems can strengthen organizational capacity and speed response, but they also face recurring problems of local ownership, data availability, institutional integration, forecast uncertainty, and evaluation [46]. These constraints are directly relevant to El Niño because the forecast itself is only the first input; governments still need trigger rules, funding authority, implementation capacity, beneficiary targeting, and mechanisms for revising decisions as information changes. The social-protection literature reinforces this point: climate-responsive protection is most effective when registries, delivery systems, eligibility rules, and financing can expand or adjust before or during shocks rather than being improvised after welfare losses have already occurred [47-48].

Agricultural and water resilience should combine structural and anticipatory measures. Climate-smart irrigation can reduce water use while maintaining much of crop yield under variable conditions, and broader reviews of irrigated agriculture emphasize portfolios of adaptation rather than single technologies. Diversification of crops and livelihoods, soil and water management, stress-tolerant varieties, improved extension, strategic reserves, and flexible trade policy are complementary rather than substitutable. In food systems, the objective is to reduce the probability that a production shock becomes a nutrition crisis.

Figure 4 expresses this logic as a forecast-to-finance-to-action cycle. The figure's central message is that forecast information acquires economic value only when it is translated into sectoral risk, connected to explicit decision thresholds, backed by pre-arranged financing, converted into implementable actions, and followed by evaluation and learning. This sequencing is consistent with research showing that forecast value depends not simply on predictive skill but also on the timing of decisions, the cost of acting versus not acting, and the institutional arrangements that connect warning to finance and implementation.

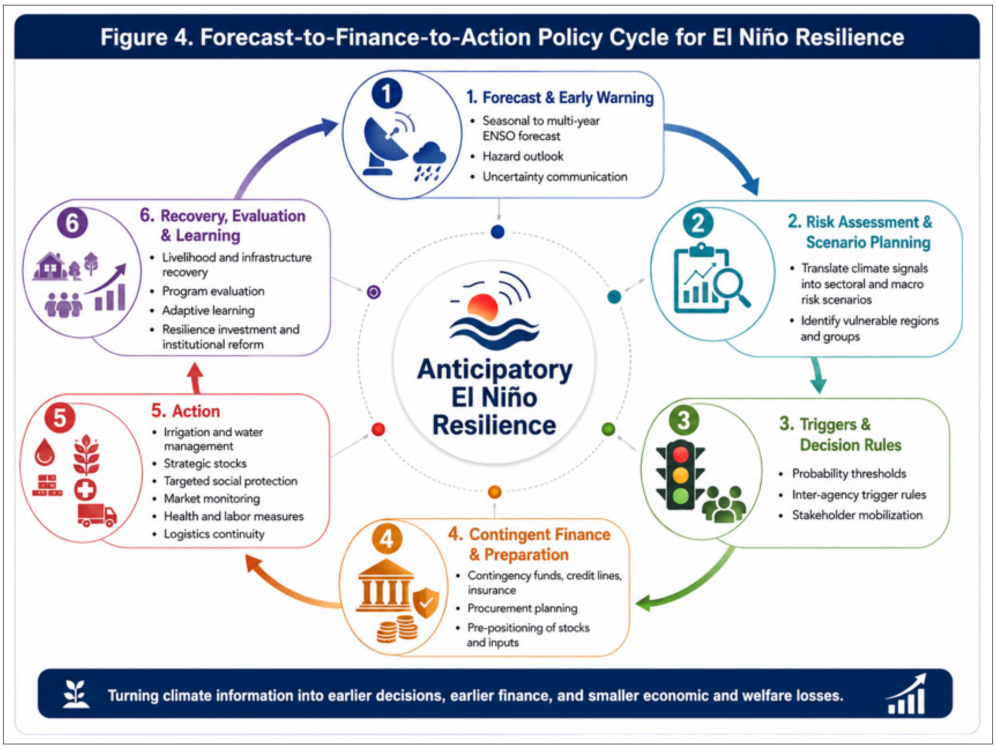

Figure 4: Forecast-to-finance-to-action cycle for anticipatory El Niño economic resilience. Source: authors synthesis.

