ANALYSIS
https://doi.org/10.1038/s43016-022-00588-7

nature food

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Global food systems transitions have enabled affordable diets but had less favourable outcomes for nutrition, environmental health, inclusion and equity

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Over the past 50 years, food systems worldwide have shifted from predominantly rural to industrialized and consolidated systems, with impacts on diets, nutrition and health, livelihoods, and environmental sustainability. We explore the potential for sustainable and equitable food system transformation (ideal state of change) by comparing countries at different stages of food system transition (changes) using food system typologies. Historically, incomes have risen faster than food prices as countries have industrialized, enabling a simultaneous increase in the supply and affordability of many nutritious foods. These shifts are illustrated across five food system typologies, from rural and traditional to industrial and consolidated. Evolving rural economies, urbanization and changes in food value chains have accompanied these transitions, leading to changes in land distribution, a smaller share of agri-food system workers in the economy and changes in diets. We show that the affordability of a recommended diet has improved over time, but food systems of all types are falling short of delivering optimal nutrition and health outcomes, environmental sustainability, and inclusion and equity for all. Six 'outlier' case studies (Tajikistan, Egypt, Albania, Ecuador, Bolivia and the United States of America) illustrate broad trends, trade-offs and deviations. With the integrated view afforded by typologies, we consider how sustainable transitions can be achieved going forward.

The systems that produce, process, package and sell food have undergone a series of transitions over the past several decades, impacting diets, nutrition and health; livelihoods and wages; and the environment and climate[1]. Actors from farmers, micro-enterprises and medium-sized enterprises to transnational corporations participate in food system activities. Drivers of change include rising incomes, market liberalization and expanding foreign investment, international trade agreements, infrastructure investment, technological change and innovation, population growth, urbanization, and changes in consumer demand. These actors and drivers are interlinked with intended and unintended as well as positive and negative consequences[2–4].

Food systems have enabled enough food to be grown to keep pace with the rapidly increasing population[5] while reducing devastating famines that caused hundreds of millions of deaths[6], but with that great acceleration has come trade-offs and new challenges, particularly with climate change, ecosystem resilience[7] and deepening issues of inequity, which hamper progress to ensure that all people are well nourished. Food systems objectives have therefore evolved from a focus on producing enough nutritious food to feed the world to doing so in an environmentally sustainable way while facilitating fair and equitable livelihoods, social justice and respect for cultural values[8,9].

In this paper, we use a food system typology to understand how food systems transitioned historically and potential implications for countries to consider as their food systems continue to change[10]. This typology has five categories: (1) rural and traditional, (2) informal and expanding, (3) emerging and diversifying, (4) modernizing and formalizing, and (5) industrial and consolidated. This categorization is based on the agricultural value added per worker, dietary change as reflected by the share of dietary energy from staple grains and cereals, urbanization, and supermarket density, which are all closely related to economic growth. The food system typology covers 155 countries and 97% of the world's population, with 30–32 countries in each category[10], as illustrated in Supplementary Fig. 1.

The typology enables comparisons of countries going through similar transitions (changed as they occurred) to understand where, for some drivers and outcomes, countries deviate from the norm and why. Understanding food system transitions will help guide the future food system transformation—an ideal state with equitable livelihoods, environmental sustainability and affordable nutritious foods. The typology does not presume to suggest a linear path, with countries moving across the categories towards increased transition, but is instead a snapshot in time grouping countries by shared characteristics. The paper is organized around three analyses to demonstrate how food systems have transitioned, including diet affordability, structural transformations and outcomes of food system transformation. Case studies of informative outlier countries are examined under each main result to understand conditions under which transitions are consistent with positive

