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Selected Paper prepared for presentation at the 2025 AAEA & WAEA Joint Annual Meeting in Denver, CO; July 27-29, 2025

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Governance and resilience as entry points for transforming food systems in the countdown to 2030

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Abstract

Due to complex interactions, changes in any one area of food systems are likely to impact – and possibly depend on – changes in other areas. Here, we present the first annual monitoring update of the indicator framework proposed by the Food Systems Countdown Initiative, with new qualitative analysis elucidating interactions across indicators. Since 2000, we find that 20 of 42 indicators with time series have been trending in a desirable direction, indicating modest positive change. Qualitative expert elicitation assessed governance and resilience indicators to be most connected to other indicators across themes, highlighting entry points for action – particularly governance action. Literature review and country case studies add context to the assessed interactions across diets, environment, livelihoods, governance, and resilience indicators, helping different actors understand and navigate food systems towards desirable change.

Introduction

Achieving transformative change in food systems is necessary to meet the Sustainable Development Goals (SDGs), Paris Agreement targets, Global Biodiversity Framework, and many other global goals.[1,2] Food systems impact all sectors, populations, and ecosystems. Consequently, understanding and tracking transformation is particularly important. The Food Systems Countdown Initiative (FSCI) provides annual monitoring updates of systems-wide indicators across five thematic areas: i) diets, nutrition, and health; ii) environment, natural resources, and production; iii) livelihoods, poverty, and equity; iv) governance; and v) resilience.[3,4] This article presents the first update relative to the 2023 baseline[3] with new quantitative analysis of time trends since 2000 and qualitative assessments of interactions between indicators. Interactions between indicators mean that changes in one area (e.g., diets) can (directly or indirectly) affect others (e.g., environment).[5,6] Interactions may present tradeoffs or synergies and illuminate entry points for governance action to steer food systems towards desired outcomes or to unlock roadblocks to change.

Food systems span multiple domains, actors, governance systems, spaces, and time horizons, and decisions may be made without structured, systematic consideration of these multiple dimensions, or the diverse outcomes to which food systems contribute. For example, policies targeting short-term objectives to ensure calorie sufficiency may not consider the long-term impacts of large-scale monocropping on biodiversity or pest adaptation, nor the impacts of staple-focused policies on nutrition.[5,6] As a result, many food systems challenges have arisen owing to unintended consequences and systemic conflicts among multiple objectives. For example, maximizing crop and livestock productivity through intensive systems has led to increased food availability but also contributed to environmental degradation, declining diet quality for some populations, and increased inequality between small- and large-holder production systems.[7–12] Part of understanding, addressing, and preventing these pernicious unintended outcomes is making food systems' interactions more explicit so that they can be directly managed and governed.

Governance therefore has a specific role in navigating these interactions, especially through decision-making processes that consider potential consequences across domains.[13] Appropriate governance for food systems transformation has been gaining recognition on the global political agenda. Recent analysis of country progress along national food system transformation pathways shows 70 countries reporting efforts since 2021 to strengthen food systems governance.[14] Governance impacts food system transformation through multiple channels. Corporate concentration and influence on policymaking through lobbying and campaign contributions can bias governments against policies that are important for food environments and diets.[15–17] Political polarization and electoral turnover can impede policy momentum and detract attention from long-term policymaking.[18] Countries with weak institutional capacity may be unable to manage risks from economic or climate shocks, thereby affecting their ability to drive food systems change and undermining prior gains.[19,20] Geopolitical conflicts have cross-jurisdictional impacts on food systems, as demonstrated by the Ukraine war's impact on global food security.[21] Ongoing civil conflict also stresses global humanitarian resources, especially food assistance, and strain relationships that shape the multilateral system on which global humanitarian systems depend.[22,23] In summary, governance is cardinal to accelerating transformative change. The thematic focus of this article is on governance indicators in both the monitoring update and the analysis of interactions, on the premise that governance quality is linked to whether synergies are enabled, and tradeoffs are identified and managed.

To identify the network of interactions across food systems, we build on growing literature on food system interactions from multiple disciplines focused on food, environment, water, health, socio-ecological, political, and economic systems.[12,24–27] These studies underscore that data limitations, lack of interoperability, and gaps across domains, geographies, and scales pose challenges to understanding complex food systems interactions. Yet the imperative for urgent, widespread transformation cannot delay action; societies and individuals must make decisions despite uncertainty and incomplete information. In this context, we use qualitative expert elicitation to identify where theory supports a direct causal relationship between each pair of indicators at the global level.[12] Recognizing the foundational role that

governance plays in navigating these interactions, we ground these global results through two related analyses focused on interactions involving governance indicators. First, in-country qualitative expert elicitations explore how interactions involving governance have become more or less important for food systems change over time in the context of Ethiopia, Mexico, and the Netherlands. It highlights different potential synergies, tradeoffs, and entry points for action, and how considering interactions explicitly helps to identify trajectories for change relevant to each country's unique context and food system transformation pathway goals. Second, systematic literature search (automated search with manual screening) suggests where there is likely to be conceptual validity for these relationships involving governance indicators, and highlights priority evidence gaps to drive change.

Methods

Data

We compiled an updated dataset harmonized to the country-year unit of analysis and following data construction methods delineated in Schneider et al. (2023).[3] Global, regional, and income group means are calculated as weighted means per year, excluding missing data, weighted by the weighting variables defined in **Supplementary Table 1** and **Supplementary Table 2.** No further data transformation was applied, and we did not impute any missing data. All data compilation and analyses are carried out in R version 4.4. Data were downloaded in March 2024 with final pulls from APIs in October 2024 and reflect all available data points from 2000 to 2022, with data from 2023 or 2024 for a few indicators where older data are not available. All data sources are listed in **Supplementary Data 1: Metadata and Codebook**, including the year of the latest data point available. The full dataset is provided in **Supplementary Data 2: FSCI_2024.csv**.

We made a few modest changes to the indicator framework and data sources since the baseline publication. First, we renamed a few indicators for ease of interpretation. That is, in the theme of 'diets, nutrition and health', sugar-sweetened soft drink consumption has become soft drink consumption, "All-

5" is clarified as "All-5: consumption of all 5 food groups", and the indicator of "Retail value of ultra-processed foods per capita" has been transformed into current PPP dollars. Under the environment, natural resources, and production theme, we clarified agri-food system emissions to be "Agri-food system greenhouse gas emissions", cropland expansion has been renamed more accurately as "Cropland area change", and functional integrity has added more description in the name to "Functional integrity: agricultural land with minimum level of natural habitat". We also revised the emissions intensity and yield indicators to specify product groups in the name of the indicator. Under resilience, we clarified the ratio of damages to GDP as "Ratio of total damages from all disasters to GDP".

We have also replaced the indicator or data source for several indicators. First, we replaced the Sustainable Nitrogen Management Index with Nitrogen Use Efficiency. The former was more challenging to interpret because it combines multiple indicators, including the direct indicator of nitrogen use efficiency. The Nitrogen Use Efficiency indicator is available from FAOSTAT and has a clearer interpretation. We have also revised the threshold to calculate functional integrity based on more recent data showing that a 10% threshold is insufficient to preserve ecosystem function,[54] so we have recalculated the indicator at the recommended 20% threshold. We replaced female landholdings with the SDG indicator "Share of women among owners or rights-bearers of agricultural land (SDG 5.a.1)" because the Gender and Land database of FAO is no longer being updated and although there are fewer than 70 countries with available data for the SDG indicator, it will continue to be updated as new data are collected. Additionally, we revised the weighting of averages for functional integrity and the proportion of agricultural land with minimum species richness. Both indicators are based on the proportion of agricultural land, and we weight the averages using an internally consistent calculation of agricultural land area for each variable. Previously, we used the FAOSTAT indicator of agricultural land area, which differs slightly due to source data differences.

Updating the 2023 baseline,[3] we have expanded the indicator previously reflecting health-related food taxes to include health-related food environment policies more broadly: "Presence of national health-related food environment policies". We use the same data source (the NOURISHING database from the

World Cancer Research Fund) and text analysis to classify policies into economic or regulatory, identify and remove any regulatory policies that are not mandatory, and ensure that we are not including any policies that only apply at a subnational level (e.g., soda tax in Berkeley, CA). We include any policies classified in the NOURISHING database under the food environment categories including: "Nutrition label standards and regulations on the use of claims and implied claims on food", "Offer healthy food and set standards in public institutions and other specific settings", "Use economic tools to address food affordability and purchase incentives", "Restrict food advertising and other forms of commercial promotion", "Improve nutritional quality of the whole food supply", "Set incentives and rules to create a healthy retail and food service environment." Policies catalogued under the "Use economic tools" category are coded as economic tools, policies in all other categories are coded as regulatory instruments. We use text search to identify whether the regulatory policies apply nationally and are voluntary or mandatory. The text strings were iteratively developed through manual inspection and are shown in **Supplementary Table 6.** Of note, the database was constructed through a comprehensive search only in the European Union, all other regions rely on periodic scanning and reporting networks of local collaborators and therefore the data may not be entirely comprehensive of all policies outside the European Union.

Analysis methods

Trend analysis. Trend analysis is conducted with linear regression of the indicator on time (year), with regional fixed effects and weighted by the weighting variable shown in **Supplementary Table 1**, computed using the *lm* package in R, version 4.4. We first normalize the indicator data using feature scaling (min-max normalization) so that all the values for each indicator (pooled over countries and years) are on a scale from 0-1. We then multiply by 100 so that the coefficients when regressed on time can be interpreted as an average percentage change per year. Of note, this normalization choice is consequential for the results for a few indicators because the normalization reduces the variance and therefore results in

a conclusion of statistical significance (or also non-zero in magnitude) that would not be made when regressing the indicator in its original units on time. This affects only eight indicators, specifically: emissions intensity for milk and rice, pesticide use, civil society participation, government accountability, government effectiveness, food price volatility, and the social capital index.

We classify the slope, sign, and statistical significance to categorize each indicator's change over time into "Desirable change", "No change", and "Undesirable change". Change is defined as desirable if the trend line is statistically significantly different from zero with the sign agreeing with the desirable direction of change and as changing in the undesirable direction if statistically significantly different from zero with a sign in opposition to the desirable direction of change. Coefficients that are equal to zero or not statistically significantly different from zero are classified as no change. Weighting variables and desirable direction of change defined in **Supplementary Table 1**. **Supplementary Figures 1-5** show the predicted values (margins) at every combination of year and region to illustrate heterogeneity in intercept and slope across regions, per indicator. It is computed as the predicted margins at all values of year and region from a linear regression of the indicator on the interaction between year and region, weighted as defined above.

Identifying interactions at the global level. We used three methods to identify and understand interactions between indicators. First, we carried out an expert elicitation process with all the co-authors, organized into working groups by theme. For each pair of indicators (all possible combinations), the experts identified where there is theoretical evidence of a direct causal relationship and the direction of the relationship in terms of the cause variable and impact variable. This process did not identify the nature of the relationship (synergy or tradeoff). We converted these responses into a matrix and took the square and cube of the matrix to identify second- and third-order connections, respectively. Second-order connections are identified as two indicators connected to each other indirectly via one intermediating indicator to which both are directly connected. Third-order connections pass through two other indicators to connect the pair.

Automated literature search. We used an automated literature search with manual screening to assess the presence of literature on the pairs of governance-related indicators identified as connected through the expert elicitation. Dimensions is a comprehensive research database designed to link documents across the project cycle (e.g., grants to final publication) and to study alternative metrics.[43] It has been shown to perform as well as Google Scholar to capture literature from across traditional databases (e.g., Web of Science, PubMed) as well as grey literature,[55–57] and unlike Google Scholar, it has an API permitting large scale automated search. Using the Dimensions.ai application, we searched title and abstract for the pairs of indicators involving at least one governance indicator for which a direct causal relationship was identified. We eliminated the directionality information from this search, meaning we searched once for a pair of indicators even if causality has been identified in both directions. In a few cases, we replaced the indicator name with closely related terminology from the Dimensions database of concepts, when no results were returned with the specific indicator name. Search terms are provided in **Supplementary Table 3.**

We implemented the search in Python and eliminated any results that were from a scientific poster or not in English. One author (DD) then manually screened all results by title and citation data for relevance according to the following exclusion criteria: not in English (that was not caught by the automated screening), duplicates within the same indicator pair search, incomplete titles (e.g., "book review"), and any titles that indicate complete irrelevance to both indicators in the search pair that returned the result in question. For example, a paper entitled "Wild Bornean orangutans experience muscle catabolism during episodes of fruit scarcity" was eliminated as irrelevant to the search of an interaction between reduced coping strategies and the Right to Food indicators. Another paper excluded on the relevance criterion from that same pair of indicators search was "Cognitive-behavioral treatment of depression: A three-stage model to guide treatment planning." These examples illustrate a broader pattern of the manual screening step that mostly excluded articles focused on psychological or biological phenomena in non-human animals and not in an agrifood livestock context or humans with specific mental or physical health issues

that do not fall under the category of diet-related or otherwise have a relationship to food systems (e.g., depression, short bowel, and not in the context of food system-based livelihoods).

Country case studies. We selected Mexico, Ethiopia, and the Netherlands for the case studies because they represent distinct geographical regions and food systems types, with Mexico currently being characterized as 'emerging and diversifying', Ethiopia as 'rural and traditional', and the Netherlands as 'industrial and consolidated'.[44] In addition, in the three countries, there are active processes on food systems transformation pathways to which this process can contribute and has been welcomed to contribute. Identification of participants and collaboration on the consultation structure was facilitated in Ethiopia by project teams from the Food, Agriculture, Biodiversity, Land-Use and Energy Consortium (FABLE) and Sustainable Healthy Diets through Food Systems Transformation (SHIFT) who were actively carrying out related consultations. In Mexico, we partnered with the National Institute of Public Health and FABLE teams, which have been actively involved in investigating national food systems and pathways. In the Netherlands, the workshop was co-hosted by Wageningen University and Research. In total, 20 Ethiopian, 15 Mexican, and 15 Dutch food systems experts from government, non-governmental organizations, and research organizations participated in a one-day session. This was held in-person in Addis Ababa on April 2, 2024 (Ethiopia), in hybrid format in Mexico City & online on April 17, 2024 (Mexico), and in hybrid format in Utrecht in the Netherlands on July 9th, 2024 (The Netherlands). Participants were selected based on their knowledge and involvement in national food system transformation pathways, policies, and research, as well as their availability to participate. Experts represent government officials, research organizations, and civil society. The list of participants and their affiliations is provided in **Supplementary Table 7.**

The elicitation exercise consisted of qualitative mapping guided by a lead facilitator using instructions, guiding questions, and facilitation support materials (**Supplementary Table 8**) consistent across countries. Participants worked in three breakout groups of three to seven people to qualitatively map and discuss the interactions of pairs of indicators in two dimensions: 1) the level of relevance for

achieving sustainable food systems (specifically the national food systems transformation pathway in Mexico and Ethiopia) , and 2) the change in strength over time. Plenary discussion was used to integrate and converge through discussion and to highlight the main insights emerging from the exercise. Reports of individual sessions are available on request. The Milan Urban Food Policy Pact indicator was excluded due to limited use and familiarity in Ethiopia or Mexico according to the country teams.

Results

Global trends of the FSCI indicators with time series data reported for 2000–2022 update the static view presented in the global baseline[3] with all available new data points and trends over time (**Figure 1**). Thirteen indicators use survey data collected at different times per country (or different countries per year) and therefore cannot be analyzed for trends (including all diet quality, social protection, female landholdings, child labor, and coping strategies indicators). Twenty of the remaining 42 indicators have changed in a desirable direction (positive or negative defined in **Supplementary Table 1**). The 15 indicators desirably (and statistically significantly) increasing over time are (in order of magnitude of the average annual percentage change over the period analyzed from greatest to smallest): access to information, mobile phone use (an infrastructure and connectedness proxy), safe water access, conservation of animal genetic resources, social capital, fruit yield, vegetable availability, beef yield, government effectiveness, conservation of plant genetic resources, milk, vegetable, and cereal yields, fruit availability, and nitrogen use efficiency. The five indicators desirably declining are (in order of greatest to least average annual percentage change): emissions intensity for beef and milk, food supply variability, the prevalence of undernourishment, and the percent of the population who cannot afford a healthy diet. Indicators with undesirable trends (7/42) are the cost of a healthy diet (reflecting inflation), the proportion of the population experiencing moderate or severe food insecurity, rural underemployment, pesticide use, food price volatility, civil society participation, and government accountability. Remaining indicators (12/42) show no change (coefficients of zero), which is also undesirable. Full results are in

Supplementary Table 4, regional variation in time trends are shown in **Supplementary Figures 1–5**, and data for all countries, by region and income group, in **Supplementary Figures 6–21**.


Access to information
Cost of healthy diet
Mobile phones per 100 people
Experience food insecurity
Access to safe water
Conservation of genetic resources, animals
Social capital index
Minimum species diversity
Yield, fruit
Vegetable availability
Ultra-processed food sales
Yield, beef
Government effectiveness index
Conservation of genetic resources, plants
Open budget index
Yield, milk
Yield, vegetables
Yield, cereals
Fruit availability
Rural underemployment
Pesticide use
Rural unemployment
Food price volatility
Nitrogen use efficiency
Food system emissions
Share of agriculture in GDP
Agricultural water withdrawal
Disaster damages share of GDP
Emissions intensity, cereals (excl. rice)
Emissions intensity, rice
Milan urban food policy pact
Cropland change
Emissions intensity, milk
Emissions intensity, beef
Dietary sourcing flexibility
Food supply variability
Civil society participation
Government accountability index
Prevalence of undernourishment
Food safety capacity
Cannot afford healthy diet
Food system pathway
-5
0
5
10
Average percent change per year (95% Confidence Interval)
*** p< 0.001, ** p< 0.01, * p < 0.05
Progress
Desirable change
No change
Undesirable change

Figure 1. Global linear trends over time, 2000-2022.

Coefficients of a linear regression of the indicator on time (year) for all indicators with data from more than one year. Indicator data (response variable) normalized by min-max scaling and multipled by 100 prior to regressing on the variable year with country fixed effects; original units are defined in **Supplementary Table 1.** Results are interpreted as average percentage change in the indicator per year over the period analyzed. Note the number of country-years differs per indicator. Change defined as desirable if the results per indicator meet the following criteria: 1) the trend line is statistically significantly different from zero, 2) the coefficient estimate is >0 when rounded to the nearest tenth, and 3) the sign agrees with the desirable direction of change (defined in **Supplementary Table 1**). Conversely, estimates labeled as changing in the undesirable direction if statistically significant with a non-zero coefficient when rounded to the nearest tenth, and a sign opposite the desirable direction of change. Coefficients that round to zero, even if statistically significant, are classified as no change since the magnitude of the coefficient is not practically meaningful. Least squares regression weighted by the weighting variables defined in **Supplementary 1.** Sample size (number of countries and years) per indicator included in the analysis is provided in **Supplementary Table 4.** Excluded indicators do not have time series data and are: All 5, minimum dietary diversity (women and children), soft drink consumption, zero fruits or vegetabls (adult and children), NCD-Protect, NCD-Risk, functional integrity, fisheries health index, social protection coverage, social protection adequacy, child labor, female landholdings, and reduced coping strategies.

Region-year marginal effects—defined as an indicator's predicted value at each year-region combination, from a linear regression interacting region and year, allowing slope and intercept to vary by region (see 'Trend analysis' in Methods)—help explain the global results (**Supplementary Figures 1-5**). Of the indicators changing in a desirable direction, some show relatively uniform trends across regions, including access to safe water, vegetable availability, percent of the population who cannot afford a healthy diet, fruit, cereal, and milk yields, emissions intensity for milk, access to information, mobile phone subscriptions, and plant genetic resources conservation, suggesting common trends in the desirable direction even when starting from very different starting points. For other indicators, the global trend moves in the desirable direction despite some regions heading away from it. These indicators (and the region(s) trending undesirably) are the prevalence of undernourishment (Northern Africa & Western Asia), fruit availability (Oceania), beef yields (Southern Asia), nitrogen use efficiency (Central Asia, Sub-Saharan Africa, Oceania), emissions intensity for beef (Sub-Saharan Africa), government effectiveness (Northern America and Europe, Oceania, Latin America & Caribbean, Sub-Saharan Africa), conservation of animal genetic resources (Northern America and Europe, Oceania), social capital (Northern Africa & Western Asia, Latin America & Caribbean, Oceania).

Focusing on the governance theme, one indicator that illuminates how countries are combatting the multiple forces – including corporate influence – that result in unhealthy food environments is the presence and type of health-related food environment policies in place.[16,28–30] Some countries have implemented economic policies, such as taxes on certain foods and ingredients or subsidies for healthier items.[31] Others use regulatory instruments, such as restricting what can be served, sold, or marketed to children, requiring front-of-pack labeling, and product reformulation.[28] Some countries use multiple policies. For example, Mexico taxes added sugars and requires warning labels on products exceeding healthy limits for added sugars and energy density, among other policies.[32,33] In the case study with experts in Mexico, the experts identified that health-related food environment policies have accelerated the reduction of soft drink consumption and sales of ultra-processed foods (**Supplementary Figure 25**).

Robust empirical evidence from across settings links these types of food environment policies to desirable diet, nutrition, and health outcomes.[16,28,34–36]

We find that most countries are using economic and/or regulatory tools focused on improving the healthfulness of food environments, except for the majority of sub-Saharan Africa and many Central Asian countries (**Figure 2**). Linking this with the latest indicator status (**Supplementary Table 2)** suggests that inadequate food environment governance may contribute negatively to diet quality outcomes in Central Asia, where prevalence of daily soft drink (soda, energy/sports drinks) consumption is the world's highest, nearly twice the global average (43.4% versus 19.3% globally) and dietary factors increasing NCD risk are also highest (least desirable) in the world, with a a 76% higher NCD Risk score (3.7 vs 2.1 globally). Such patterns are not as evident in Sub-Saharan Africa, which could reflect greater poverty, uneven diagnosis and reporting of NCDs, and/or lower overall consumption of unhealthy items due to unaffordability and lower availability of these foods. Central Asia provides a cautionary lesson regarding inadequate food systems governance, consistent with other research on nutrition and health in the region,[37] and illustrating the important role of interactions across indicators, in this case the dependency of nutrition outcomes on governance actions that address the food environment.[37]

Figure 2. Health-related food environment policies.

The presence of national health-related food environment policies classified into economic (taxes, subsidies) and mandatory regulatory (e.g., front-of-pack labeling), both, or none. Countries in gray have

no national health-related food environment policies. **Supplementary Table 6** contains further information on the classification of policies to construct this indicator.

Interactions describe how change (or lack thereof) in one indicator can be directly or indirectly influenced by change (or lack thereof) in another indicator. Understanding and articulating interactions between indicators is thereby critical to enabling and accelerating desirable change. We used three related methods to investigate these interactions: global expert elicitation, automated literature search, and in-country consultations.