The six stages in Figure 4 can be read as a chain of decision gates. Forecast and early warning establish a probabilistic climate signal; risk assessment and scenario planning translate that signal into possible effects on crops, water, energy, health, trade, and vulnerable groups; triggers and decision rules specify when uncertainty is sufficiently consequential to justify action; contingent finance makes those decisions executable; operational measures then seek to reduce losses; and recovery, evaluation, and learning update the system before the next ENSO episode. This structure is important because forecast skill alone does not guarantee preparedness. A technically accurate warning can still have little economic value if sector agencies cannot interpret it, if procurement takes longer than the available lead time, or if financing is released only after damages are verified.

The trigger-and-finance stages also clarify why anticipatory policy must explicitly manage uncertainty. Pre-arranged financing should not be interpreted as automatic spending whenever El Niño is forecast; it is better understood as a rules-based capacity to release resources when probabilistic thresholds and exposure conditions justify intervention. Such rules can combine forecast probabilities with crop calendars, reservoir levels, market prices, health indicators, and vulnerability data, while cost-loss analysis helps balance the consequences of false alarms against the potentially much larger cost of delayed action. Disaster-risk-finance research emphasizes that anticipatory arrangements must address basis risk, institutional accountability, and the political difficulty of committing funds before visible damage occur. Likewise, evidence from Niger shows that sustained cash transfers can strengthen household resilience to drought by facilitating consumption smoothing, savings, and protection of productive earnings, suggesting that pre-positioned social protection can be an economic resilience instrument rather than only a humanitarian transfer.

A mature El Niño preparedness system would update this cycle continuously. For example, an ENSO forecast could trigger scenario analysis; a higher probability of drought in a specific crop region could trigger water-allocation planning and pre-positioned seed; projected food-market stress could trigger procurement or temporary tariff adjustments; heat risk could trigger labor and health measures; and fiscal triggers could release contingency funds. Where vulnerable households are identifiable in advance, scalable cash or food assistance can be prepared before income and nutrition losses intensify. Post-event evaluation would then recalibrate thresholds, identify false alarms and missed impacts, and assess whether recovery spending reduced or reproduced structural vulnerability. This learning function matters because fiscal choices can either strengthen adaptation and resilience or lock in infrastructure and systems that remain exposed to future shocks [49].

Figure 5 shows the corresponding policy portfolio across the pre-event, event, and recovery phases. It is intentionally conceptual rather than econometric: the purpose is to emphasize that resilience is a sequence of coordinated interventions across agriculture and food, water and energy, health and labor, trade and logistics, social protection, fiscal and financial policy, and governance and data. The matrix therefore complements Figure 4: Figure 4 explains the decision process, whereas Figure 5 specifies the sectoral portfolio that can be activated at different points in that process. This systems framing is consistent with evidence that climate shocks can cascade across sectoral and regional boundaries rather than remaining isolated within the initially affected activity.

Figure 5: Conceptual priority matrix for comprehensive El Niño mitigation across the policy cycle.
Source: author's synthesis.

The matrix should be read both horizontally and vertically. Horizontally, each policy domain has an anticipatory, response, and recovery logic: agricultural preparedness moves from drought-resilient inputs, irrigation planning, stocks, and market intelligence to in-event stabilization and then to productivity-enhancing recovery; water and energy policy moves from reservoir and demand planning to emergency allocation and then to infrastructure strengthening; and trade policy moves from supplier diversification and port readiness to keeping channels open during disruption and rebuilding more redundant logistics afterward. This sequencing reflects evidence that food-system shocks are mediated by storage, infrastructure, market organization, and sourcing diversity, and that supply-chain diversification can reduce the propagation of moderate.

Vertically, the matrix emphasizes complementarity across sectors. A crop intervention will be less effective if electricity or irrigation fails; open import channels will not protect nutrition if vulnerable households cannot afford higher prices; cash transfers will have limited value if food is physically unavailable; and fiscal buffers will not prevent losses if institutions lack data, pre-agreed responsibilities, or delivery capacity. The need for such cross-sector coordination is supported by cascading-risk research showing that climate disturbances can propagate through production, transport, employment, income, health, and consumption networks. It is also consistent with adaptive social-protection research, which argues that climate-resilient development requires social-protection systems to address both immediate welfare losses and longer-term changes in risk.