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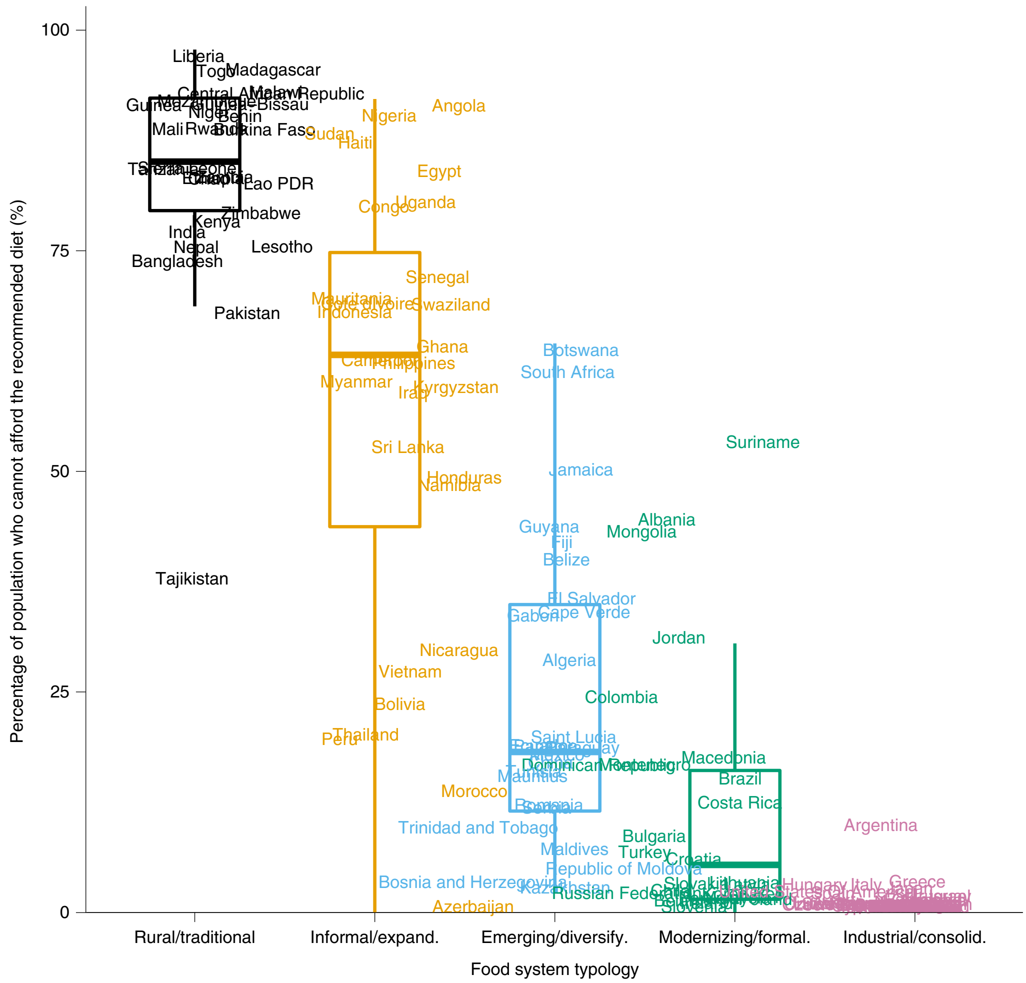


Fig. 1 | Affordability of a healthy diet by food system typology in 2018. Data on the affordability of a healthy diet are from refs. [11,13]. The healthy reference diet is defined by local food-based dietary guidelines in each country. The cost of this diet, measured around the world as the Cost of Recommended Diets (CoRD) using local dietary guidelines, food items and prices, can be compared to incomes to measure the affordability of the diet that meets dietary guidelines in each time and place[11]. To assess affordability, the CoRD is constructed by the median cost of the healthy diet compared to median incomes under the assumption that 63% of income is spent on food[11,13]. In the figure, the industrial and consolidated typology has very few variations with respect to the CoRD, as illustrated by highly clustered country names[10].