Global expert elicitation used qualitative expert elicitation developed and implemented by the FSCI interactions core analysis team and completed by all co-authors, organized by thematic working groups (see Methods and **Supplementary Table 1**).[3,4] Each working group assessed where there is theoretical support for a direct, causal relationship between each pair of FSCI indicators and, if present, the relationship's directionality and logic. An adjacency matrix of proposed interactions shows the closest assessed connections between each indicator pair, with directionality from row to column (**Figure 3;** complete list in **Supplementary Table 5**). **Figure 3** illustrates the relationships with directionality such that the indicators on the y-axis influence the indicators on the x-axis. As such, the matrix is not symmetrical because causality may only go in a single direction. The adjacency matrix illuminates connections – or lack thereof – between indicators in terms of the likelihood an action will have the desired impact. Most (70 of 104; 67%) occur between indicators within a theme, while 34 (of 104; 33%) occur across themes, mostly involving diets, nutrition, and health indicators. Rows that are highly connected to many columns, for example food price volatility, are areas where change in that indicator could have broad impact across themes. We observe more governance and resilience indicators to be directly or indirectly related to most other indicators than other themes (405/490 connections for governance indicators, 376/500 connections for resilience indicators).

Indicators in columns with direct connections from multiple rows, e.g., minimum dietary diversity, have many drivers, suggesting it may be difficult to realize desirable change with only one action, requiring coherent actions across all influencing domains. For example, reduced coping strategies are

affected by the cost of food, the efficiency of production systems, rural employment dynamics, social protection, governance factors such as recognition of the Right to Food and civil society participation, social capital, and infrastructure (proxied by mobile phones). Improving household's resilience to shocks so that they are not reliant on severe coping strategies thus requires addressing numerous factors across food systems. Further, in some cases, the causal relationship's directionality was assessed to go both ways (104 of 2,500 total possible pairs), indicating possible feedback loops (**Supplementary Figure 22**). For example, reduced pesticide use can have a positive effect on ecosystem functional integrity and in turn, increased ecosystem functional integrity can further reduce the need for pesticide use through increased biological control, resulting in a virtuous circle.

Assessing network density (number of direct connections relative to total number of possible connections; **Supplementary Table 5** and **Supplementary Figures 23**, **24**) shows that three of the top five most-connected indicators are from the governance theme – civil society participation, degree of legal recognition of the Right to Food (the right to adequate food as defined in the International Covenant on Economic, Social and Cultural Rights),[38] and government effectiveness – together with food price volatility (resilience) and yield (environment, natural resources, and production). These highly connected indicators can serve as critical 'nodes' for broad change, but also underscore the need for careful and ongoing measurement.


Cost of healthy diet
Fruit and vegetable availability
Ultra-processed food sales
Access to safe water
Prevalence of undernourishment
Experience food insecurity
Cannot afford healthy diet
Minimum dietary diversity, women
Minimum dietary diversity, child
All 5 food groups
Zero fruits or vegetables
NCD-Protect
NCD-Risk
Soft drink consumption
Food system emissions
Emissions intensity
Yield
Cropland change
Agricultural water withdrawal
Functional integrity
Fisheries health index
Pesticide use
Nitrogen use efficiency
Share of agriculture in GDP
Rural unemployment
Rural underemployment
Social protection coverage
Social protection adequacy
Child labor
Female landholdings
Civil society participation
Milan urban food policy pact
Right to food
Food system pathway
Government effectiveness index
Food safety capacity
Healthy food environment policies
Government accountability index
Open budget index
Access to information
Disaster damages share of GDP
Dietary sourcing flexibility
Social capital index
Mobile phones per 100 people
Minimum species diversity
Conservation of genetic resources, plants
Conservation of genetic resources, animals
Reduced coping strategies
Food price volatility
Food supply variability
Diets, Nutrition, & Health
Environment, Natural resources, & Production
Livelihoods, Poverty, & Equity
Governance
Resilience
Closest connection
None (or indirect via 3 or more)
Direct
Indirect via 1 indicator
Indirect via 2 indicators

Figure 3. Closest assessed connection between each pair of indicators.

Proposed causal relationships between pairs of indicators as assessed by expert assessment, directed from row to column. The darkest cells show a direct causal relationship. Medium blue reflects an indirect relationship via one connecting indicator, and lightest blue is indirect via two connecting indicators. Gray cells indicate an indirect relationship could exist via more than two indicators or there may be no relationship. Identity cells are white. Network data underlying the figure provided in **Supplementary Table 5**.

We used automated literature review to investigate whether the global expert assessment results are reflected in scientific literature. We measured the volume of peer-reviewed literature on the identified pairs of indicators with an assessed connection as a proxy for the presence of scientific inquiry into the proposed connection. This exercise focused on interactions involving governance indicators.

The volume of literature serves as a proxy for the level of scientific knowledge available on a possible relationship, a method increasingly used in generating evidence maps.[39–42] We used an automated literature search with Dimensions (see Methods)[43] and then manually screened the results for relevance to food systems (**Figure 4, Supplementary Table 3**). Scientific literature was found for all the interactions identified with most references for interactions involving the Right to Food and civil society participation index, which concurs with the assessment that these indicators have the highest density of connections to others (**Supplementary Table 5**). Seven search pairs returned over 1,000 results, over half of which involved the Right to Food (**Supplementary Table 3**). In contrast, eleven pairs had fewer than five results in the literature search, most involving the Milan Urban Food Policy Pact (an indicator of commitment to action) or government effectiveness, indicating a possible scientific knowledge gap on causal relationships for these indicators, an area for future research. The results demonstrate that certain indicators (and their interactions) of relevance to or directly measuring food systems governance have received much less attention in scientific literature. Unlocking the potential for food systems to change thus requires more evidence on which governance actions are most effective in facilitating synergies and addressing tradeoffs.

Figure 4. Volume of literature on direct relationships involving governance indicators.

Figure illustrates the number of citations returned from a literature search of titles and abstracts including both indicators for all pairs of indicators where a direct causal relationship was identified, and which includes at least one governance indicator. White space reflects pairs without an identified causal relationship. Seven indicator pairs have >1000 returned results (maximum of 10,166) and have been winsorized to 1000 for visual clarity. Specific counts shown in **Supplementary Table 5** (Panel A).

In-country consultations consisted of facilitated discussion with experts at the country level to investigate how these global expert assessment results are viewed within a country context. Consultations involved 15-20 national food system experts in Ethiopia, Mexico, and the Netherlands. This exercise also focused on interactions involving governance indicators.

Country-level expert consultations focused on assessing the relevance and trends of interactions identified at the global level for a specific country setting (Methods, **Supplementary Tables 7** and **8**). Ethiopia, Mexico, and the Netherlands were selected as cases because they reflect three distinct regions and food system types and they play active roles in food systems dialogues, policies and processes

(though the Netherlands does not have a food system transformation pathway). In both Ethiopia and Mexico, most interactions (Ethiopia: 51 of 63; Mexico: 47 of 63) were considered highly relevant to achieving the national food systems pathway goals (**Figure 5**). In the Netherlands, however, only 19 of 63 interactions were considered highly relevant. Though the democratic institutions and procedures are in place in the Netherlands, political opposition and lobbying by the food and farming sector have hindered action to address food systems concerns. Participants emphasized change in this context depends on leadership, political change, and governance innovations, which are not adequately captured by the current set of governance indicators.

For over one third of the interactions (Ethiopia: 22 of 63; Mexico: 28 of 63; Netherlands: 23 of 63), the strength of the influence of the governance indicator on the corresponding indicator was deemed to have been increasing over the last 10 years. In Mexico, for example, health-related food environment policies have contributed to reducing soft drink consumption and ultra-processed food sales (**Supplementary Figure 25**). In the Netherlands, civil society participation increasingly influences environmental, health and social protection adequacy issues. A minority of interactions (Ethiopia: 14 of 63; Mexico: 4 of 63; Netherlands: 9 of 63) have decreased in strength over time including the influence of the degree of legal recognition to the Right to Food on the cost of diet and social protection adequacy (Ethiopia) and government effectiveness (Netherlands) **(Supplementary Figure 25**). The Netherlands experts noted that increased globalization (particularly global trade, European integration, and increased power of multinationals) has contributed to lessening government control over food systems and makes it harder for governments to be effective when held accountable. Experts noted optimism for EU level policies to potentially exert greater power than any one country. The influence of government effectiveness on the percentage of the population experiencing food insecurity has been decreasing, yet the interaction was considered highly relevant for sustainable food systems with more intervention needed.

Most of the interactions were considered to be synergies, contributing to positive change (Ethiopia: 58 of 63, Mexico: 58 of 63, Netherlands: 59 of 63). Exceptions include the degree of legal recognition of

the Right to Food, which could have unintended consequences for land use change, agricultural water withdrawal, and pesticide use (if land is converted to intensify food production). The presence of health-related food environment policies (e.g. warning labels) can contribute to reducing the cost of a healthy diet but only if there is adequate supply response.[45] Below, we discuss how such qualitative assessment of interactions can help articulate and prioritize which interactions need close monitoring and management.

Figure 5. Relevance and trend over time of governance interactions in Ethiopia and Mexico

Summary of qualitative variables elicited through expert consultation. The figure synthesizes the number of interactions qualitatively plotted according to relevance to transformation towards sustainable food systems (Y-axis) and whether the strength of the interaction has been increasing, remained the same, or been decreasing over the last 10 years (X-axis). A total of 63 interactions with governance indicators, identified at global level, was plotted through national expert elicitation considering the country context. A detailed figure plotting all 63 interactions is available in **Supplementary Figure 24**.

Discussion

This paper presents the first annual update of the *Food Systems Countdown to 2030 Initiative* annual monitoring. It makes two contributions to the literature. The first contribution is to present systematic, reproduceable, analysis of trends in key food systems indicators since 2000, identifying 20 indicators, that

span all themes, trending in the desirable direction. This signals that at least some parts of food systems are heading towards desirable outcomes. We note that the direction of desirability is considered at the global level, and that nuance for some indicators is important. For example, while increasing efficiency in production (higher yields) is desirable to reduce inputs needed per unit of output, it can also lead to growth in total production, thereby consuming more total resources globally than under lower efficiency (Jevon's paradox).[46–48] Specifically, it is debated whether higher beef yields should be desired, given calls for a protein transition.[48,49] Our adjacency matrix results illustrate that yield is assessed to be a highly connected indicator, suggesting that productivity gains can come with multiple synergies and tradeoffs on resource use (e.g., cropland expansion), diets (e.g., NCD-Risk), and equity (e.g., female landholdings).

Indicators trending undesirably or showing no change may indicate slow-moving phenomena or need for vigilance. They may also indicate that upstream dependencies (interactions) are blocking their ability to progress. For example, health-related food environment policies are deployed in most of the world with robust empirical evidence of their effeciveness,[16,28,34–36] but most Central Asian countries (where diet quality is among the worst in the world) are not making use of these policy tools, suggesting a potential dependency of diet quality outcomes on food environment policies. We also observe that the cost of a healthy diet and food insecurity are trending in an undesirable direction, both attributable at least in part to rising inflation.[50]

The second contribution identified is where theory supports a direct causal relationship between each pair of indicators using expert assessment, highlighting potential synergies or tradeoffs. The results show that certain governance and resilience indicators are assessed to have the greatest number of connections to other indicators across themes (civil society participation, Right to food, government effectiveness, disaster damages share of GDP, social capita, and food price volatility), highlighting key leverage points for action. While at the same time, several diet, environmental, and resilience indicators are influenced by numerous other indicators (cost of a healthy diet, diet quality indicators, reduced coping strategies, and food price volatility), suggesting that changes to these outcomes may require numerous coordinated actions. Food price volatility is on both lists, suggesting a key indicator with feedback loops where

changes either amplify and spur further changes or act as a balancing force to send the system back towards equilibrium. The nature of this feedback loop is an important topic of future research.

Results from our literature search suggest that the proposed connections we identified between governance indicators and other indicators have conceptual validity. We found all proposed directly connected pairs have been investigated, with most literature on the Right to Food and the least on the Milan Urban Food Policy Pact and civil society participation. The Milan Urban Food Policy Pact metric may be too specific to be reflected in the literature, suggesting that perhaps focus should instead be on the urban policies and actions proposed by the pact,[51] rather than signatory status. Further, the cost of a healthy diet is a newly developed indicator, but the phrase is widely found in literature referring to the same concept but not the exact indicator and therefore the numerous results for interactions with the cost of a healthy diet likely reflect studies that are not actually about the specific indicator but rather the broader concept, which is similarly true for the Right to Food. However, this analysis provides a departure point for further research on the nature, direction, and strength of these interactions and identified some gaps, for example, indicators connected to government effectiveness.

This study contributes to the growing literature focused on understanding such systems interactions and demonstrates how case studies can add depth to understanding interactions in context.[52,53] The case studies show how food environment policies have become increasingly impactful in achieving better diet quality outcomes in Mexico, that government effectiveness is highly relevant for food systems outcomes in Ethiopia (but its influence has been decreasing on livelihoods indicators), and that civil society participation plays an increasingly important role in driving food systems change in the Netherlands, filling in the gap that government leaves. Participants testified that the process stimulated new thinking, discussions, and concrete connections among the participating experts from different backgrounds and organizations (**Supplementary Table 7**). The participants in Ethiopia expressed a desire to replicate the exercise for interactions between the monitoring indicators in their national food system transformation pathway. Participants in Mexico noted a critical gap to be the influence of industry lobbying. In the Netherlands, participants suggested not having a food systems transformation pathway illustrates lack of

political will to make fundamental changes and a further tailored set of food systems indicators could help move beyond the standstill lack of government action has created. . Such facilitated consultations demonstrate an effective method to engage local experts in identifying interactions and articulating context-specific actions that can be used (or advocated for) to navigate tradeoffs.

Going forward, there are several important directions for improving understanding of the synergies and tradeoffs among food system dimensions. First, the indicators in the FSCI framework reflect those with sufficient country coverage to meet inclusion criteria, thereby leaving out some indicators that conceptually fit in the framework, particularly affecting the livelihoods and governance themes. The FSCI makes continuous improvements to indicators and data with each annual publication wherever new options become available. Second, whether an interaction is a synergy or tradeoff is often context-specific, likely varying by spatial and temporal scale, political and environmental context, and other factors. Third, the number and nature of the relationships highlighted in these results depend upon indicator availability in each theme and their effectiveness in describing the concepts contained therein. Specifically, many governance indicators are general and focused on the enabling environment for food systems transformation. This generality may be part of the reason they emerge as so connected to other indicators. Similarly, phenomena captured by governance indicators typically, but not always, change slowly, and include binary and categorical indicators not amenable to trend analysis. Finally, case studies were carried out in three countries as illustrative examples of an effective consultation method and insights it can generate, which can be replicated in other contexts.

In conclusion, this paper provides a first global insight on change over time across food systems themes, complemented by a cross-cutting qualitative assessment on interactions to help understand and navigate towards desirable change.

Data availability. Data are available on the Food Systems Dashboard and the source data for this manuscript and raw underlying data with accompanying replication files are on GitHub at https://github.com/KateSchneider-FoodPol/FSCI_2024Interactions_Replication. Use of any materials in the GitHub repository are subject to a CC-BY-NC-SA 4.0 (non-commercial, share alike) license.

Code availability. Replication code for this paper is available on GitHub at https://github.com/KateSchneider-FoodPol/FSCI_2024Interactions_Replication.

Author contributions.

Conceptualization (KRS, RR, Interactions core analysis team, Governance working group, Co-chairs), methodology (KRS, RR, JG, YM, Interactions core analysis team), formal analysis (KRS, RR, THB, BS, CGF, TF, AF), expert elicitation (all), in-country process coordination and facilitation (Ethiopia: THB, YG, KM, BTM; Mexico: SB, MIVM, MAR, APBD, ACMS; Netherlands: JC, CVD), resources (LH, JF, MH, TB, RM), data curation (KRS, CGF, BS, CGF, TF, AF, DD), writing – original draft (KRS, RR), writing – review & editing (all), visualization (KRS, RR, THB), and project administration (KRS, JF, RM). Interactions core team (KRS, RR, THB, DA, PConforti,SD, FD, DD, CF, JAG, YJM, RM, MS). Governance working group members (KRS, SB, PCaron, NC, IdPA, SH, DR, DS, JLVP, PW, JRM). LH, MH, JRM, and JF jointly supervised this work.

KRS and RR contributed equally as first authors.

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Competing interests.

Lawrence Haddad, Mario Herrero, Jose Rosero Moncayo, and Jessica Fanzo are co-chairs of the Food Systems Countdown Initiative, co-led by the Global Alliance of Improved Nutrition, the Food and Agriculture Organization of the United Nations, Cornell University, and Columbia Climate School. The findings, ideas, and conclusions presented here are those of the authors and do not necessarily reflect the positions or policies of any of GAIN's funding partners or of United Nations member states. Other authors declare no competing interests.

Funding

GAIN Nourishing Food Pathways program, jointly funded by the German Federal Ministry for Economic Cooperation and Development; the Ministry of Foreign Affairs of the Netherlands; the European Union; the government of Canada through Global Affairs Canada; Irish Aid through the Development Cooperation and Africa Division (DCAD); and the Swiss Agency for Development and Cooperation (SDC) of the Federal Department of Foreign Affairs (FDFA): KS, SN, TB, RM, DA, DD, and BS.

Joint funding from the Global Alliance for Improved Nutrition (GAIN), Cornell University, and Columbia University: RR and THB.

Acknowledgements

We acknowledge all the participants of the expert elicitation workshops in Ethiopia, Mexico and the Netherlands. The full list of participants is available in the Supplementary Information. We also thank Ioana Vlad of the World Cancer Research Fund for her collaboration and conceptual validation in the revision to the health-related food environment policies indicator.

Supplementary Information: See https://www.nature.com/articles/s43016-024-01109-4#Sec12

Supplementary Data 1: Metadata and Codebook.xlsx

Supplementary Data 2: FSCI_2024.csv

Supplementary Tables 1-8 and Figures 1-25

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Supplementary Table 1. Monitoring global food systems indicator summary statistics by income group and metadata

Indicator metadata with income group and global weighted means. Categorical indicators (Right to Food and Health-related food environment policies) are excluded. These data reflect the latest data point per country per indicator (with any latest data point prior to 2010 excluded). Many of the variables used for weighting (e.g., population) are not yet available for 2023 or 2024, therefore some indicators with data in 2023 or 2024 are not included as the latest data point per country-indicator due to lack of a weighting variable. **Supplementary Data 1** shows the year of the latest available data point per country-indicator since 2010 and data sources.

Theme	Domain	Indicator	Unit	Weighted by	Desirable direction of change	Low income	Lower middle income	Upper middle income	High income	Global mean
Diets, Nutrition, and Health	Food environments	Cost of a healthy diet per capita	PPP dollar per day	Total population	-1	3.5	3.8	3.6	3.6	3.7
		Availability of fruits and vegetables per capita, fruits	g/day	Unweighted	1	158.9	201.7	331.2	328.1	267.3
		Availability of fruits and vegetables per capita, vegetables	g/day	Unweighted	1	133.6	227.8	356.3	406.9	300.0
		Retail value of ultra-processed foods per capita	current PPP US$/year	Total population	-1	1.2	4.8	54.9	858.9	153.6
		% population using safely managed drinking water services (SDG 6.1.1)	% population	Total population	1	17.6	51.8	85.5	97.4	67.9
	Food security	% Population experiencing moderate or severe food insecurity (SDG 2.1.2)	%	Total population	-1	66.3	37.7	21.5	7.2	29.9
		% Population who cannot afford a healthy diet	%	Total population	-1	71.0	52.0	18.7	6.4	35.8
		PoU: Prevalence of Undernourishment (SDG 2.1.1)	%	Total population	-1	27.8	12.6	5.9	3.4	13.3
	Diet quality	All-5: consumption of all 5 food groups	%	Total population	1	25.0	32.0	49.9	43.5	38.6
		MDD (IYCF): minimum dietary diversity for infants and young children	% population, 6-23 months	Total population	1	19.7	32.9	60.5	69.8	41.1
		MDD-W: minimum dietary diversity for women	%	Total population	1	47.5	55.0	83.6	84.1	66.4
		NCD-Protect	score (points out of 9)	Total population	1	3.1	3.5	4.4	3.9	3.8
		NCD-Risk	score (points out of 9)	Total population	-1	1.3	1.8	2.5	3.4	2.1

Theme	Domain	Indicator	Unit	Weighted by	Desirable direction of change	Low income	Lower middle income	Upper middle income	High income	Global mean
		Soft drink consumption	%	Total population	-1	14.5	18.4	17.1	41.7	19.3
		Zero fruit or vegetable consumption, adults	%	Total population	-1	14.0	15.4	4.3	6.4	10.9
		Zero fruit or vegetable consumption, children 6-23 months	% population, 6-23 months	Total population	-1	47.4	46.8	19.0		45.7
Environment, natural resources, and production	Greenhouse gas emissions	Emissions intensity, beef	kg CO2eq/kg product	Total production	-1	91.7	34.3	29.6	16.5	28.3
		Emissions intensity, cereals (excl. rice)	kg CO2eq/kg product	Total production	-1	0.1	0.2	0.2	0.2	0.2
		Emissions intensity, milk	kg CO2eq/kg product	Total production	-1	4.2	1.3	0.9	0.6	1.0
		Emissions intensity, rice	kg CO2eq/kg product	Total production	-1	1.5	1.1	1.0	1.3	1.1
		Agri-food systems greenhouse gas emissions	kt CO2eq (AR5)	Unweighted	-1	63,507.3	88,292.5	118,763.2	57,909.9	83,275.5
	Production	Yield, beef	kg/animal	Producing animals	1	119.6	162.6	205.0	322.9	221.0
		Yield, cereals	tonnes/ha	Area harvested	1	0.1	0.3	0.5	0.6	0.4
		Yield, fruit	tonnes/ha	Area harvested	1	0.7	1.3	1.6	1.4	1.4
		Yield, milk	kg/animal	Producing animals	1	480.2	1,732.2	2,974.5	7,467.4	2,262.9
		Yield, vegetables	tonnes/ha	Area harvested	1	1.0	1.3	2.6	3.2	2.0
	Land	Cropland area change	%	Cropland	-1	0.8	0.3	0.1	-0.3	0.1
	Water	Agricultural water withdrawal as % of total renewable water resources	% total renewable	Cropland	-1	17.8	24.8	10.9	14.1	16.8
	Biosphere integrity	Fishery health index progress score	score	Total population	1	9.3	21.1	15.9	35.8	21.2
		Functional integrity: agricultural land with minimum level of natural habitat	% agricultural land	Agricultural land area - ESA	1	0.5	0.3	0.5	0.4	0.4
	Pollution	Pesticide use per area of cropland	kg/ha	Cropland	-1	0.3	1.6	3.2	3.1	2.4
		Cropland nitrogen use efficiency	%	Cropland	1	74.6	60.3	63.3	62.0	63.1
Livelihoods, Poverty, and Equity	Poverty and income	Share of agriculture in GDP	% GDP	GDP	-1	26.8	15.1	6.9	1.3	4.4
	Employment	Underemployment rate, rural	% working age population	Total population	-1	12.8	5.5	7.3	2.8	6.0

Theme	Domain	Indicator	Unit	Weighted by	Desirable direction of change	Low income	Lower middle income	Upper middle income	High income	Global mean
		Unemployment rate, rural	% working age population	Total population	-1	2.8	3.8	7.7	4.3	4.4
	Social protection	Social protection adequacy	% of total welfare of beneficiary households	Total population	1	17.5	11.9	36.7	44.7	23.0
		Social protection coverage	% of population	Total population	1	19.3	60.3	64.1	71.7	58.7
	Rights	% of children 5-17 engaged in child labor	% population 5-17 years	Total population	-1	21.7	16.0	4.2	5.0	13.2
		Share of women among owners or rights-bearers of agricultural land (SDG 5.a.1)	% landholdings	Land area	1	39.9	26.5	13.7		30.7
Governance	Shared vision and strategic planning	Civil society participation index	index	Total population	1	0.6	0.7	0.4	0.8	0.6
		Presence of a national food system transformation pathway	binary	Unweighted	1	0.7	0.8	0.6	0.5	0.6
		% urban population living in cities signed onto the Milan Urban Food Policy Pact	% urban population	Urban population	1	5.2	3.5	13.5	14.5	8.5
	Effective implementation	Food safety capacity	index	Total population	1	41.2	58.3	82.1	90.3	69.5
		Government effectiveness index	binary	Unweighted	1	-1.2	-0.1	0.1	1.2	0.0
	Accountability	Guarantees for public access to information (SDG 16.10.2)	index	Total population	1	0.6	0.6	0.7	0.9	0.7
		V-Dem Accountability index	index	Total population	1	-0.1	0.4	-0.4	1.5	0.2
		Open Budget Index Score	number	Land area	1	25.1	42.3	39.4	64.9	43.0
Resilience	Exposure to shocks	Ratio of total damages from all disasters to GDP	ratio	GDP	-1	1.3	0.3	0.1	0.4	0.3
	Agro- and Food Diversity	Number of (a) plant genetic resources for food and agriculture secured in either medium- or long-term conservation facilities (SDG 2.5.1)	number	Land area	1	16,608.0	91,924.2	136,812.2	262,537.1	166,534.7

Theme	Domain	Indicator	Unit	Weighted by	Desirable direction of change	Low income	Lower middle income	Upper middle income	High income	Global mean
		Number of (b) animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities (SDG 2.5.1)	number	Agricultural land area - Minimum species richness	1	0.7	11.1	1.6	6.0	5.1
		Proportion of agricultural land with minimum level of species diversity (crop and pasture)	%	Agricultural land area - Minimum species richness	1	35.2	48.2	20.3	16.7	24.5
	Resilience capacities	Dietary sourcing flexibility index	index	Total population	1	0.6	0.6	0.7	0.8	0.7
		Mobile cellular subscriptions	Number per 100 people	Unweighted	1	68.3	102.2	117.6	131.0	110.1
		Social capital index	index	Total population	1	0.4	0.4	0.6	0.6	0.5
	Resilience responses/strategies	Prevalence of severe coping strategies	% population	Total population	-1	0.4	0.3	0.3		0.4
	Long-term outcomes	Food supply variability per capita	kcal/day	Unweighted	-1	35.4	26.0	26.1	30.1	29.3
		Food price volatility	index	Unweighted	-1	0.7	0.7	0.7	0.6	0.7

* Values multiplied by 1,000 for display purposes.