The recovery column is particularly important because recovery spending creates long-lived assets and institutional arrangements. Replacing damaged infrastructure on its previous design standard can reproduce the same vulnerability, whereas recovery can be used to strengthen water systems, logistics, health capacity, agricultural productivity, data interoperability, and financial protection. Evidence from cross-country fiscal responses shows that public spending can contribute directly or indirectly to adaptation and resilience, but it can also lock in non-resilient infrastructure when future climate risk is not incorporated into investment decisions. At the household level, adaptation can materially reduce the consumption effects of temperature shocks, while sustained transfers can improve the capacity of poor households to smooth climate-related income losses. The policy objective should therefore be to move from restoration of pre-event conditions toward a build-forward approach in which recovery reduces the sensitivity of the next El Niño episode.

The matrix highlights three conclusions. First, pre-event investment is critical in food production, food-market governance, water-energy planning, fiscal readiness, social protection, and information systems because these capacities cannot be constructed after the shock begins. Second, during-event measures should protect essential flows - food, water, energy, finance, health services, transport, and household purchasing power - while avoiding broad interventions that create unnecessary fiscal costs or distort recovery incentives. Third, recovery policy must avoid simply restoring pre-shock vulnerability. Reconstruction and agricultural support should improve irrigation efficiency, logistics redundancy, health preparedness, data systems, and financial protection so that the next ENSO episode produces smaller welfare losses; more generally, fiscal policy should be screened for both its direct adaptation effects and its indirect contribution to long-term resilience.

Discussion and Analysis

Why El Niño Economic Vulnerability Is Multidimensional

The synthesis indicates that El Niño should be conceptualized as a risk multiplier moving through interconnected systems. A country with high agricultural employment is exposed through rural income and output. A country with a high food CPI weight is exposed through consumer prices and real wages. A hydropower-dependent system is exposed through water-energy linkages. A dense urban trading hub is exposed through shipping, imports, energy, and external prices. The relevant policy question is therefore not whether a country is "vulnerable to El Niño" in the abstract, but which channels can become binding in a particular event.

This explains why exposure and realized loss must be separated. The scorecard's aggregate z-score is valuable for screening structural sensitivity, but it cannot incorporate the spatial footprint of a specific event or the full set of buffers. India can have a high structural score without suffering the largest loss in every El Niño; Singapore can have a low aggregate score while still experiencing significant imported food-price or logistics shocks. An economically useful warning system should therefore layer real-time hazard forecasts and market indicators onto the structural exposure baseline.

Resolving Cross-Country Paradoxes

The first apparent paradox is the vulnerability of food exporters. Net exports reduce dependence on foreign supply, but they do not insure domestic crops, farm income, water availability, or rural labor. In India and Thailand, large agricultural employment shares mean a production shock can damage household income even if national trade balances are comparatively favorable. Exporters may also face a policy trade-off between allowing high international prices to benefit producers and preserving affordable domestic supply.

The second paradox is the vulnerability of economies with almost no agriculture. Singapore and Hong Kong illustrate how urbanization shifts, rather than eliminates, climate exposure. Their resilience depends on diverse suppliers, efficient ports, inventory management, cold chains, energy reliability, and the ability of households and firms to absorb temporary price spikes. This form of vulnerability is more networked and external than agrarian vulnerability, and it may be underestimated by indices that focus only on domestic climate-sensitive output.

The third paradox concerns food CPI weights. A large food weight raises the sensitivity of headline inflation and welfare to food shocks, but it also reflects income structure and consumption patterns. Monetary policy cannot neutralize a crop failure directly. Aggressive tightening in response to a temporary supply shock can deepen real-activity losses, while ignoring persistent second-round effects can de-anchor expectations. The appropriate response therefore requires coordination among agricultural, trade, fiscal, social-protection, and monetary authorities rather than expecting the central bank to solve a physical supply problem alone.

Reconciling Competing Macroeconomic Findings

The contrast between persistent-damage estimates and more benign global time-series results is analytically productive. emphasize dynamic losses that accumulate over several years [50]. find that El Niño can be associated with positive output responses and limited inflation in their monthly global model, with La Niña producing more pronounced food-inflation effects. These differences likely arise from multiple sources: samples and periods, monthly versus annual dynamics, event definitions, linear versus nonlinear specifications, country weighting, fixed effects, lag structures, and the fact that El Niño produces winners as well as losers [51-54].