(and negative) food system transformation. The cases were purposively selected from outliers across multiple metrics and include examples from each food system type. Similarly, the indicators shown do not reflect the totality of food systems and are in part a reflection of data availability.

Results

Recommended diets have become more affordable. Recommended diets have become more affordable as food systems have transitioned from rural to industrialized, although access depends on poverty levels, which vary within food system types. A recommended diet is considered affordable if it does not exceed 63% of the median income (the average percentage of budgets spent on food by the lowest-income consumers in low-income countries)[11,12]. The percentage of the population who can afford the least-cost diet adhering to food-based dietary guidelines (henceforth 'a nutritious diet') increases from 15% (at the median) in countries with rural and informal food systems to nearly 100% in countries with industrial and consolidated food systems (Fig. 1). We estimate that nearly all residents of industrialized countries and a median of 82% in countries with an emerging and diversifying food system are able to afford a nutritious diet[11,13].

Figure 2 shows the relationship between income (as measured by gross domestic product (GDP) per capita) and poverty using three different poverty lines: US$1.90 per day, US$3.20 per day and US$5.50 per day[14]. Although poverty declines as countries industrialize across all poverty lines, there is substantial heterogeneity in the poverty headcount across countries within each typology group. Among countries categorized in the rural and traditional group, the percentage of the population living below the lowest international poverty line of US$1.90 per day ranges from less than 20% in most years (Tajikistan, Lao People's Democratic Republic and Pakistan) to over 70% in most years (Madagascar). At the highest international poverty line (corresponding to poverty thresholds in upper-middle-income countries), there is less heterogeneity among countries in the industrial and consolidated group, with the percentage of the population below US$5.50 per day ranging from near zero (Switzerland, Iceland, Denmark, Norway and the Czech Republic) to over 25% (Argentina). Though the food system typology classification correlates strongly with the country's income level, certain low- and middle-income countries have relatively low rates of moderate and severe food insecurity despite low incomes and affordability, such as Senegal, Bangladesh and Indonesia[15].