Supplementary Table 2. Monitoring global food systems indicator summary statistics by region and metadata

Indicator metadata with region and global weighted means. Categorical indicators (Right to Food and Health-related food environment policies) are excluded. These data reflect the latest data point per country per indicator (with any latest data point prior to 2010 excluded). Many of the variables used for weighting (e.g., population) are not yet available for 2023 or 2024, therefore some indicators with data in 2023 or 2024 are not included as the latest data point per country-indicator due to lack of a weighting variable. **Supplementary Data 1** shows the year of the latest available data point per country-indicator since 2010 and data source.

Domain	Indicator	Unit	Weighted by	Desirable direction of change	Southern Asia	Northern America and Europe	Northern Africa & Western Asia	Sub-Saharan Africa	Latin America & Caribbean	Oceania	South-eastern Asia	Eastern Asia	Central Asia	Global mean
Food environments	Cost of healthy diet	PPP dollar per day	Total population	-1	3.5	3.1	4.0	3.6	4.1	3.0	4.4	3.7	4.5	3.7
	Fruit availability	g/day	Unweighted	1	195.1	318.7	271.0	183.4	397.9	245.1	183.7	169.6	174.5	267.3
	Vegetable availability	g/day	Unweighted	1	246.0	445.5	424.2	144.6	228.3	225.8	227.8	534.2	623.3	300.0
	Ultra-processed food sales	current PPP US$/year	Total population	-1	1.1	877.3	115.3	3.8	71.0	577.3	11.2	43.1	15.5	153.6
	Access to safe water	% population	Total population	1	61.8	93.5	62.1	21.5	58.3	96.2	36.5	97.0	74.8	67.9
Food security	Experience food insecurity	%	Total population	-1	39.9	7.8	30.0	61.6	30.3	23.1	16.5	4.8	11.1	29.9
	Cannot afford healthy diet	%	Total population	-1	53.1	4.6	26.5	72.1	27.1	5.1	36.6	16.4	16.3	35.8
	Prevalence of under-nourishment	%	Total population	-1	14.1	4.5	11.5	22.1	6.8	23.9	5.9	10.2	4.1	13.3
Diet quality	All 5 food groups	%	Total population	1	27.4	37.8	40.0	25.0	47.0		49.6	54.7	43.7	38.6
	Minimum dietary diversity, child	% population, 6-23 months	Total population	1	27.4	71.1	37.5	24.1	62.1	34.3	51.9	60.3	51.2	41.1
	Minimum dietary diversity, women	%	Total population	1	44.5	80.3	73.9	52.0	82.2		84.4	86.2	88.3	66.4
	NCD-Protect	score (points out of 9)	Total population	1	3.3	3.7	3.5	3.1	4.4		4.4	4.6	3.8	3.8
	NCD-Risk	score (points out of 9)	Total population	-1	1.5	3.3	1.8	1.7	2.8		3.0	2.4	3.7	2.1
	Soft drink consumption	%	Total population	-1	14.2	35.6	24.9	25.1	37.1		21.0	11.6	43.4	19.3
	Zero fruits or vegetables, adult	%	Total population	-1	19.8	6.3	7.4	13.8	5.6		4.4	3.7	2.0	10.9
	Zero fruits or vegetables, child	% population, 6-23 months	Total population	-1	50.9	25.7	35.8	43.6	20.3	51.4	27.6			45.7
Greenhouse gas emissions	Emissions intensity, beef	kg CO2eq/kg product	Total production	-1	29.5	14.9	17.5	63.3	42.4	25.1	64.3	13.5	16.3	28.3
	Emissions intensity, cereals (excl. rice)	kg CO2eq/kg product	Total production	-1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Emissions intensity, milk	kg CO2eq/kg product	Total production	-1	1.2	0.6	1.0	3.6	1.0	0.8	2.8	0.8	1.1	1.0
	Emissions intensity, rice	kg CO2eq/kg product	Total production	-1	0.8	2.0	1.1	1.5	0.9	1.1	1.5	0.9	3.0	1.1
	Food system emissions	kt CO2eq (AR5)	Unweighted	-1	216,683.4	74,185.8	32,321.9	52,416.6	85,465.8	20,297.4	150,226.5	520,631.0	32,377.2	83,275.5
Production	Yield, beef	kg/animal	Producing animals	1	128.5	318.8	208.6	154.0	237.1	242.9	179.6	157.0	189.3	221.0

Domain	Indicator	Unit	Weighted by	Desirable direction of change	Southern Asia	Northern America and Europe	Northern Africa & Western Asia	Sub-Saharan Africa	Latin America & Caribbean	Oceania	South-eastern Asia	Eastern Asia	Central Asia	Global mean
	Yield, cereals	tonnes/ha	Area harvested	1	0.4	0.5	0.2	0.2	0.5	0.3	0.4	0.6	0.2	0.4
	Yield, fruit	tonnes/ha	Area harvested	1	1.4	1.3	1.4	0.8	1.7	1.3	1.5	1.6	1.4	1.4
	Yield, milk	kg/animal	Producing animals	1	1,825.4	6,970.9	2,184.0	383.3	2,583.3	4,827.6	1,578.4	2,480.3	2,326.7	2,262.9
	Yield, vegetables	tonnes/ha	Area harvested	1	1.6	2.9	2.8	0.6	1.9	2.0	1.2	2.6	3.6	2.0
Land	Cropland change	%	Cropland	-1	-0.1	-0.3	0.0	1.0	0.4	0.4	0.4	-0.3	-0.1	0.1
Water	Agricultural water withdrawal	% total renewable	Cropland	-1	40.6	3.2	101.3	4.3	3.7	1.7	8.4	12.6	28.8	16.8
Biosphere integrity	Fisheries health index	score	Total population	1	27.2	38.3	13.5	10.1	24.2	27.2	13.7	12.2		21.2
	Functional integrity	% agricultural land	Agricultural land area - ESA	1	0.1	0.4	0.4	0.5	0.6	0.5	0.6	0.5	0.5	0.4
Pollution	Pesticide use	kg/ha	Cropland	-1	0.4	2.2	1.2	0.7	7.5	2.0	4.7	2.2	0.3	2.4
	Nitrogen use efficiency	%	Cropland	1	41.6	66.9	60.0	81.9	63.7	80.5	55.3	50.6	82.8	63.1
Poverty and income	Share of agriculture in GDP	% GDP	GDP	-1	16.2	1.5	4.6	18.0	6.0	3.1	9.7	6.0	10.6	4.4
Employment	Rural underemployment	% working age population	Total population	-1	2.6	2.5	3.3	10.9	10.0	6.5	5.6	2.4		6.0
	Rural unemployment	% working age population	Total population	-1	4.4	4.9	7.9	4.3	4.9	3.1	1.7	2.1	5.2	4.4
Social protection	Social protection adequacy	% of total welfare of beneficiary households	Total population	1	8.1	40.4	26.3	21.1	31.6	12.2	20.0	36.8	31.3	23.0
	Social protection coverage	% of population	Total population	1	73.6	71.7	68.6	23.7	59.6	37.8	50.5	63.1	36.5	58.7
Rights	Child labor	% population 5-17 years	Total population	-1	8.1	6.1	5.2	25.6	4.7	16.9	9.2	5.4	18.3	13.2
	Female landholdings	% landholdings	Land area	1	24.9	48.4	24.3	34.1	9.4	58.7	26.7		62.6	30.7
Shared vision and strategic planning	Civil society participation	index	Total population	1	0.6	0.8	0.4	0.7	0.6	0.8	0.7	0.4	0.3	0.6
	Food system pathway	binary	Unweighted	1	0.7	0.4	0.6	0.8	0.6	0.9	0.6	0.8	0.8	0.6
	Milan urban food policy pact	% urban population	Urban population	1	1.9	12.7	6.7	8.5	29.1	1.7	5.3	8.3	3.5	8.5
Effective implementation	Food safety capacity	index	Total population	1	57.3	88.7	71.8	44.9	85.0	82.0	69.3	81.9	42.5	69.5
	Government effectiveness index	binary	Unweighted	1	0.0	0.8	-0.6	-0.8	-0.5	0.9	0.1	0.6	-0.4	0.0
Accountability	Access to information	index	Total population	1	0.9	1.0	0.7	0.5	0.8	0.4	0.5	0.8	0.8	0.7
	Government accountability index	index	Total population	1	0.3	1.2	-0.3	0.4	0.9	1.5	0.3	-0.9	-0.5	0.2
	Open budget index	number	Land area	1	37.5	67.1	30.5	37.4	65.8	71.9	59.1	25.1	50.0	43.0

Domain	Indicator	Unit	Weighted by	Desirable direction of change	Southern Asia	Northern America and Europe	Northern Africa & Western Asia	Sub-Saharan Africa	Latin America & Caribbean	Oceania	South-eastern Asia	Eastern Asia	Central Asia	Global mean
Exposure to shocks	Ratio of total damages from all disasters to GDP*	ratio	GDP	-1	0.1	0.4	0.5	0.9	0.3	0.5	0.0	0.1	0.0	0.3
Agro- and Food Diversity	Conservation of genetic resources, plants	number	Land area	1	279,885.9	237,131.5	18,881.0	12,978.3	109,762.5	272,872.4	12,279.5	59,968.7	40,246.9	166,534.7
	Conservation of genetic resources, animals	% agricultural land	Agricultural land area - Minimum species richness	1	43.5	6.1	0.2	1.2	0.6	0.0	5.2	1.3	6.5	5.1
	Minimum species diversity	%	Agricultural land area - Minimum species richness	1	62.5	13.6	28.3	38.1	29.6	11.8	60.1	33.5	17.9	24.5
Resilience capacities	Dietary sourcing flexibility	index	Total population	1	0.7	0.7	0.8	0.6	0.7	0.7	0.6	0.7	0.7	0.7
	Mobile phones per 100 people	Number per 100 people	Unweighted	1	110.1	124.2	126.1	92.1	112.8	74.5	126.3	121.3	116.3	110.1
	Social capital index	index	Total population	1	0.4	0.6	0.4	0.4	0.3	0.6	0.4	0.7	0.5	0.5
Resilience responses/ strategies	Reduced coping strategies	% population	Total population	-1	0.3	0.4	0.4	0.4	0.4		0.1		0.5	0.4
Long-term outcomes	Food supply variability	kcal/day	Unweighted	-1	24.7	30.4	33.0	28.9	30.0	20.2	26.7	31.4	26.0	29.3
	Food price volatility	index	Unweighted	-1	0.8	0.6	0.7	0.7	0.6	0.8	0.7	0.6	0.8	0.7

* Values multiplied by 1,000 for display purposes.

Supplementary Table 3. Search terms and returned results for automated literature search of indicator pairs.

Search queries and results for the pairs of indicators identified as having a direct causal connection. Queries searched title and abstract only. Automated screening eliminated posters and results not in English. Further manual screening to eliminate irrelevant results was carried out only for the search pairs including at least one governance indicator.

Indicator 1	Indicator 2	Number of results
Civil society participation	Prevalence of undernourishment	2
Civil society participation	Experience food insecurity	145
Civil society participation	Food system emissions	111
Civil society participation	Emissions intensity	48
Civil society participation	Functional integrity	75
Civil society participation	Pesticide use	68
Civil society participation	Nitrogen use efficiency	9
Civil society participation	Rural unemployment	238
Civil society participation	Rural underemployment	8
Civil society participation	Social protection coverage	346
Civil society participation	Social protection adequacy	513
Civil society participation	Child labor	1,453
Civil society participation	Female landholdings	10
Civil society participation	Milan urban food policy pact	5
Civil society participation	Right to food	913
Civil society participation	Food system pathway	111
Civil society participation	Government effectiveness index	360
Civil society participation	Food safety capacity	257
Civil society participation	Healthy food environment policies	218
Civil society participation	Reduced coping strategies	95
Milan urban food policy pact	Fruit and vegetable availability	2
Milan urban food policy pact	Experience food insecurity	3
Milan urban food policy pact	Food system emissions	10
Milan urban food policy pact	Pesticide use	4
Milan urban food policy pact	Nitrogen use efficiency	1
Milan urban food policy pact	Right to food	13
Milan urban food policy pact	Reduced coping strategies	3
Milan urban food policy pact	Food supply variability	3
Right to food	Cost of healthy diet	6,436
Right to food	Prevalence of undernourishment	76
Right to food	Experience food insecurity	1,443
Right to food	Cannot afford healthy diet	3
Right to food	Cropland change	2,664
Right to food	Agricultural water withdrawal	298
Right to food	Fisheries health index	111
Right to food	Pesticide use	10,166
Right to food	Share of agriculture in GDP	438
Right to food	Rural unemployment	467
Right to food	Rural underemployment	15
Right to food	Social protection coverage	594
Right to food	Social protection adequacy	1,421
Right to food	Reduced coping strategies	231
Right to food	Food price volatility	358
Right to food	Food supply variability	695
Food system pathway	Milan urban food policy pact	7
Food system pathway	Government effectiveness index	31
Food system pathway	Healthy food environment policies	111
Food system pathway	Minimum species diversity	34
Government effectiveness index	Access to safe water	231
Government effectiveness index	Prevalence of undernourishment	2
Government effectiveness index	Experience food insecurity	224
Government effectiveness index	Fisheries health index	26

Indicator 1	Indicator 2	Number of results
Government effectiveness index	Rural unemployment	50
Government effectiveness index	Rural underemployment	1
Government effectiveness index	Social protection coverage	124
Government effectiveness index	Social protection adequacy	105
Government effectiveness index	Milan urban food policy pact	1
Government effectiveness index	Open budget index	196
Government effectiveness index	Social capital index	457
Government effectiveness index	Food price volatility	85
Food safety capacity	Government effectiveness index	107
Healthy food environment policies	Ultra-processed food sales	136
Healthy food environment policies	Cannot afford healthy diet	10
Healthy food environment policies	Soft drink consumption	376
Healthy food environment policies	Milan urban food policy pact	9
Access to information	Government accountability index	7,419

Source: Dimensions.ai database.

Supplementary Table 4. Weighted linear regression of indicators on time.

Results of a weighted linear regression by indicator on year. Color coding aligns to manuscript Figure 1 where green indicators have a time trend that is statistically significantly different from zero towards the desirable direction of change and red indicators have a time trend that is statistically significantly different from zero away from the desirable direction of change. Weights defined in **Extended Data Table 1**. Regression model includes regional fixed effects. Excluded indicators do not have time series data and are: All 5, minimum dietary diversity (women and children), soft drink consumption, zero fruits or vegetabls (adult and children), NCD-Protect, NCD-Risk, functional integrity, fisheries health index, social protection coverage, social protection adequacy, child labor, female landholdings, and reduced coping strategies.

Indicator	Coef.	SE	p val.		95% Conf.	Int.	Desirable direction	N countries	Years		N years
Cost of healthy diet	2.538	0.192	0.000	***	2.160	2.916	-1	165	2017	2022	6
Fruit availability	0.149	0.058	0.010	**	0.036	0.262	1	184	2010	2022	13
Vegetable availability	0.343	0.070	0.000	***	0.207	0.480	1	184	2010	2022	13
Ultra-processed food sales	0.316	0.163	0.053		-0.004	0.635	-1	180	2017	2021	5
Access to safe water	0.683	0.038	0.000	***	0.609	0.757	1	137	2000	2022	23
Experience food insecurity	1.268	0.233	0.000	***	0.811	1.726	-1	151	2015	2021	7
Cannot afford healthy diet	-0.991	0.243	0.000	***	-1.467	-0.515	-1	149	2017	2022	6
Prevalence of undernourishment	-0.483	0.036	0.000	***	-0.553	-0.414	-1	137	2001	2021	21
Emissions intensity, beef	-0.048	0.007	0.000	***	-0.062	-0.033	-1	183	2000	2021	22
Emissions intensity, cereals (excl. rice)	0.000	0.000	0.000	***	0.000	0.000	-1	174	2000	2021	22
Emissions intensity, milk	-0.046	0.005	0.000	***	-0.055	-0.036	-1	179	2000	2021	22
Emissions intensity, rice	0.000	0.000	0.000	***	0.000	0.000	-1	117	2000	2021	22
Food system emissions	0.018	0.024	0.457		-0.029	0.064	-1	194	2000	2021	22
Yield, beef	0.307	0.034	0.000	***	0.241	0.373	1	182	2000	2022	23
Yield, cereals	0.156	0.008	0.000	***	0.140	0.173	1	177	2000	2022	23
Yield, fruit	0.348	0.020	0.000	***	0.308	0.387	1	187	2000	2022	23
Yield, milk	0.216	0.024	0.000	***	0.169	0.262	1	179	2000	2022	23
Yield, vegetables	0.188	0.008	0.000	***	0.172	0.204	1	187	2000	2022	23
Cropland change	-0.013	0.007	0.055		-0.027	0.000	-1	193	2005	2022	18

Indicator	Coef.	SE	p val.		95% Conf. Int.		Desirable direction	N countries	Years		N years
Agricultural water withdrawal	0.001	0.003	0.811		-0.006	0.008	-1	175	2000	2020	21
Pesticide use	0.107	0.012	0.000	***	0.084	0.130	-1	180	2000	2022	23
Nitrogen use efficiency	0.025	0.005	0.000	***	0.016	0.035	1	187	2000	2021	22
Share of agriculture in GDP	0.010	0.010	0.314		-0.009	0.029	-1	192	2000	2022	23
Rural underemployment	0.120	0.055	0.029	*	0.012	0.228	-1	111	2000	2022	23
Rural unemployment	0.083	0.043	0.056		-0.002	0.168	-1	140	2000	2022	23
Civil society participation	-0.416	0.043	0.000	***	-0.500	-0.332	1	172	2000	2022	23
Food system pathway	-1.546	2.344	0.510		-6.155	3.062	1	194	2022	2024	2
Milan urban food policy pact	0.000	0.000			0.000	0.000	1	194	2020	2023	2
Food safety capacity	-0.630	0.840	0.454		-2.281	1.021	1	191	2018	2020	3
Government effectiveness index	0.226	0.028	0.000	***	0.170	0.281	1	193	2000	2022	22
Access to information	8.432	2.710	0.002	**	3.107	13.756	1	194	2021	2023	3
Government accountability index	-0.419	0.039	0.000	***	-0.496	-0.342	1	172	2000	2022	23
Open budget index	0.216	0.561	0.700		-0.887	1.318	1	120	2017	2021	3
Disaster damages share of GDP	0.000	0.001	0.983		-0.002	0.002	-1	155	2000	2022	23
Conservation of genetic resources, plants	0.220	0.066	0.001	***	0.089	0.350	1	116	2000	2022	12
Conservation of genetic resources, animals	0.466	0.083	0.000	***	0.303	0.629	1	100	2000	2022	23
Minimum species diversity	0.352	0.232	0.130		-0.104	0.807	1	183	2010	2020	2
Dietary sourcing flexibility	-0.124	0.097	0.205		-0.315	0.068	1	167	2011	2019	9
Mobile phones per 100 people	2.131	0.033	0.000	***	2.066	2.196	1	193	2000	2022	23

Indicator	Coef.	SE	p val.		95% Conf. Int.		Desirable direction	N countries	Years		N years
Social capital index	0.367	0.042	0.000	***	0.285	0.449	1	165	2007	2021	15
Food supply variability	-0.206	0.024	0.000	***	-0.254	-0.158	-1	175	2000	2022	23
Food price volatility	0.071	0.019	0.000	***	0.033	0.109	-1	183	2000	2022	23

Supplementary Table 5. Direct and indirect indicator connections and total network density

Table of connections from each indicator to other indicators, classified as direct, indirect via one intermediating indicator, or indirect via two intermediating indicators. The "Percent direct" reflects the percentage of total connections from the indicator to other indicators that are direct connections. Network density represents the total number of direct connections relative to the total number of edges (potential direct connections, in this case all other indicators). Indicators are sorted in descending order by network density.