A qualitative synthesis should therefore avoid presenting any single global damage estimate as universally settled. The more robust conclusion is that ENSO is economically important, heterogeneous, and capable of persistent effects in exposed contexts. Policy should be stress-tested against plausible ranges rather than anchored to a single point estimate. For finance ministries and central banks, scenario analysis may be more useful than a deterministic forecast: mild, moderate, and severe hazard pathways can be linked to food, energy, fiscal, and growth assumptions, with explicit probability ranges [55].

A Forecast-to-Finance-to-Action Architecture

The strongest policy implication from the combined climate and anticipatory-action literature is that forecast lead time should be treated as an economic asset. A forecast that arrives six months before a probable drought has little value if budget authority requires nine months, procurement takes four months, or social registries cannot identify beneficiaries. Conversely, even an imperfect forecast can generate value when decision rules, financing, and implementation are prepared in advance. This institutional interpretation is also consistent with evidence that the resilience effect of public spending depends on whether resources are deliberately aligned with adaptation rather than simply disbursed after a shock.

The architecture proposed here has six components. First, physical forecasting should combine ENSO, rainfall, temperature, soil moisture, reservoir, and marine indicators. Second, sectoral translation should convert those signals into crop, food-market, energy, health, infrastructure, and distributional scenarios, consistent with impact-chain approaches that explicitly map how climate signals propagate through exposed systems. Third, pre-agreed triggers should define when agencies move from monitoring to action. Fourth, contingent finance should be automatically or rapidly releasable when thresholds are met, with governance arrangements that address uncertainty and accountability. Fifth, interventions should be differentiated by country archetype and hazard. Sixth, post-event evaluation should update both forecast interpretation and institutional performance, including whether social-protection and fiscal instruments reached exposed groups at the required scale and timing [56].

This structure is superior to a purely reactive model for three reasons. It can prevent irreversible losses such as livestock mortality, missed planting windows, child malnutrition, or business failure; it can reduce the peak fiscal cost by acting before emergency procurement becomes expensive; and it encourages agencies to coordinate around shared thresholds. The main risk is acting unnecessarily after a false alarm. That is why cost-loss analysis, probabilistic thresholds, pre-agreed financing rules, and evaluation are integral rather than optional. The welfare case for preparedness is reinforced by evidence that ongoing cash-transfer systems can improve resilience to drought shocks and that adaptation can attenuate the negative consumption effects of temperature extremes [57].

Differentiated Policy Packages by Country Archetype

For agriculture-intensive economies such as India and Indonesia, the policy center of gravity should be water and farm resilience, rural income protection, crop and livestock advisories, input availability, insurance, and targeted cash or food support. High agricultural employment means that livelihood stabilization is as important as consumer-price stabilization. Because vulnerability is often subnational, national ENSO signals should be translated into district- or basin-level crop and water risk maps. Diversification across crops, livelihoods, and market channels can reduce dependence on a single source of income or supply, while pre-existing cash-transfer systems can help households' smooth consumption and protect productive activities when drought occurs [58].

For the Philippines, the overlap of high food CPI, rice weight, net food imports, and substantial agricultural employment argues for a dual strategy. Domestic production resilience should be strengthened through irrigation, seed systems, extension, and harvest-risk management, while market resilience should emphasize diversified rice sourcing, transparent reserve rules, logistics, and narrowly targeted consumer support. Inflation surveillance should explicitly distinguish first-round rice and food effects from broader second-round pressures. The rationale for diversified sourcing is supported by evidence that supply-chain diversity can buffer food shocks, whereas concentrated connectivity can transmit external disruptions into domestic availability and prices [59].

For Thailand and Malaysia, policy should reflect mixed production, trade, and energy channels. Thailand's net export position can be a buffer, but drought can still reduce farm incomes and hydropower-related regional trade, while its energy CPI weight is the highest in the scorecard. Malaysia's net food imports and moderate agricultural exposure suggest a balanced focus on import diversification, domestic production resilience, and energy/logistics continuity [60].

For China, the national average masks scale and regional diversity. The scorecard shows meaningful food and agricultural exposure, while the literature on Chinese agriculture and health demonstrates that ENSO can influence crop conditions, pest dynamics, and mortality pathways. A national framework therefore requires subnational differentiation, integrating agricultural early warning with health, water, and disaster-risk systems rather than relying on one countrywide indicator [61].

For Singapore, Hong Kong, South Korea, and Taiwan, the primary resilience question is external network robustness. Policies should emphasize diversified suppliers, inventory adequacy, port and cold-chain continuity, cyber-physical reliability of logistics, energy resilience, and targeted support for vulnerable households if imported inflation rises. Maintaining open trade relationships across multiple producing regions may be more effective than attempting to recreate large domestic food sectors in economies where land and labor structures make that inefficient. This approach is consistent with research showing that sourcing diversity and supply-chain redundancy can attenuate shocks, while international trade can simultaneously increase diversity and create dependence if supplier networks become concentrated [62].

Regional and Global Coordination

El Niño is inherently transboundary, so purely national responses can generate negative spillovers. Export bans can protect domestic prices temporarily but worsen scarcity for importers. Competitive stockpiling can amplify price volatility. Uncoordinated reservoir operations can shift water and energy risk across borders. Smoke and marine impacts ignore jurisdictional boundaries. More broadly, shocks can cascade across sectors and regions through trade, infrastructure, employment, and consumption networks, which means that national resilience can depend on decisions taken elsewhere. Regional resilience therefore requires transparency about inventories and trade measures, shared forecast interpretation, compatible early-warning thresholds, and mechanisms for emergency food and financial support; trade-network evidence also supports diversification and redundancy rather than reliance on a narrow set of suppliers [63-65].

International institutions can support three public goods. The first is information: interoperable climate-food-energy dashboards that connect probabilistic ENSO forecasts with crop calendars, reservoir levels, shipping conditions, and market prices. The second is finance: contingent credit, insurance, grants, and other pre-arranged facilities that release resources before losses become irreversible; the disaster-risk-finance literature emphasizes that such instruments are most effective when triggers, governance, and responsibilities are specified before the emergency. The third is coordination: principles that discourage destabilizing trade restrictions, encourage diversified procurement, and support the poorest countries when global food or energy prices rise. Because fiscal decisions can either strengthen resilience or lock in future vulnerability, international finance should also encourage adaptation screening and resilient investment standards in recovery programs [66-69].

These priorities are consistent with the wider climate-resilience literature. Trade can redistribute geographically uneven food shock; diversified supply networks can buffer disruptions; integrated food-system adaptation benefits from stakeholder-informed transformatio; and resilience depends on diversification across production, markets, livelihoods, and institutions rather than on a single technology. The global objective should not be to eliminate all ENSO-related variability - an impossible task - but to prevent predictable climatic variability from becoming preventable economic and humanitarian crises [70-76].

Conclusion

El Niño is best understood as a multi-sector economic shock whose consequences emerge through the interaction of physical hazards and economic structure. The attached scorecard demonstrates that structural exposure differs markedly even within a relatively connected set of Asian economies. India, the Philippines, and Indonesia exhibit high aggregate exposure for different reasons; Thailand combines export strength with domestic agricultural sensitivity; and Singapore, Hong Kong, South Korea, and Taiwan illustrate how vulnerability can shift toward external prices and networks when domestic agriculture is small. Rice and energy CPI weights add important price-transmission information but should not be confused with the four variables used to construct the aggregate z-score.

The literature since 2020 shows that food is central but not sufficient. El Niño can affect crop yields, livestock, food prices, and nutrition, while also moving through water and hydropower, heat and labor productivity, health, wildfire and smoke, landslides, fisheries, transport, and trade. Macro outcomes can persist beyond the initial event, but the magnitude and even sign of estimated effects vary across studies. This uncertainty strengthens the case for probabilistic scenario planning rather than weakening the case for preparation.

The most important policy recommendation is to build an anticipatory governance system that converts climate information into earlier economic decisions. Governments should develop ENSO-to-economic dashboards, map structural exposure at subnational level, pre-agree trigger thresholds, pre-arrange financing, protect water and food systems, diversify trade and energy sources, strengthen public-health and heat preparedness, and connect social protection to forecast-based triggers. Central banks and finance ministries should incorporate food, energy, and fiscal climate scenarios into inflation and budget risk assessments while recognizing that monetary policy cannot substitute for physical supply resilience.

At the global level, resilience depends on cooperation. Countries need shared early-warning information, predictable trade rules, transparent strategic inventories, regional water-energy coordination, and financing facilities that support action before the shock peaks. The central strategic principle is simple: forecast lead time is an economic resource. The policy challenge is to transform that resource into pre-emptive investment, targeted protection, and institutional learning so that future El Niño events generate smaller losses in output, welfare, and human development.

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