Theme	Indicator	Direct	Indirect via 1	Indirect via 2	Total connections	Percent direct	Network density
Governance	Civil society participation	22	24	2	48	46	0.45
Resilience	Food price volatility	19	13	4	36	53	0.39
Governance	Right to food	17	23	8	48	35	0.35
Governance	Government effectiveness index	16	25	7	48	33	0.33
Environment, Natural resources, & Production	Yield	15	19	2	36	42	0.31
Resilience	Disaster damages share of GDP	15	19	1	35	43	0.31
Resilience	Reduced coping strategies	15	10	10	35	43	0.31
Governance	Milan urban food policy pact	14	34	0	48	29	0.29
Diets, Nutrition, & Health	Experience food insecurity	12	16	6	34	35	0.24
Diets, Nutrition, & Health	Cost of healthy diet	11	17	7	35	31	0.22
Diets, Nutrition, & Health	Cannot afford healthy diet	10	12	10	32	31	0.20
Livelihoods, Poverty, & Equity	Social protection coverage	10	11	11	32	31	0.20
Diets, Nutrition, & Health	Fruit and vegetable availability	9	18	8	35	26	0.18
Environment, Natural resources, & Production	Cropland change	9	20	6	35	26	0.18
Resilience	Social capital index	9	30	7	46	20	0.18
Resilience	Food supply variability	9	12	11	32	28	0.18
Livelihoods, Poverty, & Equity	Social protection adequacy	8	14	10	32	25	0.16
Resilience	Minimum species diversity	8	22	7	37	22	0.16
Environment, Natural resources, & Production	Pesticide use	7	25	5	37	19	0.14
Environment, Natural resources, & Production	Nitrogen use efficiency	7	21	6	34	21	0.14
Diets, Nutrition, & Health	Prevalence of undernourishment	5	10	10	25	20	0.10
Diets, Nutrition, & Health	Zero fruits or vegetables	5	0	0	5	100	0.10
Livelihoods, Poverty, & Equity	Rural unemployment	5	21	9	35	14	0.10
Livelihoods, Poverty, & Equity	Rural underemployment	5	21	9	35	14	0.10
Governance	Food system pathway	5	33	10	48	10	0.10
Governance	Government accountability index	5	23	18	46	11	0.10
Environment, Natural resources, & Production	Agricultural water withdrawal	4	19	11	34	12	0.08
Environment, Natural resources, & Production	Functional integrity	4	26	7	37	11	0.08
Governance	Healthy food environment policies	4	13	12	29	14	0.08
Resilience	Conservation of genetic resources, plants	4	23	9	36	11	0.08
Resilience	Conservation of genetic resources, animals	4	23	9	36	11	0.08
Governance	Open budget index	3	19	24	46	7	0.06
Governance	Access to information	3	24	19	46	7	0.06
Resilience	Mobile phones per 100 people	3	21	10	34	9	0.06
Diets, Nutrition, & Health	Ultra-processed food sales	2	4	16	22	9	0.04
Diets, Nutrition, & Health	Soft drink consumption	2	0	0	2	100	0.04
Environment, Natural resources, & Production	Food system emissions	2	18	12	32	6	0.04

Theme	Indicator	Direct	Indirect via 1	Indirect via 2	Total connections	Percent direct	Network density
Environment, Natural resources, & Production	Emissions intensity	2	16	11	29	7	0.04
Environment, Natural resources, & Production	Fisheries health index	2	20	11	33	6	0.04
Livelihoods, Poverty, & Equity	Share of agriculture in GDP	2	4	23	29	7	0.04
Livelihoods, Poverty, & Equity	Child labor	2	13	10	25	8	0.04
Livelihoods, Poverty, & Equity	Female landholdings	2	8	22	32	6	0.04
Resilience	Dietary sourcing flexibility	2	19	11	32	6	0.04
Diets, Nutrition, & Health	NCD-Protect	1	0	0	1	100	0.02
Diets, Nutrition, & Health	NCD-Risk	1	0	0	1	100	0.02
Diets, Nutrition, & Health	Access to safe water	0	0	0	0	0	0.00
Diets, Nutrition, & Health	Minimum dietary diversity, women	0	0	0	0	0	0.00
Diets, Nutrition, & Health	Minimum dietary diversity, child	0	0	0	0	0	0.00
Diets, Nutrition, & Health	All 5 food groups	0	0	0	0	0	0.00
Governance	Food safety capacity	0	0	0	0	0	0.00

Supplementary Table 6. Text strings used to classify economic and regulatory policies to construct the health-related food environment policies indicator.

The following terms were used to identify whether policies apply nationally and are regulatory or voluntary. Economic tools are classified as mandatory. Only policies applied nationally are included as well as only mandatory regulatory policies. The necessary information is contained in the original NOURISHING database in multiple classification columns termed "Sub-policy area" and "Policy action". The latter includes extensive text describing the policy.

Panel A: Text searches used to code voluntary, mandatory, and subnational policies.

Text string	**Database column searched**	**Coding**
Mandator*	Sub-policy area	Code as mandatory
Voluntary	Sub-policy area	Code as voluntary
compuls*	Policy action	Code as mandatory
law	Policy action	Code as mandatory
Act	Policy action	Code as mandatory
legislat*	Policy action	Code as mandatory
Regulation*	Policy action	Code as mandatory
EU-wide rules	Policy action	Code as mandatory
ban	Policy action	Code as mandatory
standards	Policy action	Code as mandatory
rules	Policy action	Code as mandatory
voluntar*	Policy action	Code as voluntary
guideline	Policy action	Code as voluntary
guidance*	Policy action	Code as voluntary
recommend*	Policy action	Code as voluntary
award*	Policy action	Code as voluntary
Bans specific to vending machines in schools	Sub-policy area	If not already classified as mandatory or voluntary based on more specific text strings above, code as mandatory
Clearly visible "interpretative" labels and warning labels	Sub-policy area	If not already classified as mandatory or voluntary, code as voluntary
memorandum of	Policy action	If not already classified as mandatory or voluntary based on more specific text strings above, code as voluntary
discretion of local authorities	Policy action	If not already classified as mandatory or voluntary based on more specific text strings above, code as voluntary
participating schools	Policy action	If not already classified as mandatory or voluntary based on more specific text strings above, code as voluntary
at*discretion of	Policy action	Code as voluntary
local level	Policy action	Code as subnational (exclude), unless it also contains "EU" or "national"
subnational	Policy action	Code as subnational (exclude), unless it also contains "EU" or "national"

Panel B: Coding applied to specific countries based on visual inspection.

Country	Case	Coding
UK	Government engage with industry to develop self-regulation to restrict food marketing to children	Code as mandatory
South Korea	Warning labels on menus and displays in out-of-home venues	Code as voluntary
Mexico	Standards in social support programmes with "Subsidised milk" in the policy action	Code as voluntary
USA	The Food Labelling Guide	Code as voluntary
Canada	The Northern Fruit and Vegetable Program	Code as voluntary
Canada	Fruit & vegetable initiatives in schools with "Manitoba" or "British Columbia" in the policy action	Code as voluntary
Ireland	Healthier vending policy	Code as mandatory
Romania	ORDIN Nr. 25/2019	Code as voluntary
Netherlands	The National Prevention act	Code as mandatory
Portugal	Healthy Eating in Higher Education	Code as voluntary
Australia & New Zealand	Nutrition, Health and Related Claims Standard 1.2.7	Code as mandatory
Australia	Crunch & Sip	Code as mandatory
Croatia	Nutrition standards in hospitals	Code as mandatory
Estonia	Health protection requirements	Code as mandatory
Ghana	Standards on level of fat in meat	Code as mandatory
Latvia	Salt levels limits for food served in hospitals	Code as mandatory
Switzerland	Swiss quality standards	Code as voluntary
UK	School Fruit and Vegetable Scheme	Code as mandatory
USA	Policies including reference to San Francisco, NYC, Detroit, WIC	Code as mandatory
USA	Policies including reference to Santa Clara, California USA, Berkeley, Davis, Stockton, Perris	Code as voluntary

Panel C: Sub-national policies identified by manual review occur in the following places.

Country	Subnational localities
USA	San Francisco, NYC, New York City, Philadelphia, Detroit, Boston, Puerto Rico, Maine, Santa Clara, Berkeley, Davis, Stockton, Perris, California, Seattle, Oakland, Boulder, Albany, Navajo Nation, Cook County, Massachusetts, San Bernadino, Arkansas
Australia	Crunch & Sip, local health district, Queensland, Western district, New South Wales
Belgium	French region
Canada	Ontario, British Columbia, Manitoba, North Canada
New Zealand	Cook Islands
Spain	Catalonia
China	Taiwan
UAE	Abu Dhabi
UK	Brighton, England, Scotland, Wales, Northern Ireland

Supplementary Table 7. Participants and affiliations in country case-study expert elicitations

List of food system expert participants in the Ethiopia and Mexico expert elicitation processes. Participants were selected based on their knowledge and involvement in national food system transformation pathways, policies, and research, as well as their availability to participate. Experts represent government officials, research, and civil society. Structured facilitation of the process (**Supplementary Table 5**) by a group of facilitators focused on creating space for inputs from all participants and equal consideration of inputs across participants.

Panel A: Ethiopia expert elicitation (2 April 2024, Addis Ababa, Ethiopia, ILRI campus)

Main facilitator: Tesfaye Haile Bekele supported by Yonas Getaneh and Kalkidan Mulatu		
	Name	**Institutional Affiliation**
1	Getachew Diriba	Ministry of Agriculture
2	Professor Ali Mohammed	Ministry of Agriculture
3	Ato Fisseha Tekle	Ministry of Health - SD
4	Ato Abdurahman Seid	Ministry of Trade and Regional Integration
5	Senait Zemenu	Agricultural Transformation Institute
6	Naomi Berhanu	Alliance2015
7	Misbaha Kedir	EIAR
8	Yirgalem Nigusse	Policy Studies Institute
9	Mekonen Bekele	Policy Studies Institute
10	Mulugeta Teamir	MoA, Senior Food System Transformation advisor
11	Akalu Teshome	SWR, Advisor, Food System Transformation
12	Genet Gebremedhin	GAIN, Head of Policy and Advocacy,
13	Aregash Samuel	EPHI, Senior researcher and NIPN coordinator
14	Maru Bekele	FAO, Project coordinator
15	Alemtsehay Sergawi	MOA Head, Food and Nutrition Office
16	Maya Haile	FAO
17	Tsion Temane	ILRI
18	Daniel Tsegaye	MoH
19	Mengesha, Belay Terefe	Alliance Bioversity & CIAT
20	Getachew Legese Feye	ILRI

Panel B: Mexico expert elicitation (17 April 2024, Mexico DF, Mexico, National Public Health Institute)

Main facilitator: Isabel Valero supported by Ana Munguía, Mariana Arellano, Ana Paula Domínguez, Simón Barquera		
1	Amanda Gálvez	Coordinator of the University Food Program- Universidad Nacional Autónoma de México
2	Anabelle Bonvecchio	Director of nutrition policy area at the Nutrition and Health Research Center - INSP
3	Laura Ramírez	Researcher CONAHCYT (Mexican Science Agency)
4	Natividad Díaz	Ministry of Agriculture
5	Paulina Magaña	Alianza por la Salud Alimentaria
6	Sonia Rodriguez Ramirez	Researcher at the Nutrition and Health Research Center – INSP, FABLE
7	Ana Laura González Alejo	Posdoctoral researcher, UNAM
8	Doré Castillo	ContraPESO
9	Hugo López Gatell	Former Undersecretary of Health
10	Lizbeth Díaz	Ministry of Health (REPRESENTATIVE)
11	Mishel Unar	Researcher at the Nutrition and Health Research Center - INSP
12	Rolando Herrera y Saldaña	Ministry of Agriculture
13	Charlotte Gonzalez-Abraham	FABLE
14	Ileana Guadalupe Fajardo Niquete	Director of Nutrition and Chronic Diseases of the Yucatan Health Services
15	Rebeca Monroy Torres	University of Guanajuato

Panel C: Netherlands expert elicitation (9 July, 2024, Utrecht, Netherlands, Space to Create)

Main facilitator: Roseline Remans, Silvia Martinez, Maaike van Houtert, Janne Vervaeke		
1	Annie Trevenen Jones	Global Alliance for Improved Nutrition
2	Corne van Dooren	Wageningen University & World Wildlife Fund
3	Daan Boezeman	PBL Netherlands Environmental Assessment Agency
4	Evelien de Olde	Wageningen University
5	Frederike Praasterink	HAS Applied sciences
6	Hanneke Muilwijk	Rekenkamer Oost
7	Henk Westhoek	PBL Netherlands Environmental Assessment Agency
8	Herman Lelieveldt	University College Roosevelt (UCR)
9	Jeroen Candel	Wageningen University
10	José Mogollón	Leiden University
11	Krijn Poppe	Wageningen Economic Research
12	Maartje Poelman	Wageningen University
13	Marieke van Bakel	National Institute for Public Health and the Environment (RIVM)
14	Simone Eijsink	Ministry of Agriculture, Nature, & Food Quality

Supplementary Table 8. Country case study elicitation guidelines

Agenda, Instructions and facilitation materials for the Ethiopia and Mexico expert elicitation processes. For Mexico, main materials were translated in Spanish.

Panel A: Agenda

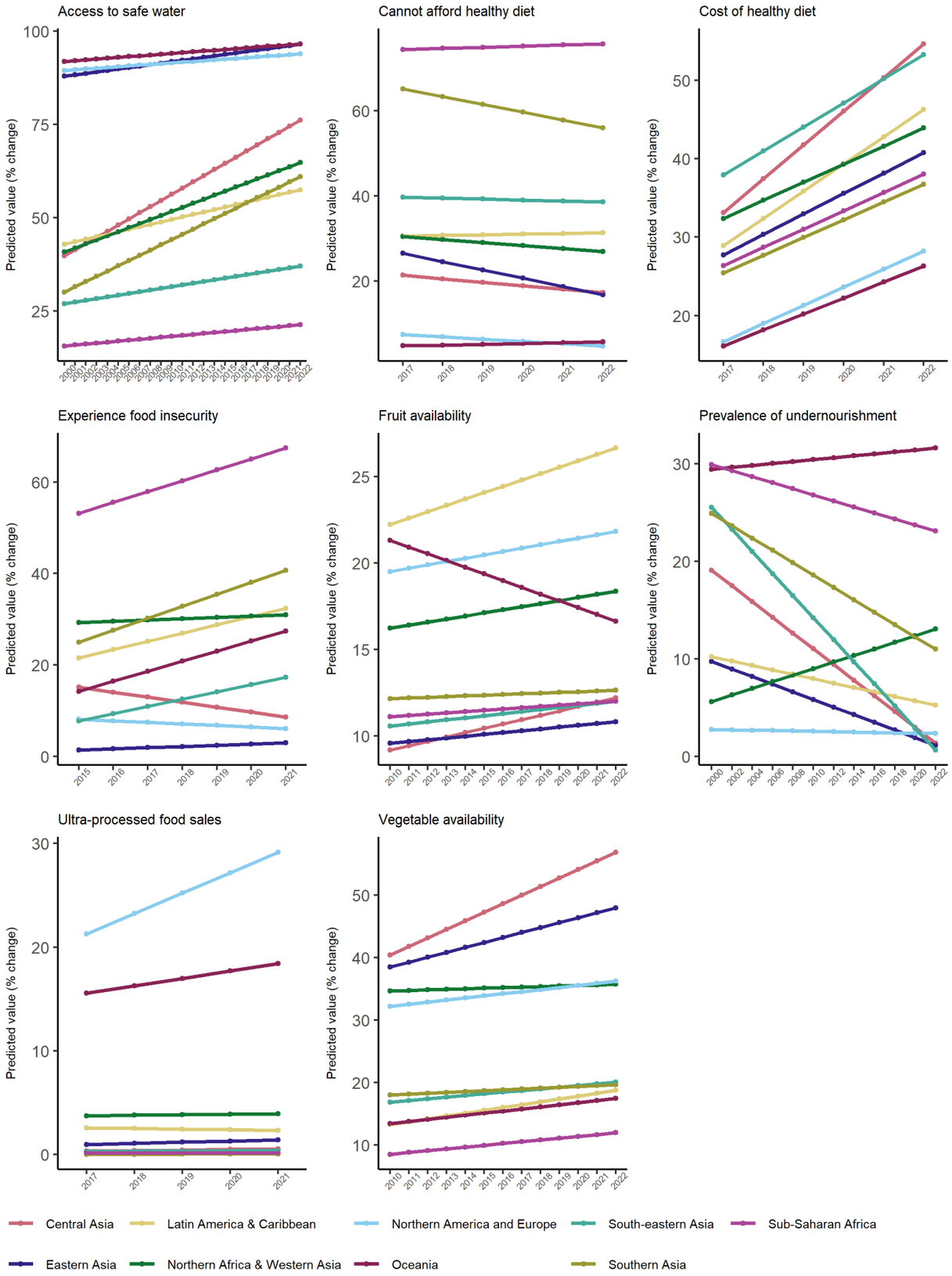
Step	Time (approximate)	Topic
1	60 min.	Welcoming Workshop agenda and objectives Participants introductions Short introduction to the Food Systems Countdown Initiative and how it serves to complement national processes Introduction to the workstream on interactions and the specific ask for this workshop with time for questions and answers
2	60 min.	Breakout groups: How do these interactions between FSCI indicators play out in the Mexican context? (logic and ranking) Qualitative mapping of interactions between indicators along two axes: 1) increasing, maintaining or decreasing over time, 2) relevance of interaction for the Mexican food system pathway/in the Mexican context
3	60 min.	Breakout groups continued: How do these interactions between FSCI indicators play out in the Mexican context? (logic and ranking) Qualitative mapping of interactions between indicators along two axes: 1) increasing, maintaining or decreasing over time, 2) relevance of interaction for the Mexican food system pathway/in the Mexican context
4	60 min.	Feedback presentation from each group in plenary, clarifications, integration and convergence
5	45 min.	Roundtable on reflections and adaptations in qualitative mapping Plus additional insights, comments, learnings and suggestions
6	15 min.	Synthesis and wrap up

Panel B: Instructions and facilitation materials

Step	Content	Guidance
1	2 core questions addressed in elicitation process	1. If you would rank the relationship between these two indicators in terms of importance/relevance for national food systems pathways/ future positive food systems change in the country, how would you rank it on the graph? In order to achieve the vision from the food system pathways, how important is the dependence of indicator A on indicator B? 2. Over the last ten years, has the interaction between these two indicators for food systems change been increasing, decreasing, or remaining the same? How does the relationship between these two indicators play out in the Mexican context?
2	Print-outs of graphic and pairs of indicators to plot interactions for ranking to X and Y axis	Large print-out posters with the empty graph structure of Figure 5 and Supplementary Figure 24, in combination with circle printouts of the 63 interactions of pairs of indicators (illustrated in Supplementary Figure 24), were used as facilitation supporting materials.
3	Online Miro	In addition to the printouts an online Miro with the graphic and the circles with the pairs of indicators served to enable and support 1) online participants (there were three online participants in Mexico, 2) consolidation and reflection after the in-person session.
4	Facilitators	For each of the sessions there was a main facilitator, supported by additional facilitators for the breakout groups. The facilitators also took notes on the discussions and the reasoning behind the plotting and on any other insights into how the interactions play out in the country context. Facilitators had three preparation meetings in advance to the workshops to align on and fine-tune the process. Facilitators Ethiopia session: Tesfaye Haile Bekele supported by Yonas Getaneh and Kalkidan Mulatu Facilitators Mexico session: Isabel Valero supported by Ana Munguía, Mariana Arellano, Ana Paula Domínguez, Simón Barquera
5	Notes and reports	Synthesized workshop reports with qualitative notes and a link to the compiled Miro were compiled by the main facilitators and shared with the participants for further reflections and inputs.

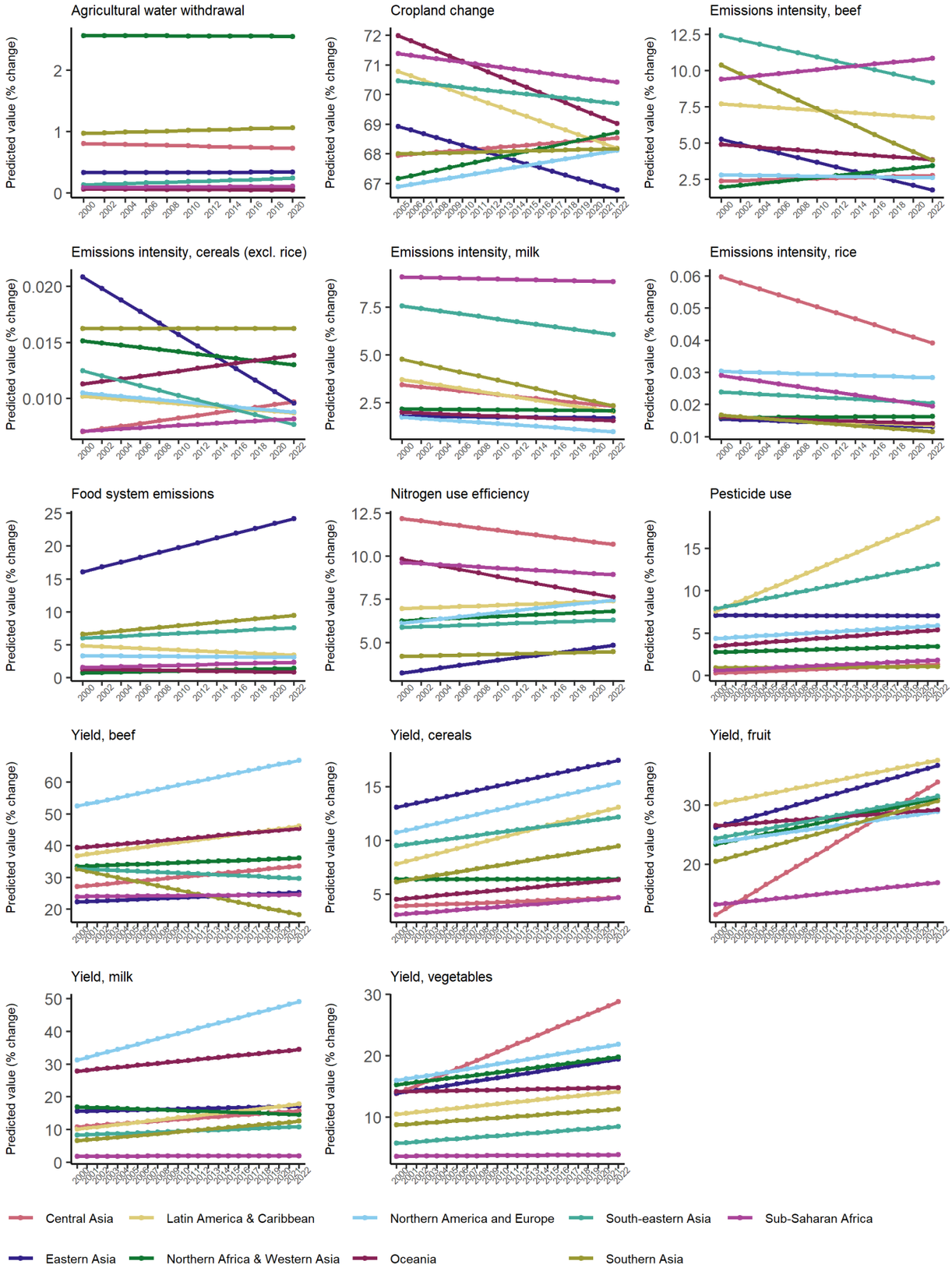
Supplementary Figure 1. Trends over time, marginal effects, 2000-2022: Diets, Nutrition & Health.

Predicted values of pooled linear weighted regression with an interaction term between region and time illustrate the heterogeneity in intercepts and trends per indicator across regions over time. All diet quality indicators are excluded because data are collected in different countries each year and cannot be analyzed as trends.



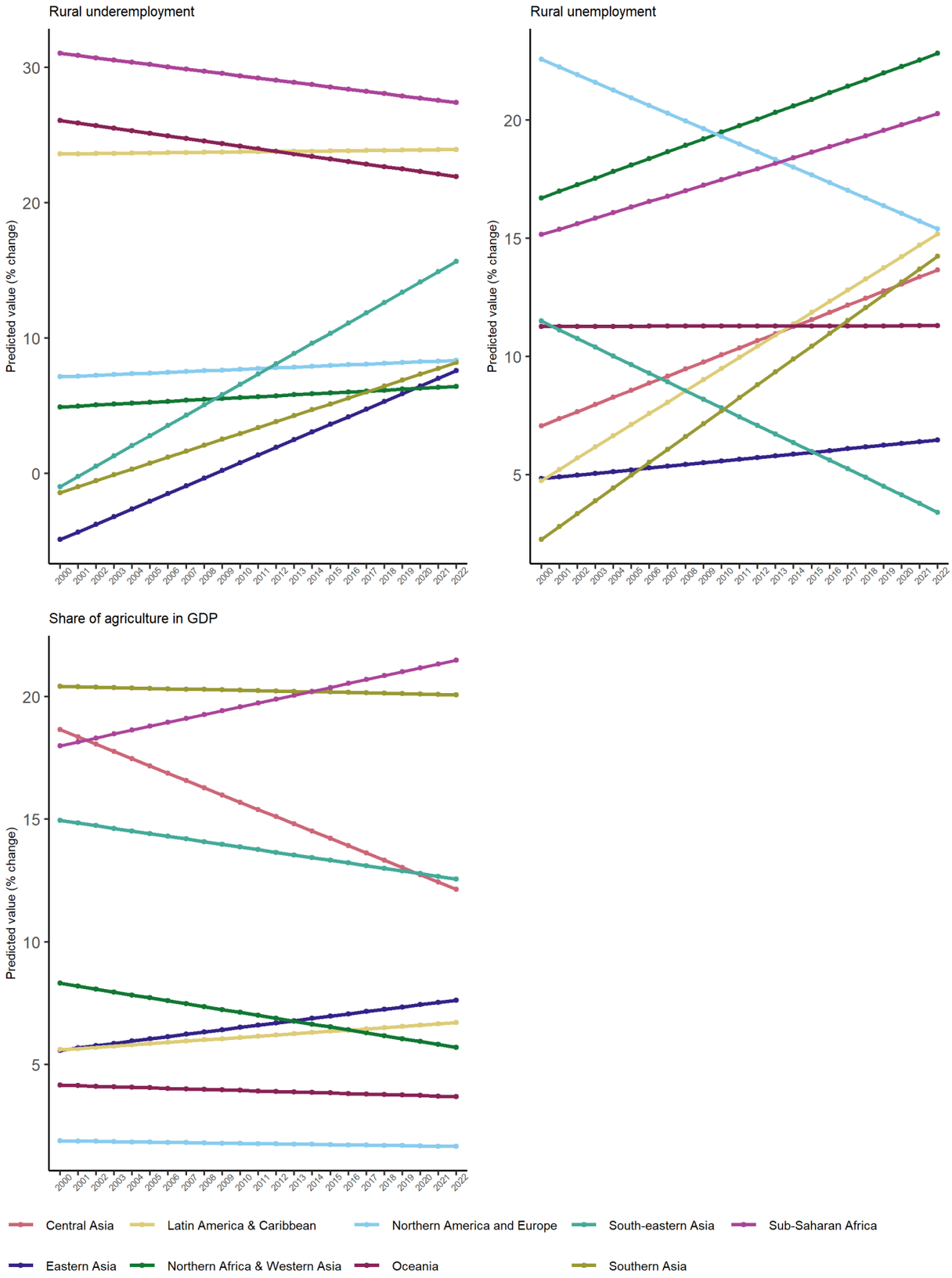
Supplementary Figure 2. Trends over time, marginal effects, 2000-2022: Environment, Natural resources, & Production.

Predicted values of pooled linear weighted regression with an interaction term between region and time illustrate the heterogeneity in intercepts and trends per indicator across regions over time. Functional integrity and the fisheries health index are excluded because they do not have time series.

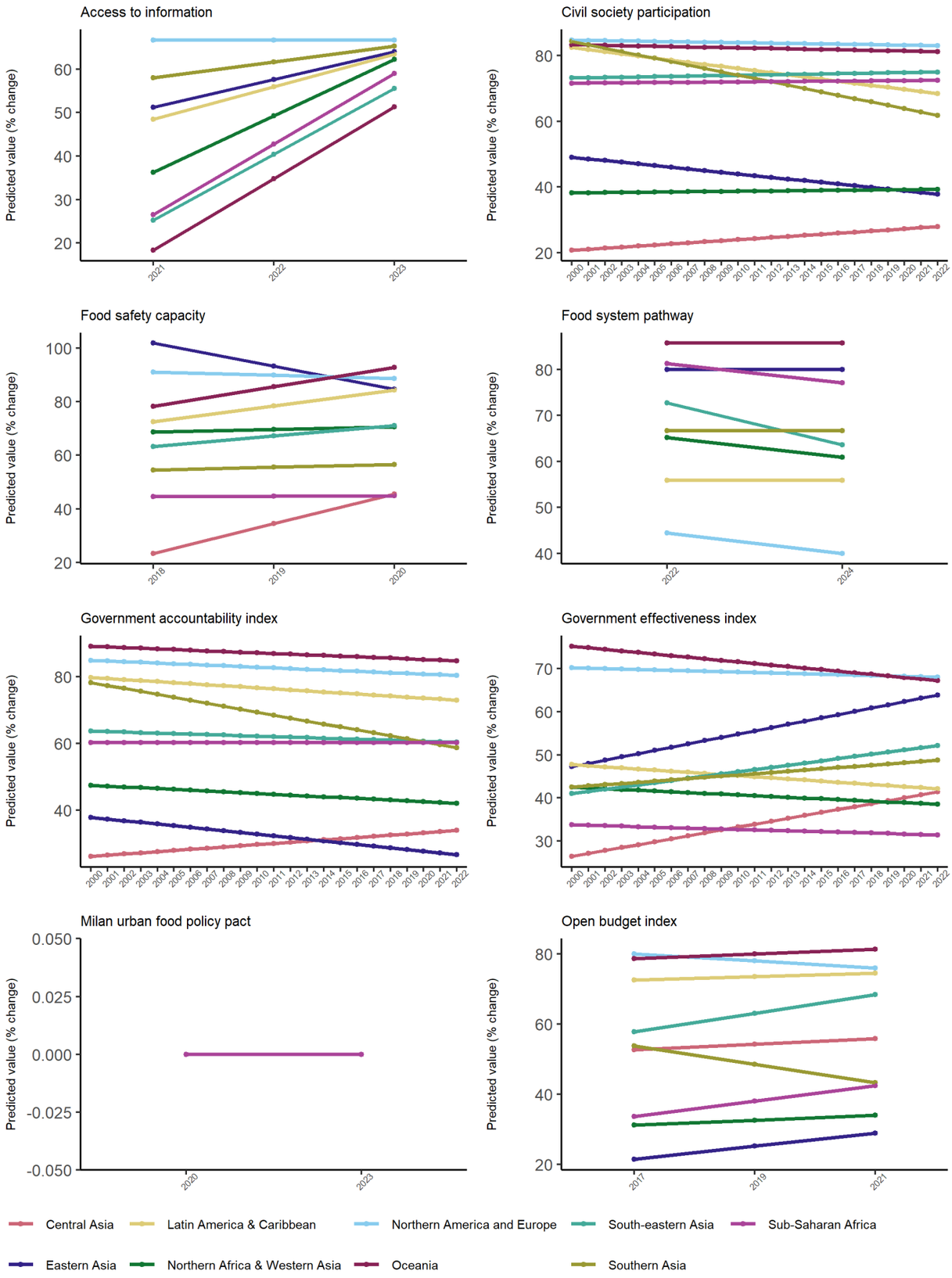


Supplementary Figure 3. Trends over time, marginal effects, 2000-2022: Livelihoods, Poverty, & Equity.

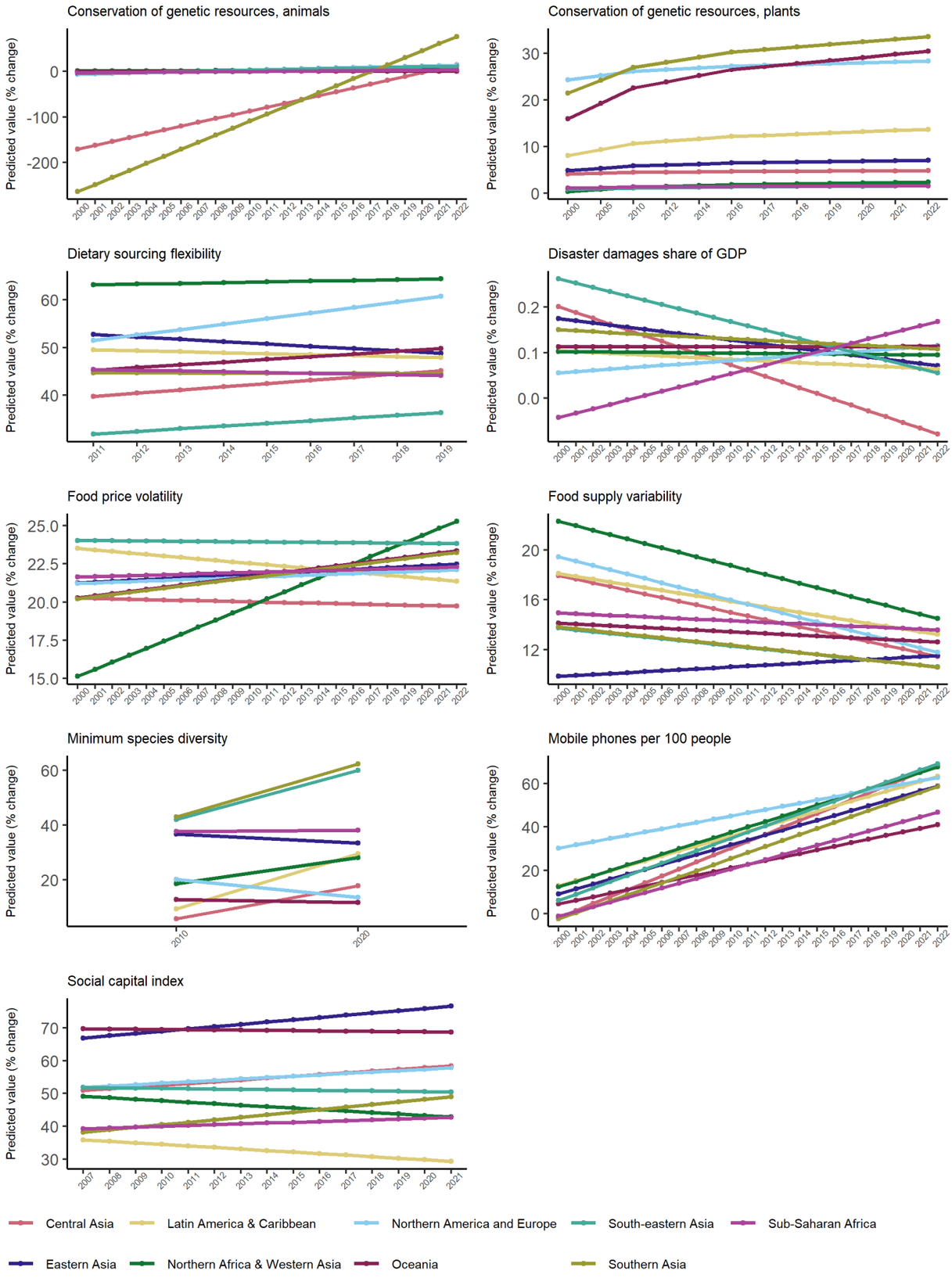
Predicted values of pooled linear weighted regression with an interaction term between region and time illustrate the heterogeneity in intercepts and trends per indicator across regions over time. Indicators excluded where data are collected in different countries each year and cannot be analyzed as trends. Social protection coverage, social protection adequacy, child labor, and female landholdings are excluded for lack of time series.



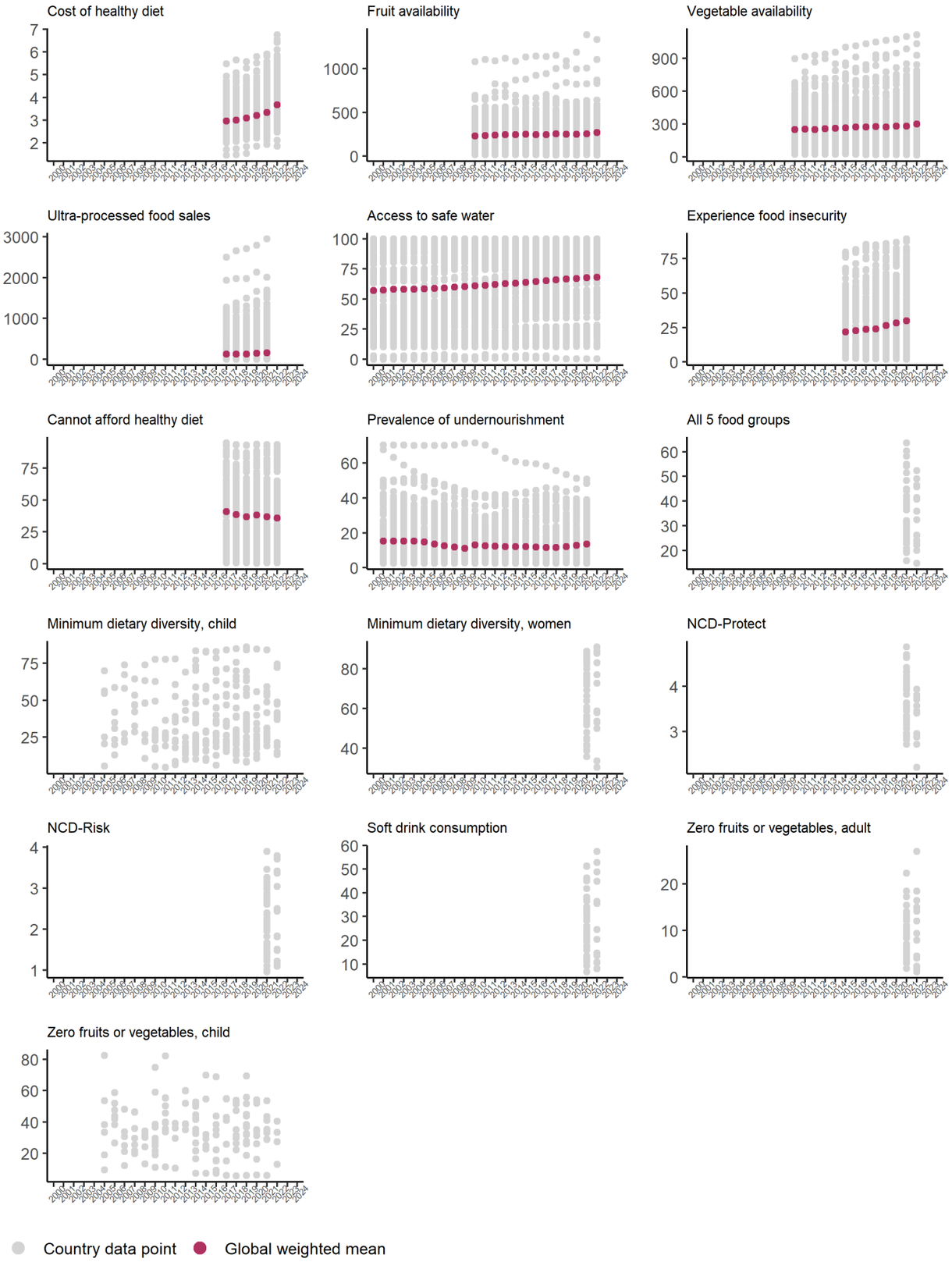
Supplementary Figure 4. Trends over time, marginal effects, 2000-2022: Governance.
Predicted values of pooled linear weighted regression with an interaction term between region and time illustrate the heterogeneity in intercepts and trends per indicator across regions over time.



Supplementary Figure 5. Trends over time, marginal effects, 2000-2022: Resilience.
Predicted values of pooled linear weighted regression with an interaction term between region and time illustrate the heterogeneity in intercepts and trends per indicator across regions over time. Indicators are excluded where data are collected in different countries each year and cannot be analyzed as trends. Reduced coping strategies are excluded for lack of time series.

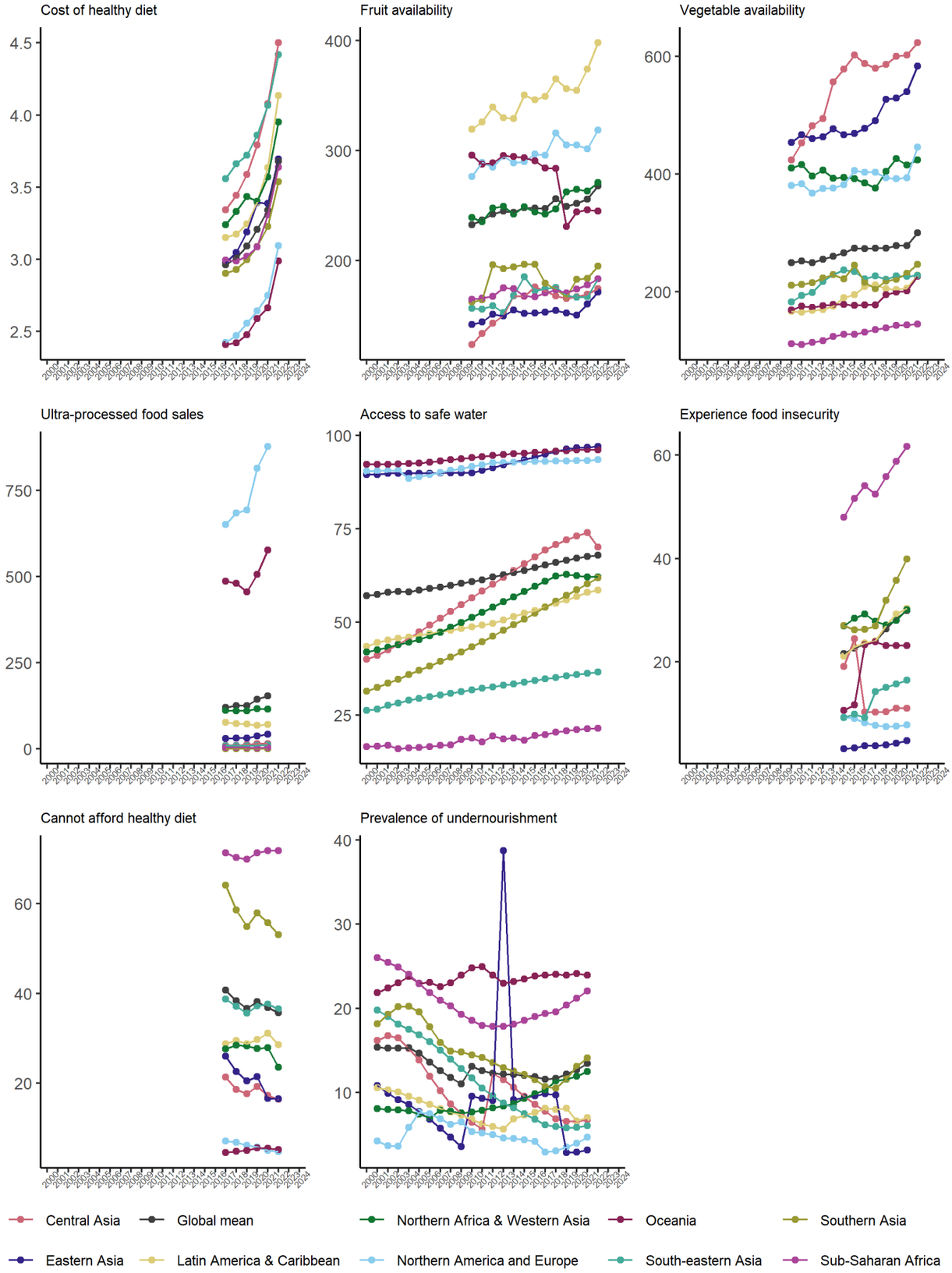


Supplementary Figure 6. All data with global weighted mean: Diets, Nutrition, & Health
All country-year observations shown for every indicator in light gray. Maroon points show the global weighted mean, excluded for all diet quality indicators where data are collected in different countries each year and cannot be analyzed as trends. Weighting variables defined as shown in **Extended Data Table 1**, no weighted mean shown in 2023 or 2024 if the weighting variable is not yet available for that year. All diet quality indicators excluded for lack of time series.



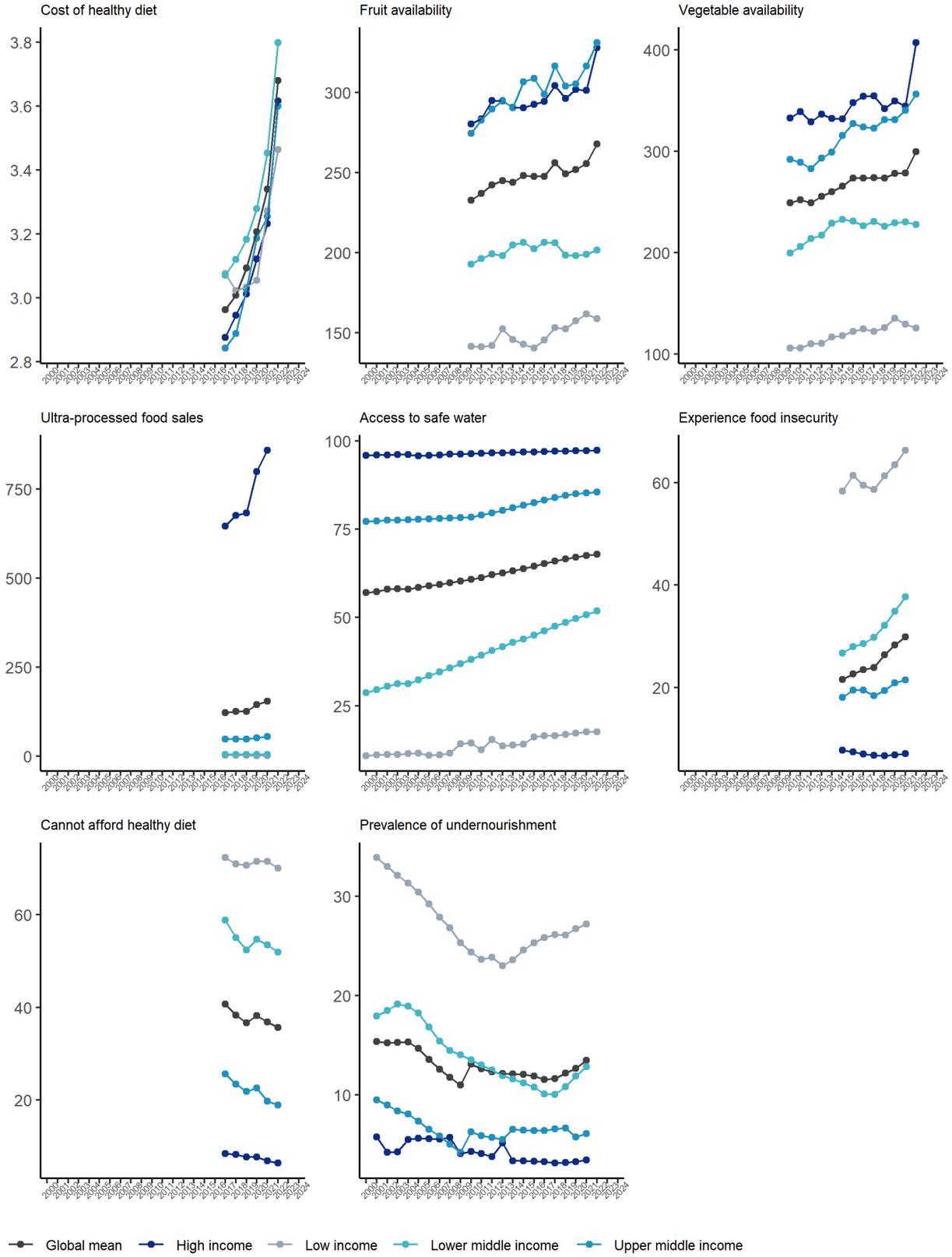
Supplementary Figure 7. Regional weighted mean: Diets, Nutrition, & Health

Time trends for all indicators, by region. Excluded for all diet quality indicators where data are collected in different countries each year and cannot be analyzed as trends.Weighting variables defined in **Extended Data Table 1.** All diet quality indicators excluded for lack of time series.



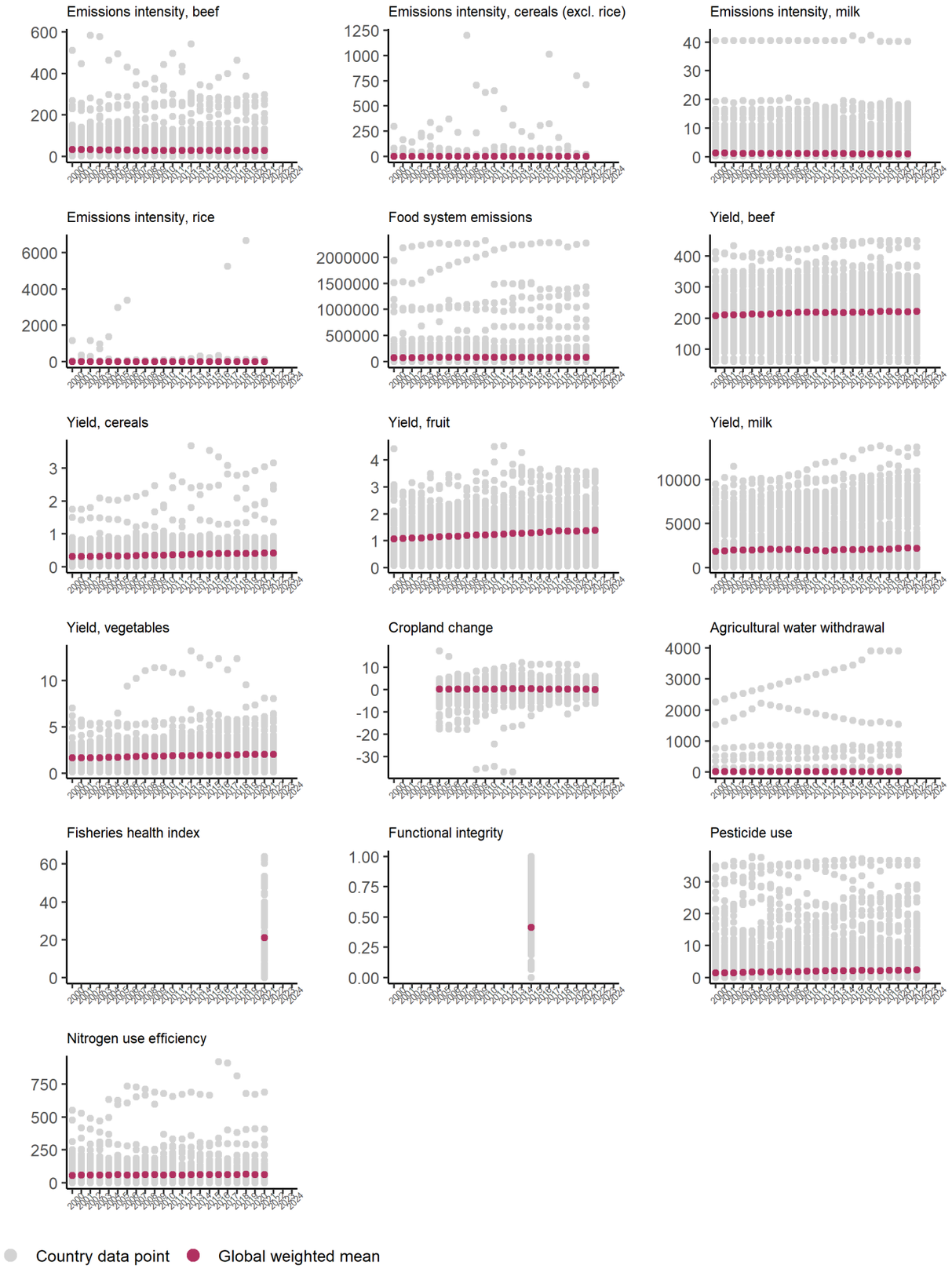
Supplementary Figure 8. Income group weighted mean: Diets, Nutrition, & Health

Time trends for all indicators, by income group. Excluded for all diet quality indicators where data are collected in different countries each year and cannot be analyzed as trends. Weighting variables defined in **Extended Data Table 1.** All diet quality indicators excluded for lack of time series.



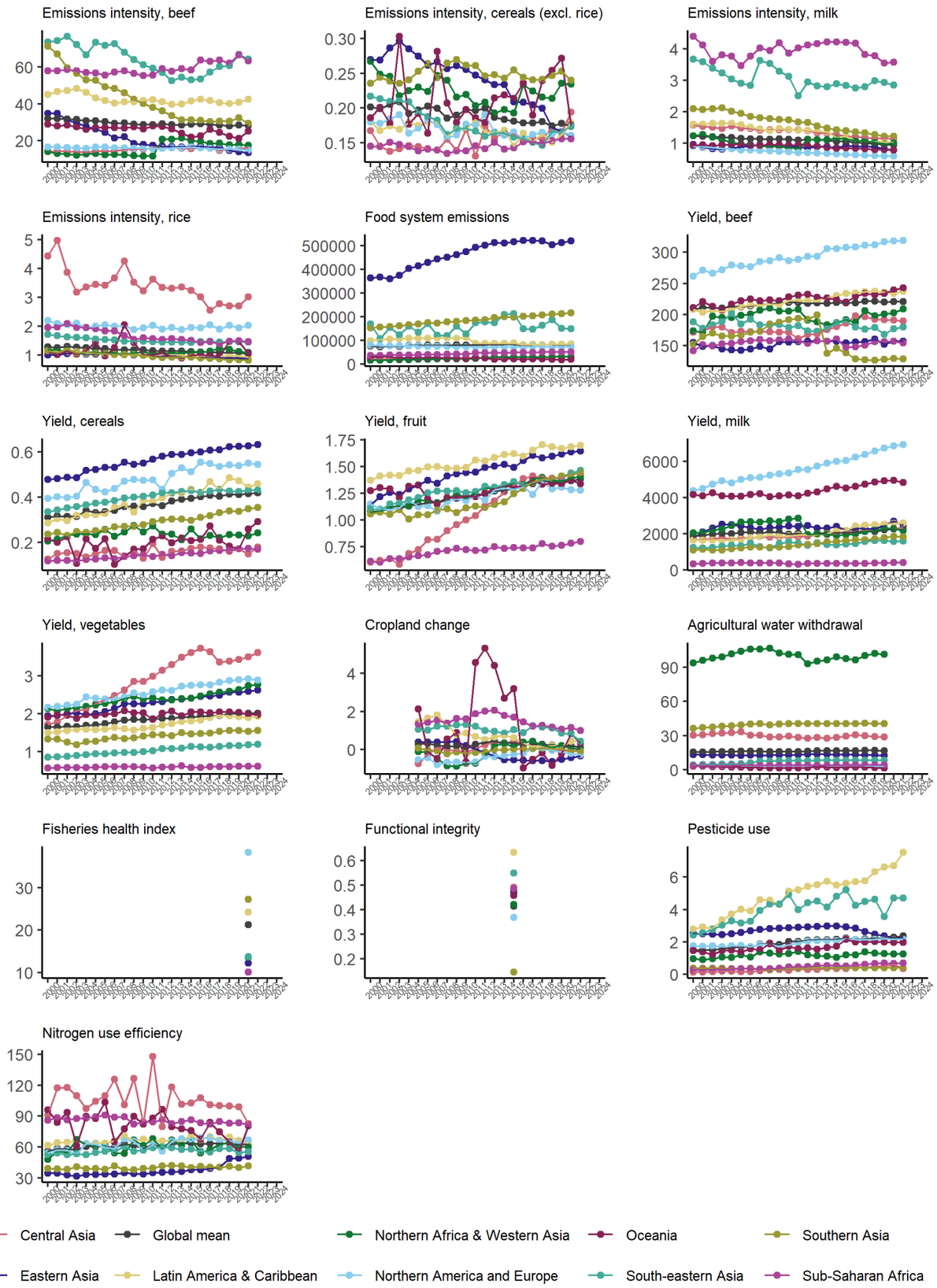
Supplementary Figure 9. All data with global weighted mean: Environment, Natural resources, & Production

All country-year observations shown for every indicator in light gray. Maroon points show the global weighted mean. Weighting variables defined as shown in **Extended Data Table 1**, no weighted mean shown in 2023 or 2024 if the weighting variable is not yet available for that year. Functional integrity and fisheries health index excluded for lack of time series.



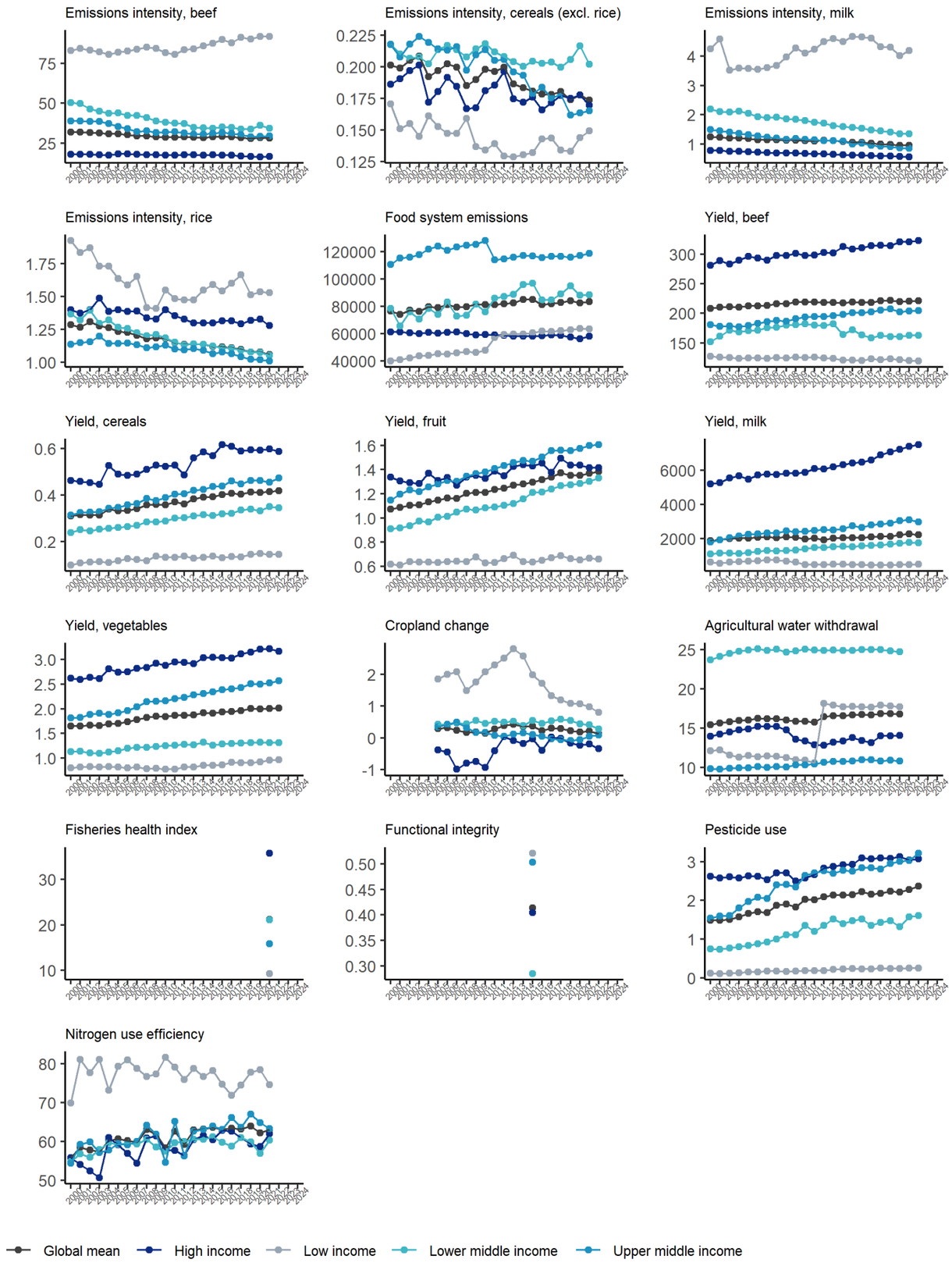
Supplementary Figure 10. Regional weighted mean time trends: Environment, Natural resources, & Production

Time trends for all indicators, by region. Weighting variables defined in **Extended Data Table 1.** Functional integrity and fisheries health index excluded for lack of time series.



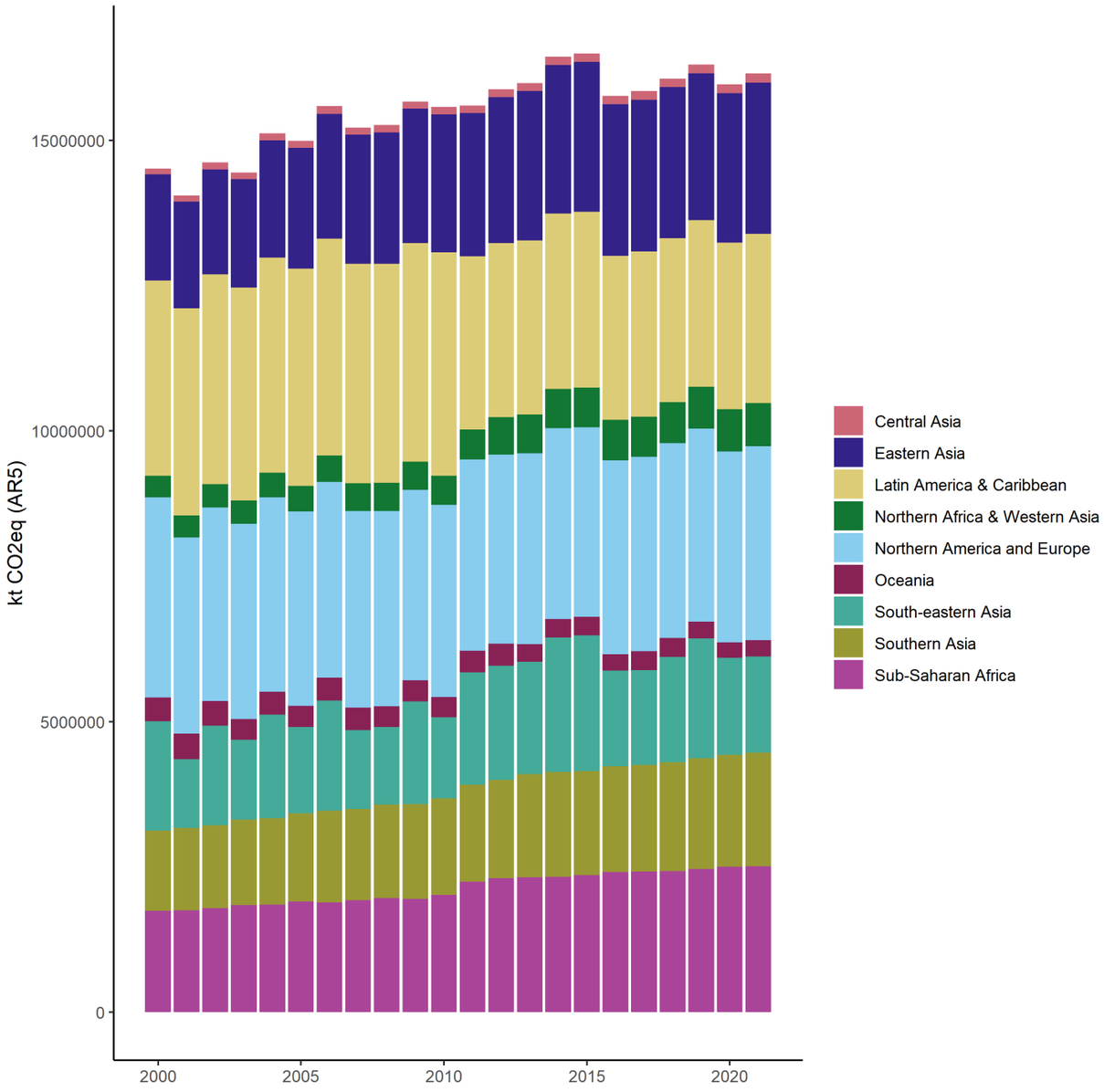
Supplemetary Figure 11. Income group weighted mean time trends: Environment, Natural resources, & Production

Time trends for all indicators, by income group. Weighting variables defined in **Extended Data Table 1.** Functional integrity and fisheries health index excluded for lack of time series.

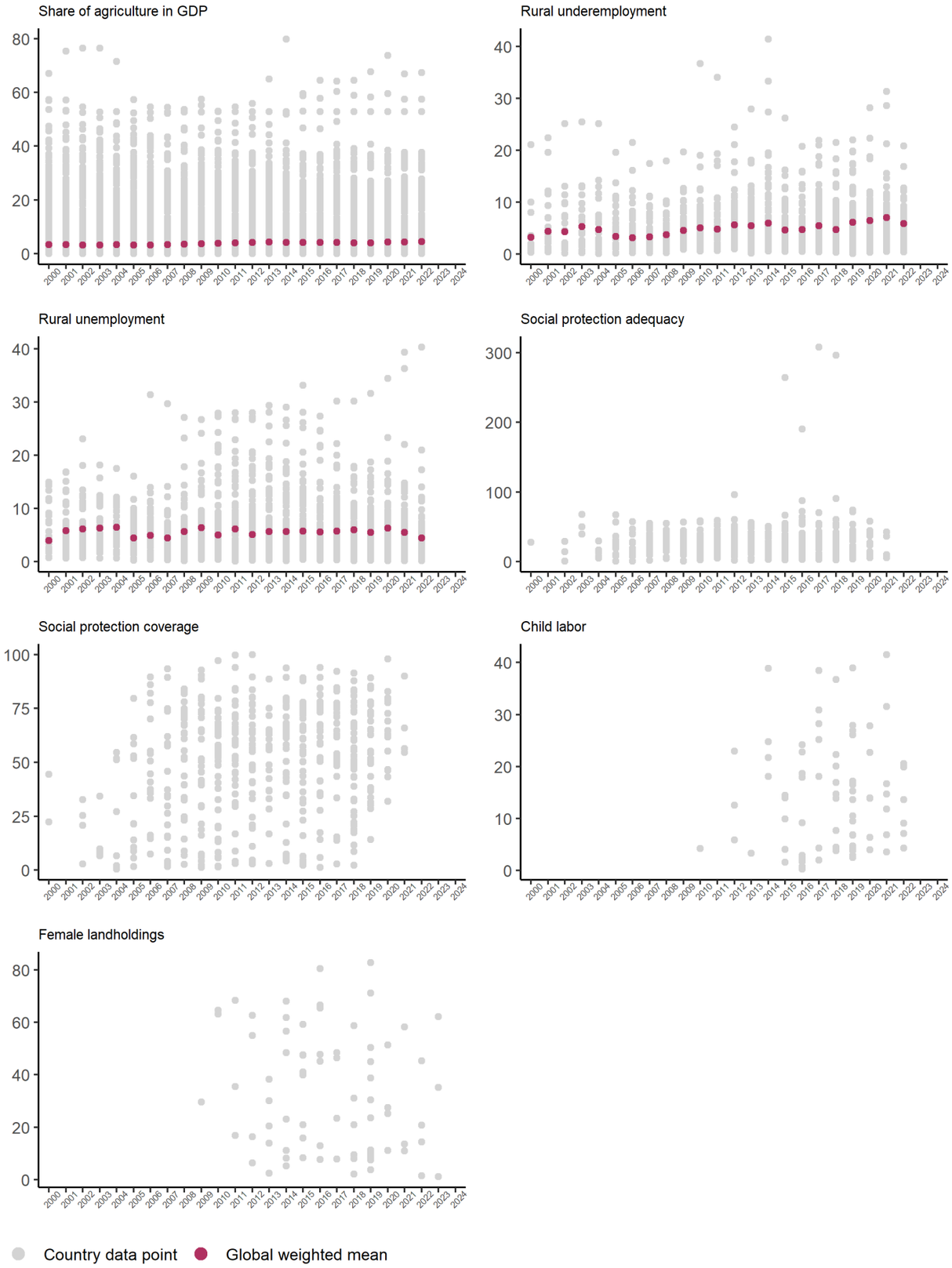


Supplementary Figure 12. Total GHG Emissions from Agrifood Systems over time

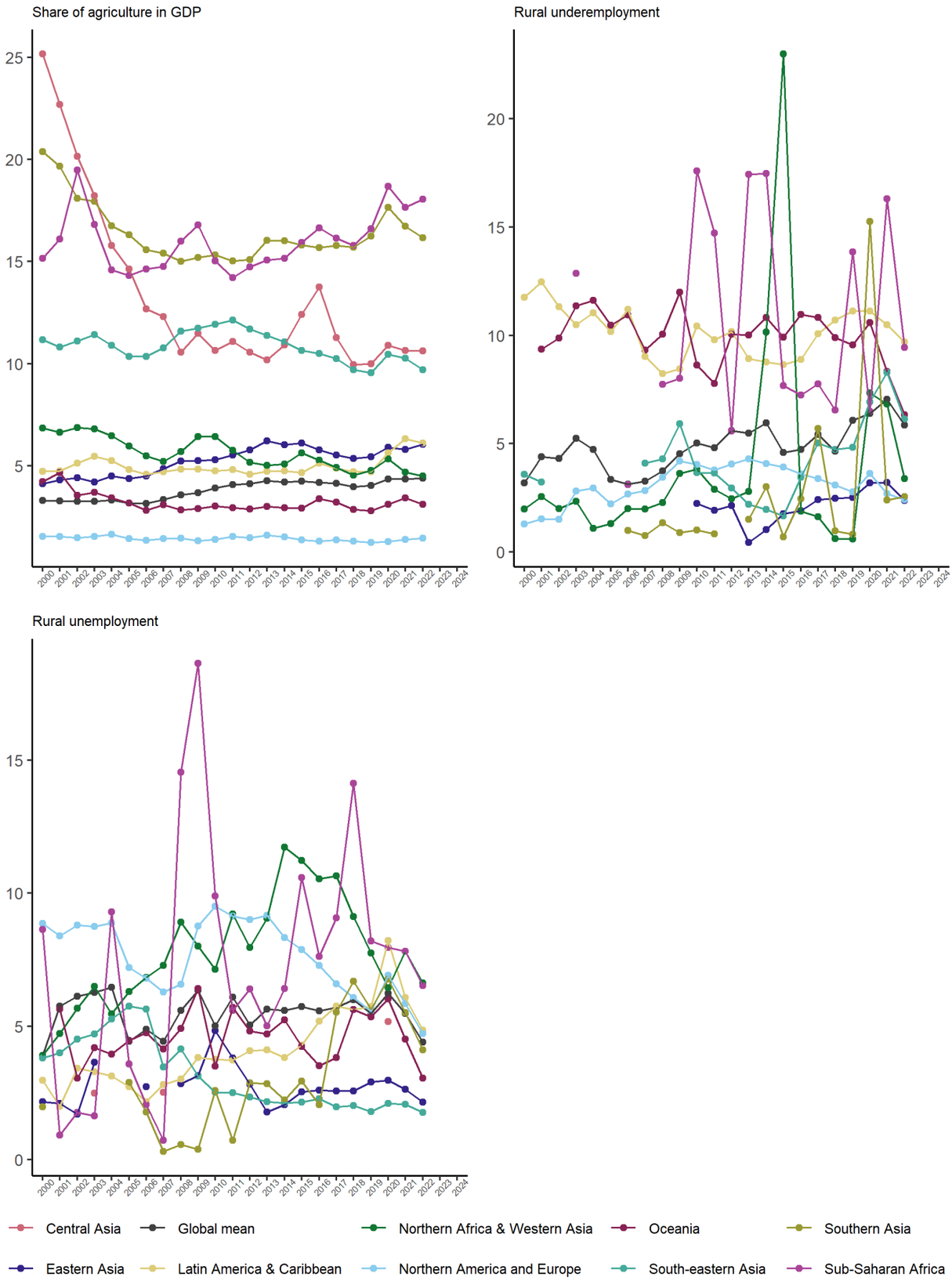
Time trends for greenhouse gas emissions from agrifood systems are best analyzed in terms of totals, rather than weighted means.



Supplementary Figure 13. All data with global weighted mean: Livelihoods, Poverty, & Equity
All country-year observations shown for every indicator in light gray. Maroon points show the global weighted mean, excluded for indicators where data are collected in different countries each year and cannot be analyzed as trends. Weighting variables defined as shown in **Extended Data Table 1**, no weighted mean shown in 2023 or 2024 if the weighting variable is not yet available for that year. Social protection coverage, social protection adequacy, child labor, and female landholdings excluded for lack of time series.

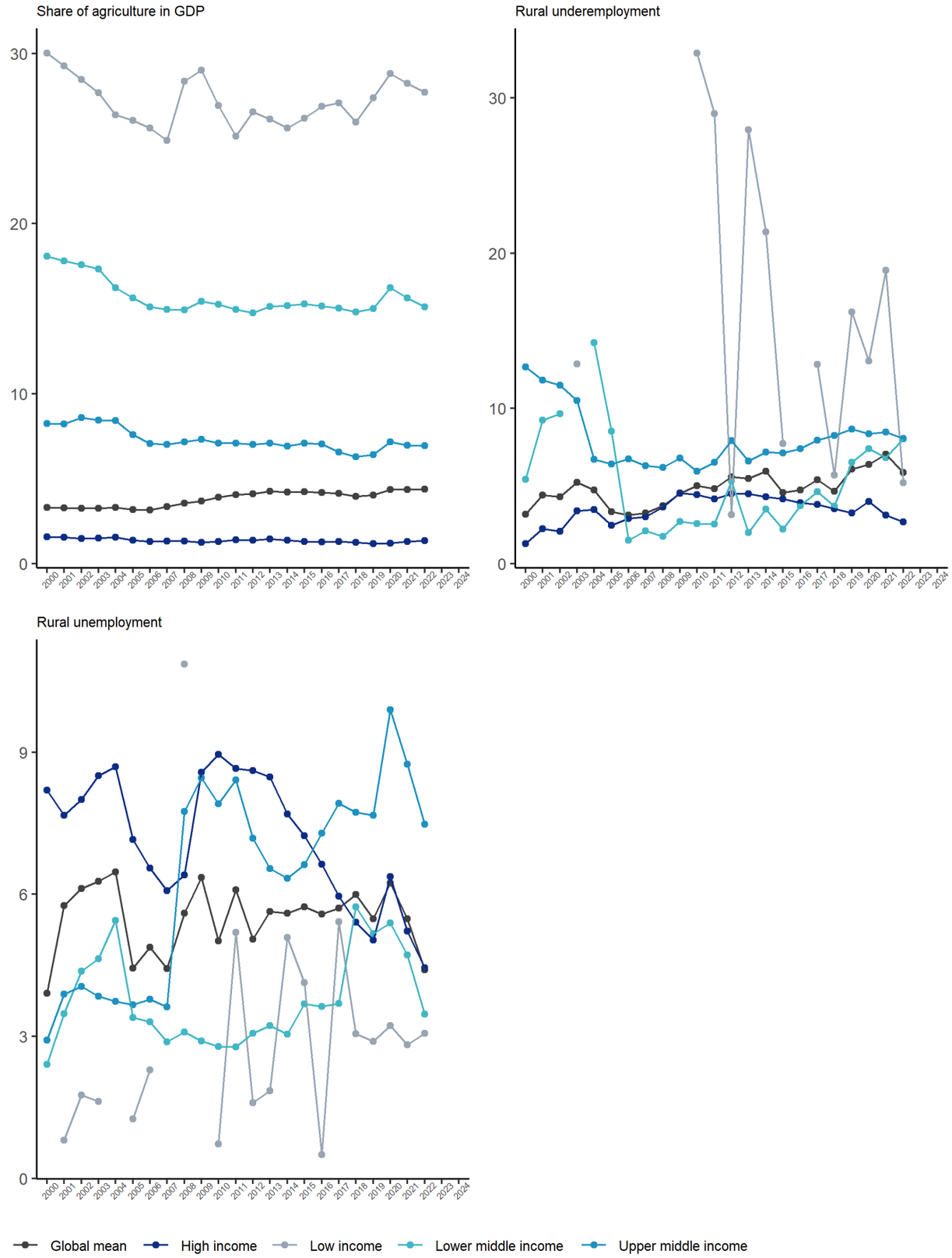


Supplementary Figure 14. Regional weighted mean time trends: Livelihoods, Poverty, & Equity
Time trends for all indicators with time series data, by region. Excluded for indicators where data are collected in different countries each year and cannot be analyzed as trends Weighting variables defined in **Extended Data Table 1.** Social protection coverage, social protection adequacy, child labor, and female landholdings excluded for lack of time series.



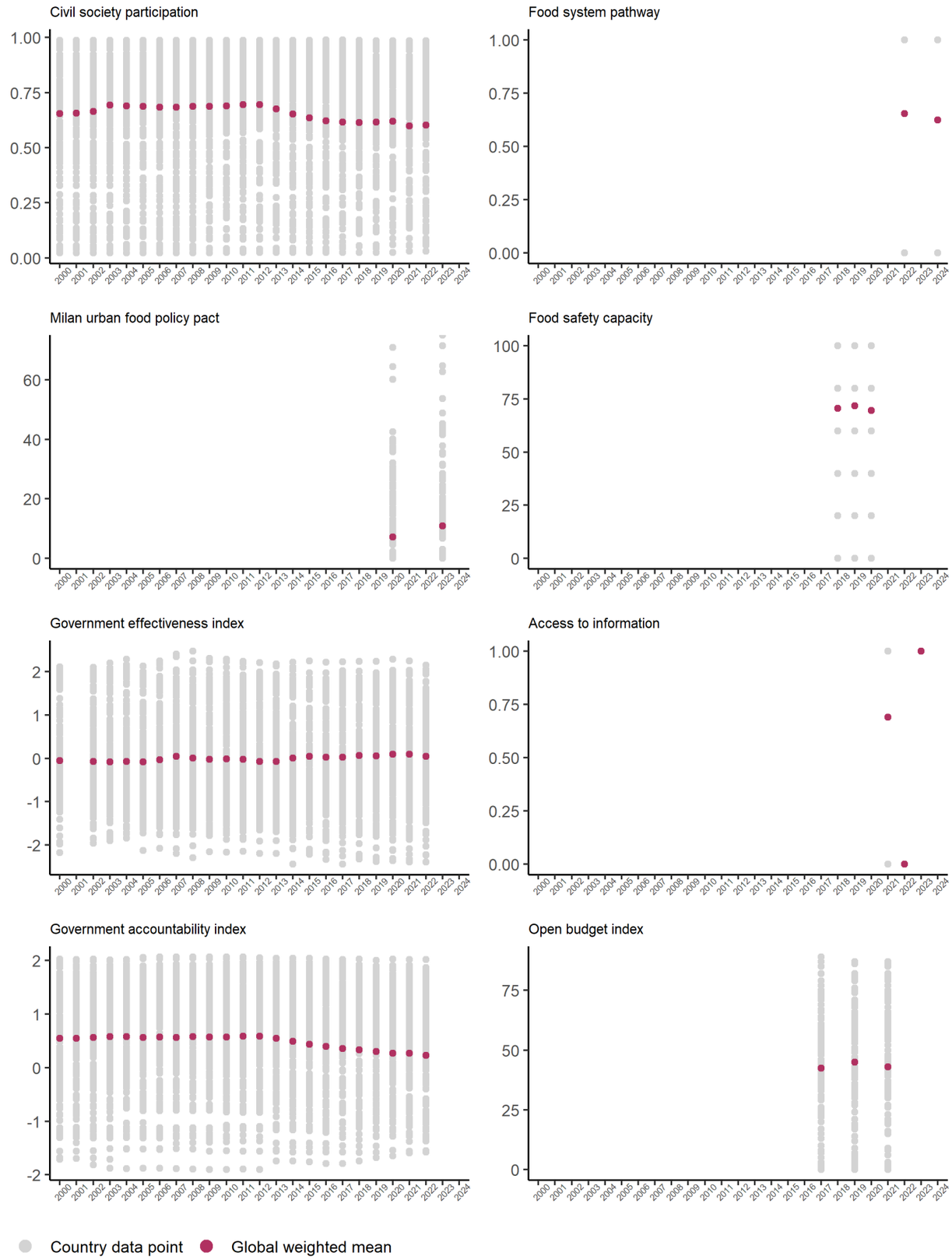
Supplementary Figure 15. Income group weighted mean time trends: Livelihoods, Poverty, & Equity

Time trends for all indicators with time series data, by region. Excluded for indicators where data are collected in different countries each year and cannot be analyzed as trends Weighting variables defined in **Extended Data Table 1.** Social protection coverage, social protection adequacy, child labor, and female landholdings excluded for lack of time series.



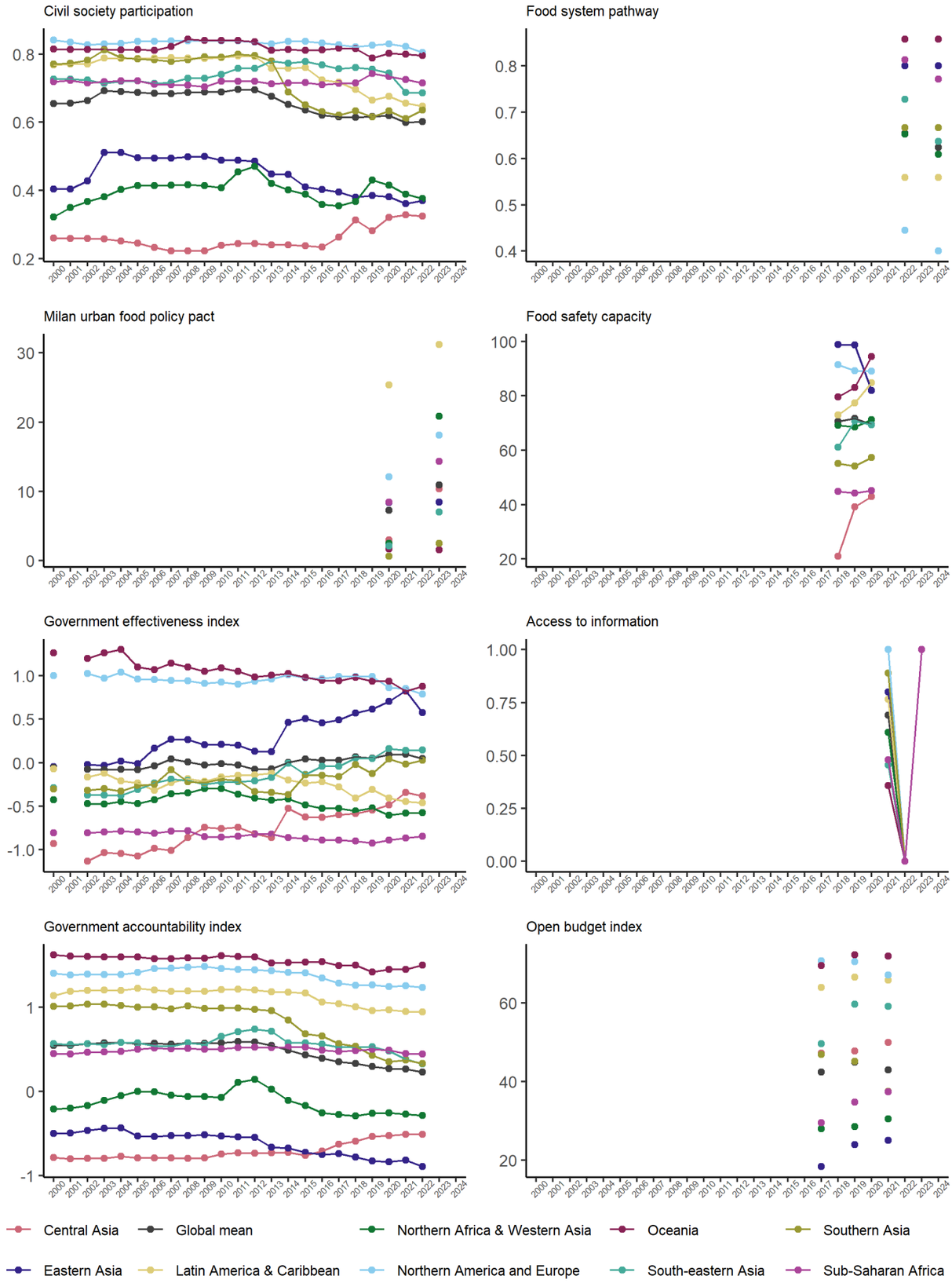
Supplementary Figure 16. All data with global weighted mean: Governance

Time trends for all indicators. Light gray points illustrate all country-year observations. Maroon points show the global weighted mean. Weighting variables defined in **Extended Data Table 1.**



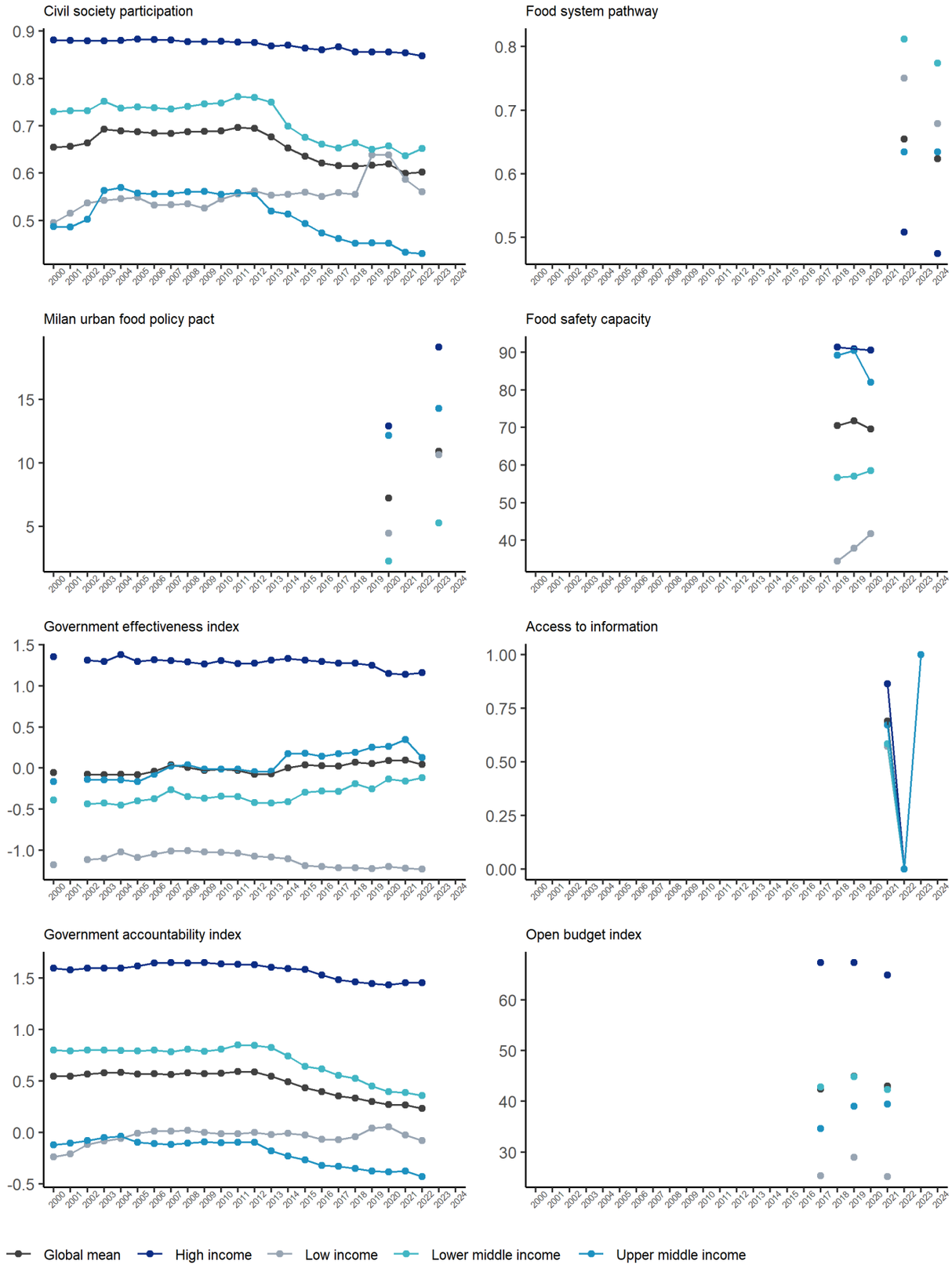
Supplementary Figure 17. Regional weighted mean time trends: Governance

Time trends for all indicators, by region. Weighting variables defined in **Extended Data Table 1.**



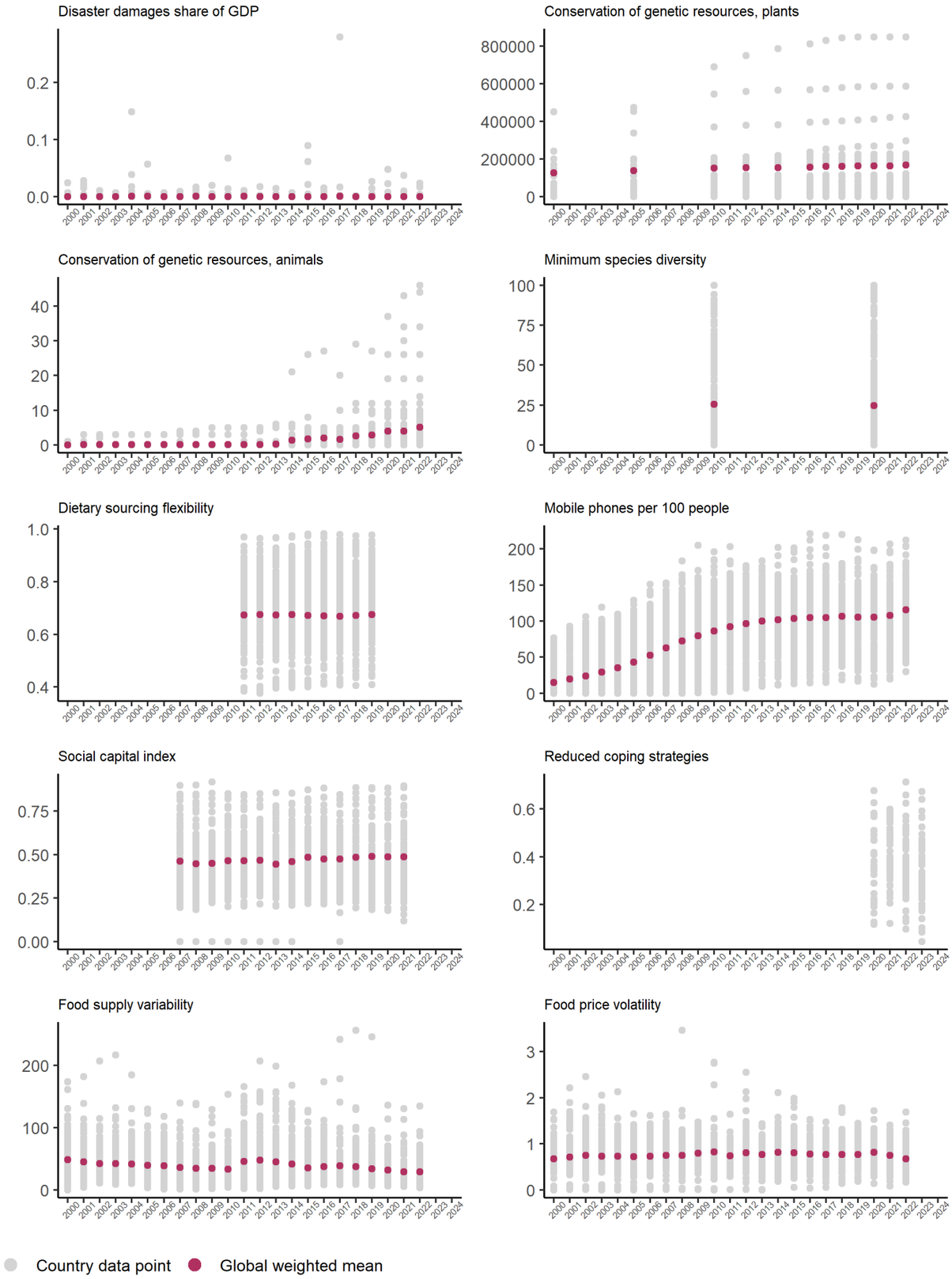
Supplementary Figure 18. Income group weighted mean time trends: Governance

Time trends for all indicators, by income group. Weighting variables defined in **Extended Data Table 1.**



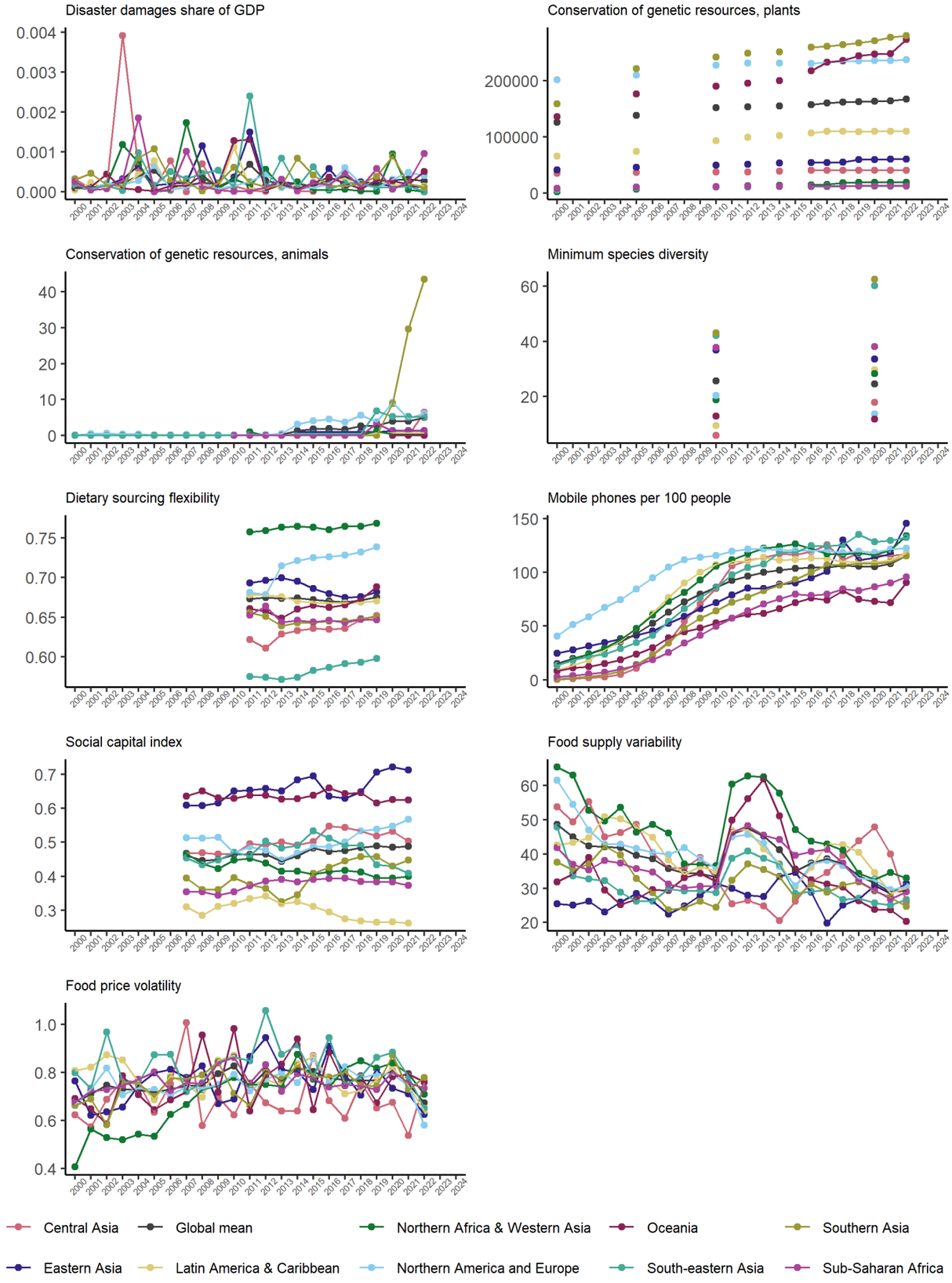
Supplementary Figure 19. All data with global weighted mean: Resilience

All country-year observations shown for every indicator in light gray. Maroon points show the global weighted mean, excluded for indicators where data are collected in different countries each year and cannot be analyzed as trends. Weighting variables defined as shown in **Extended Data Table 1**, no weighted mean shown in 2023 or 2024 if the weighting variable is not yet available for that year. Reduced coping strategies excluded for lack of time series.



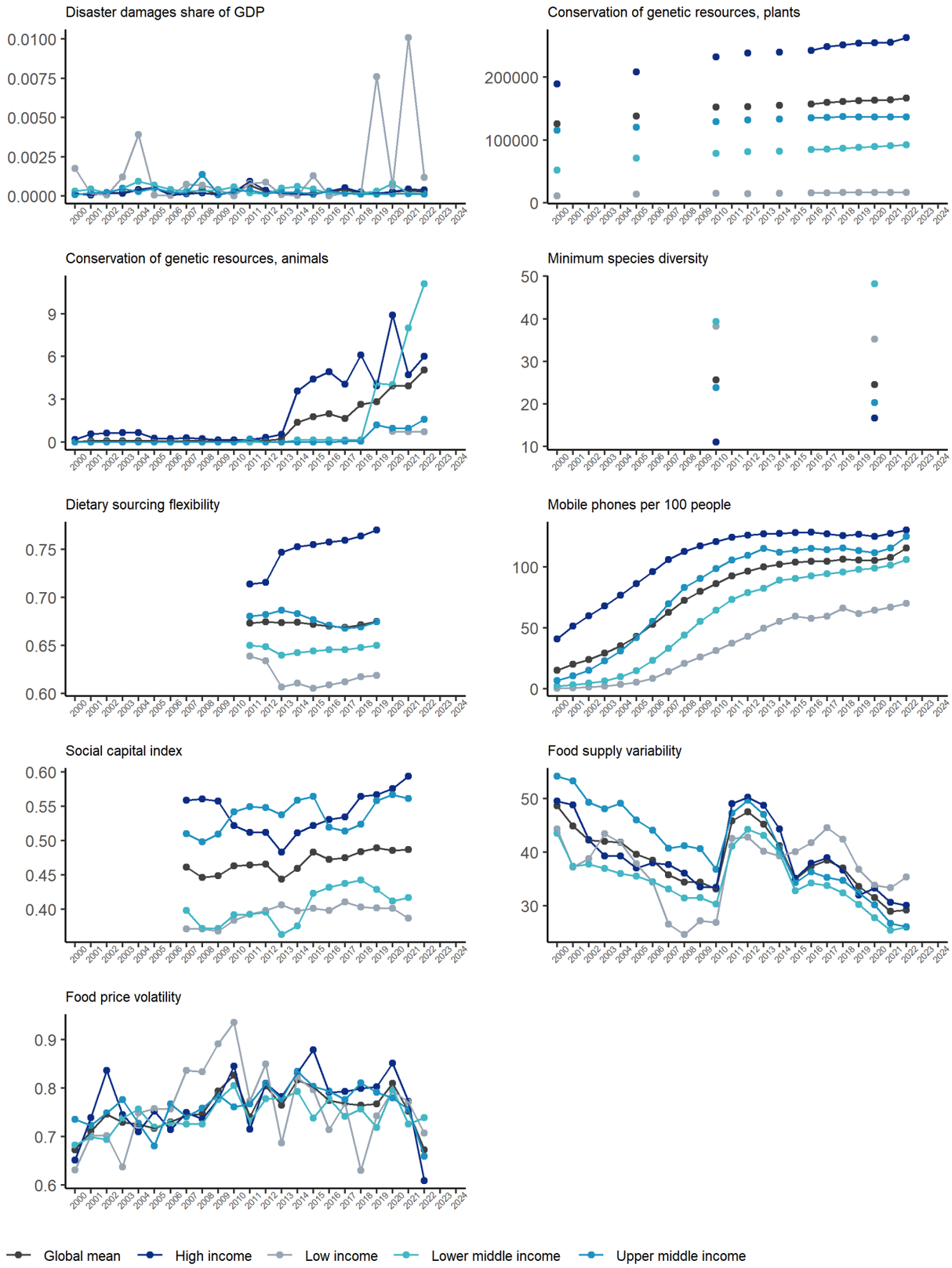
Supplementary Figure 20. Regional weighted mean time trends: Resilience

Time trends for all indicators with time series data, by region. Excluded for indicators where data are collected in different countries each year and cannot be analyzed as trends Weighting variables defined in **Extended Data Table 1.** Reduced coping strategies excluded for lack of time series.



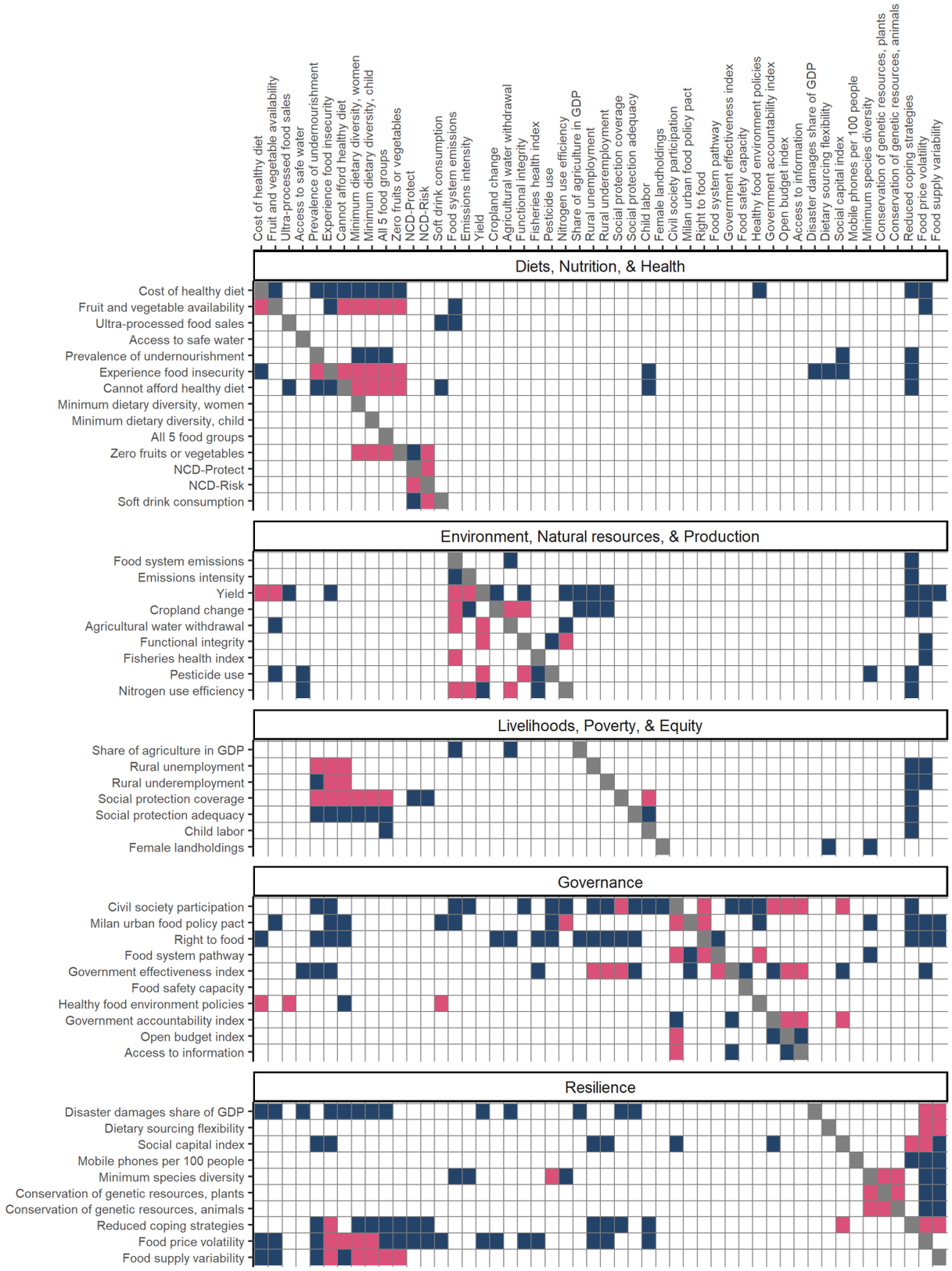
Supplementary Figure 21. Income group weighted mean time trends: Resilience

Time trends for all indicators, by income group. Weighting variables defined in **Extended Data Table 1.** Reduced coping strategies excluded for lack of time series.



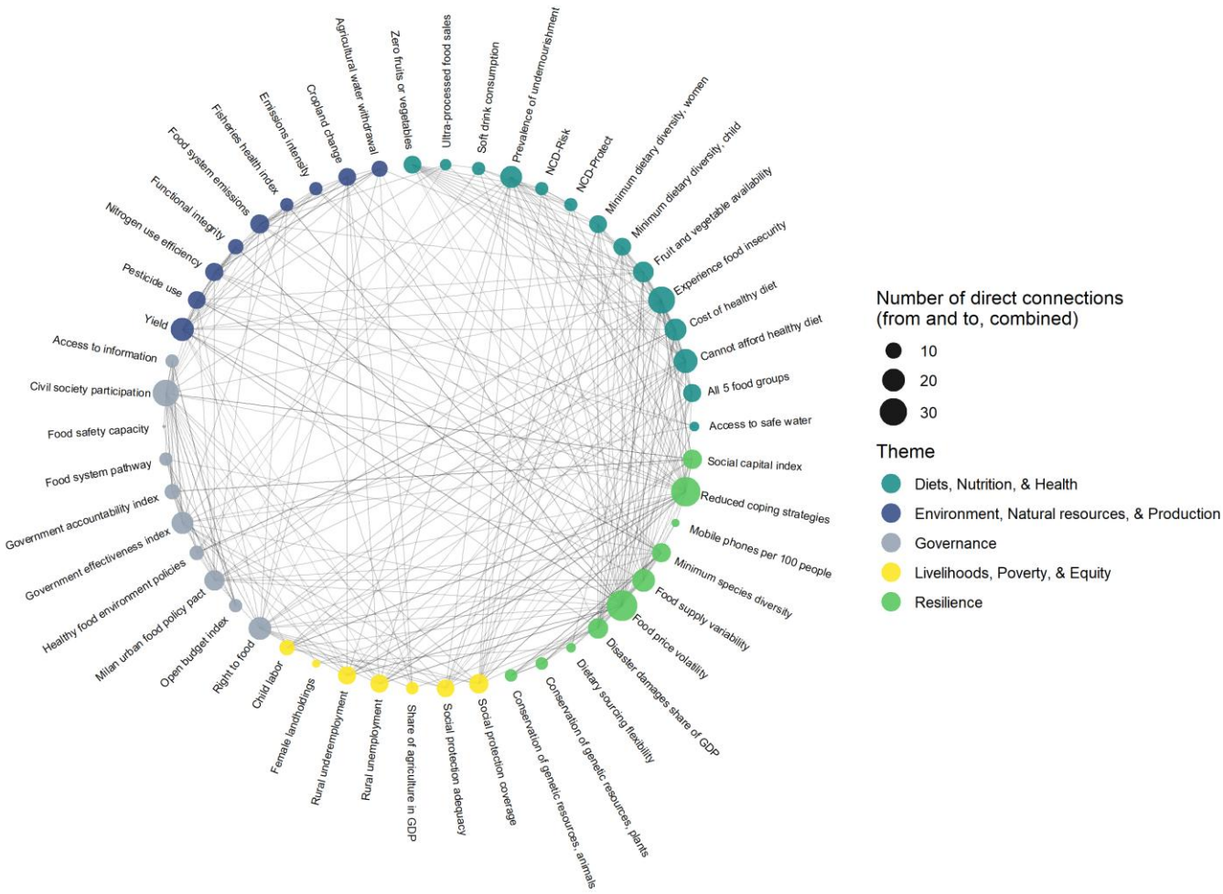
Supplementary Figure 22. Direct relationships between indicators including bidirectional causality.

Direct relationships identified through the expert elicitation process, including where causality was identified from the row variable to the column variable and in the other direction as well. Blue cells show causality from row to column only. Maroon cells indicate causality in both directions. Identity cells are dark gray.

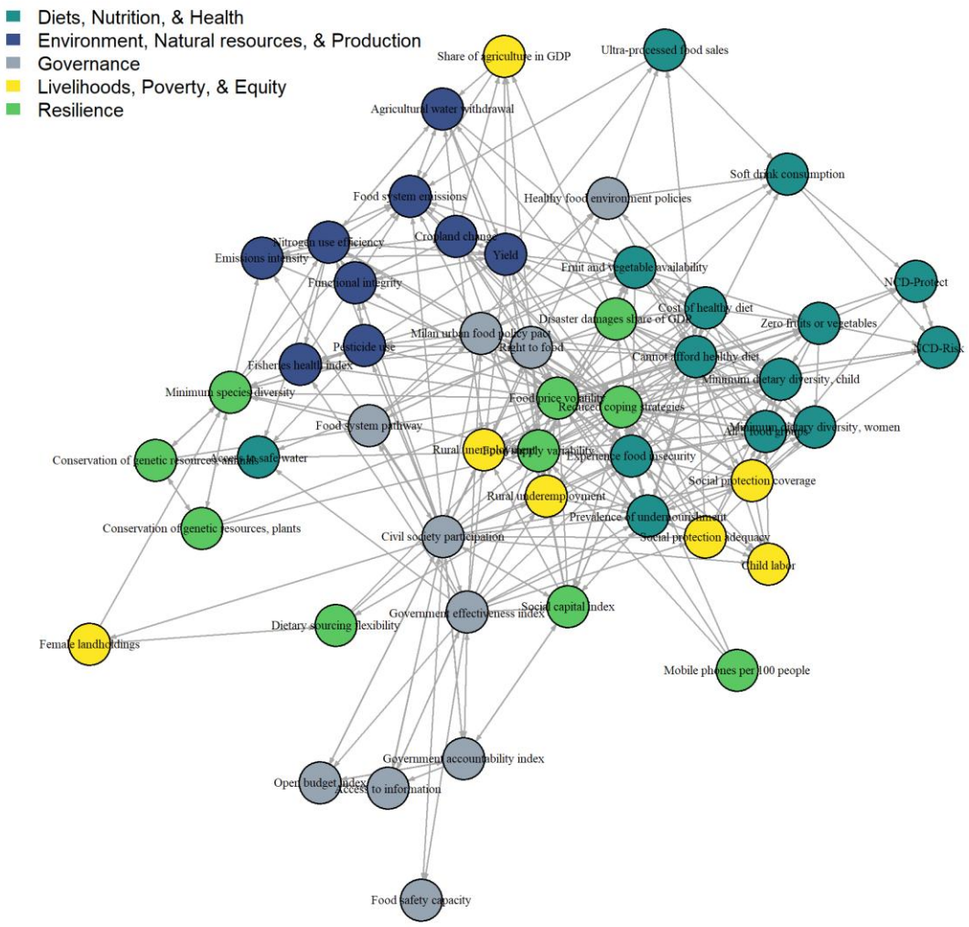


Supplementary Figure 23. Direct connections between indicators

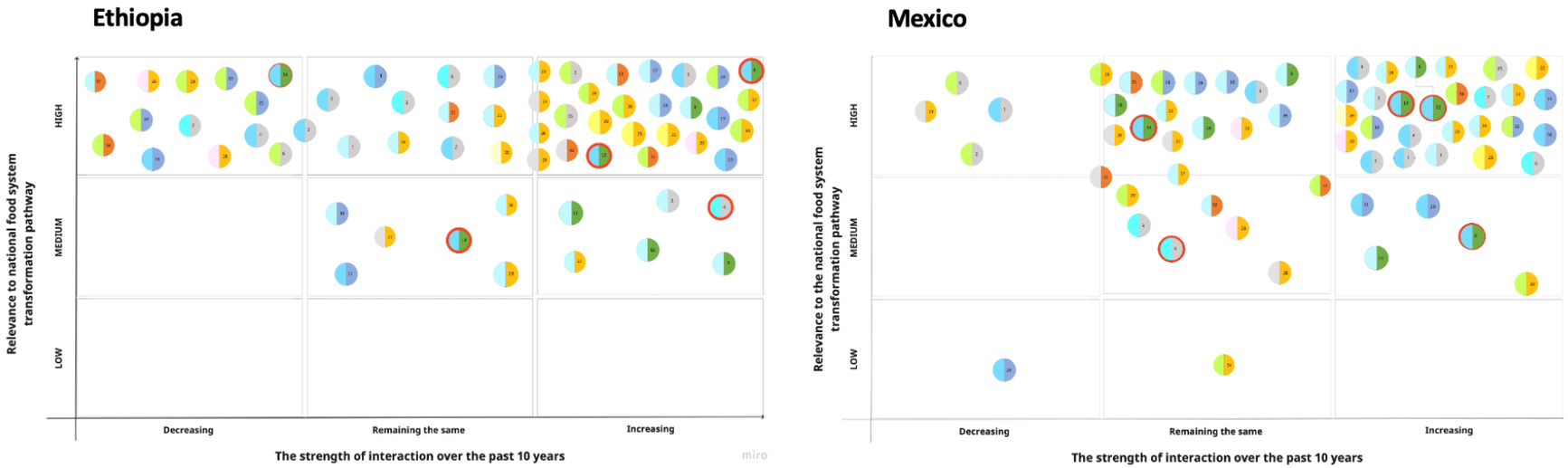
Illustration of all direct connections between indicators. Directionality has been combined such that the size of connections with each indicator includes assessed causal connections from that indicator to others plus those from other indicators affecting that indicator.



Supplementary Figure 24. Network diagram of direct connections between indicators
Network illustration of all direct connections between indicators, as assessed through global expert elicitation of proposed causal relationships.



Supplementary Figure 25. Map of food system governance interactions in food in Ethiopia and Mexico.
Maps from each qualitative consultation showing relevance to achieving the national food systems transformation pathway and whether the strength of the interaction has been increasing, remained the same, or been decreasing over the last 10 years. Created through expert elicitation with 15 to 20 in-country experts reflecting on the interactions of FSCI governance indicators with other FSCI indicators. Maps illustrate ranking in terms of relevance to achieving the food systems transformation pathway (Y-axis) and if the relationship has been decreasing, maintaining the same, or increasing over the last 10 years according to expert opinion. Color keys represent different governance indicators (key for governance indicators) and FSCI thematic areas (key for thematic areas). Negative interactions (tradeoffs) are indicated with a red perimeter.



Key for governance indicators

- Civil society participation index
- Degree of legal recognition of the right to food
- Presence of a food system transformation pathway)
- Government effectiveness index
- Presence of health-related food taxes
- V-Dem accountability index
- Open budget index score
- Guarantees for public access to information
- Negative interaction (tradeoff)

Key for indicators per theme

Theme	FSCI indicators (Code used)
Diet, nutrition, and health	Prevalence of Undernourishment (1), % Population experiencing moderate or severe food insecurity (2), Cost of a healthy diet (3), % Population who cannot afford a healthy diet (4), % Population using safely managed drinking water services (5), Retail value (total sales) of ultra-processed foods (6), Sugar-sweetened soft drink consumption (7),
Environment, natural resource and production	Total pesticides per unit of cropland (8), Food systems greenhouse gas emissions (9), Greenhouse gas emissions intensity, by product group (10), Sustainable nitrogen management index (11), Agriculture water withdrawal as % of total renewable water resources (12), Cropland expansion (13), Fishery health index progress score (14), Functional integrity: % agricultural land with minimum level of natural habitat (35)
Livelihoods, poverty, and equity	Social protection coverage (15), Social protection adequacy (16), % Children 5-17 engaged in child labor (17), Female share of landholdings (18), Unemployment, rural (19), Share of agriculture in GDP (20), Underemployment rate, rural (21),
Governance	Degree or legal recognition of the Right to Food (22), Government effectiveness index (23), Food safety capacity (24), Presence of health-related food taxes (25), V-Dem Accountability index (26), Open Budget Index Score (27), Guarantees for public access to information (28), Civil society participation index (29), Presence of a national food system transformation pathway (30)
Resilience	Ratio of total damages of all disasters to GDP (31), Social capital index (32), Coping strategies index (21), Food price volatility (34)