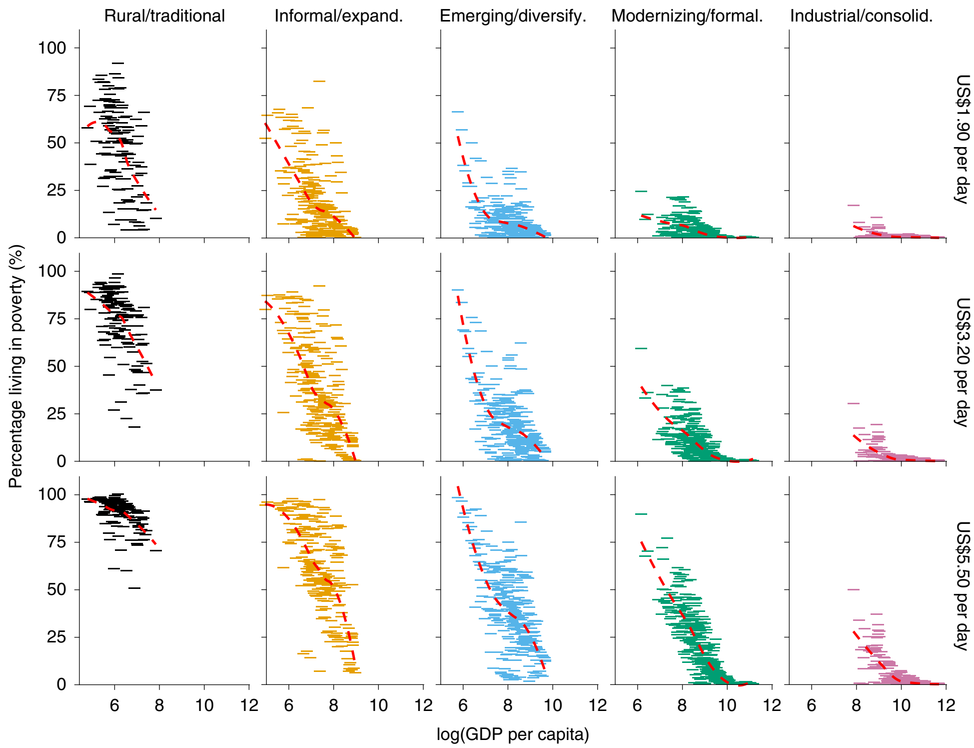


Fig. 2 | Relationship between the share of the population living below international poverty lines and GDP per capita (1990–2019), by food system typology. The data on population living below international poverty lines (poverty) and GDP per capita in current US dollars (income) were sourced from the World Bank[129].

Figure 3 shows the prices and availability side of the affordability ratio, depicting the changes in the price and availability of nutrient-dense foods and food groups necessary for nutritious diets across the typology. Figure 3a shows the (internationally comparable) overall price level by food group (vegetables, fruits, dairy/eggs, meat, seafood, cereals and all food) across the typology, demonstrating that absolute food prices increase across the typology along with incomes. If prices and incomes increase and affordability also improves, this implies that incomes have increased faster than prices. Supplementary Fig. 2 shows the price levels of the foods and food groups by food system typology; it shows that there is no consistent relationship between the prices of different food groups moving across the typology and that food prices overall are the highest in the industrialized food systems. Importantly, increasing food prices may also reflect an increase in the quality of the food supply[16–18]. A prerequisite for an affordable healthy diet is the availability of diverse foods to meet the dietary recommendations for a balanced, nutritious diet[19]. Availability implicates both production and trade, where shortfalls of domestic or local production could be met through imports, but doing so would require a deliberate nutrition-sensitive trade policy[20].

Figure 3b shows the per capita supply of several nutritious food groups selected to illustrate the nutrient-dense food groups necessary as part of a balanced diet. We show that availability increases across each group in the typology, but the patterns are distinct by food group. There is a positive linear relationship for some food groups, particularly for animal proteins coming from eggs, meat and dairy. Though the supply of fish is the lowest in countries with rural and traditional food systems, no clear pattern emerges for the remaining food system types, potentially indicative of geographic proximity to large bodies of water. Fruits and vegetables show increasing per capita supply up to the modernizing and formalizing food systems, but then diminishing supply in countries categorized as industrial and consolidated. Lower levels of government support for fruit and vegetable production relative to other crops, particularly staple crops and livestock products, may contribute to this feature of food systems in the industrial and consolidated group[21]. Pulses show a clear downward trend across the typology, with the highest per capita supply in countries with rural and traditional food systems. In many places, pulses (legumes and nuts) and coarse grains (for example, millets) are seen as inferior goods, and people choose to consume less of these foods when they have more income[22–25]. The data confirm the well-established observation that people purchase more animal-sourced foods as incomes increase[26–28]. This is demonstrated in Fig. 3, which shows the large increases in the supply of meat, eggs and milk as food systems transition to meet those higher demands for animal-source foods. Globally, animal-source foods (dairy, meat, eggs and fish) contribute to 45% of the protein supply compared with all other food sources (Supplementary Fig. 3). In countries with industrial and consolidated food systems, 62% of the protein supply comes from animal-source food compared with 21% among countries with rural and traditional food systems.

Affordability outliers. A few notable exceptions to the trends include Angola, Tajikistan and Egypt. Angola stands out for extremely high food prices relative to any other country with an informal and expanding food system. This is primarily a result of an overall low food supply (Fig. 3 and Supplementary Fig. 2) and a high currency exchange rate from substantial oil revenue. A high exchange rate makes other export sectors less competitive and makes domestic agricultural production less competitive with imports. This, in addition to historical disinvestment in domestic production and macroeconomic mismanagement, has led some countries to rely on food imports. The increased food trade has had mixed impacts across settings, expanding food access, affordability and variety while also sometimes raising costs and lowering quality[29–33].

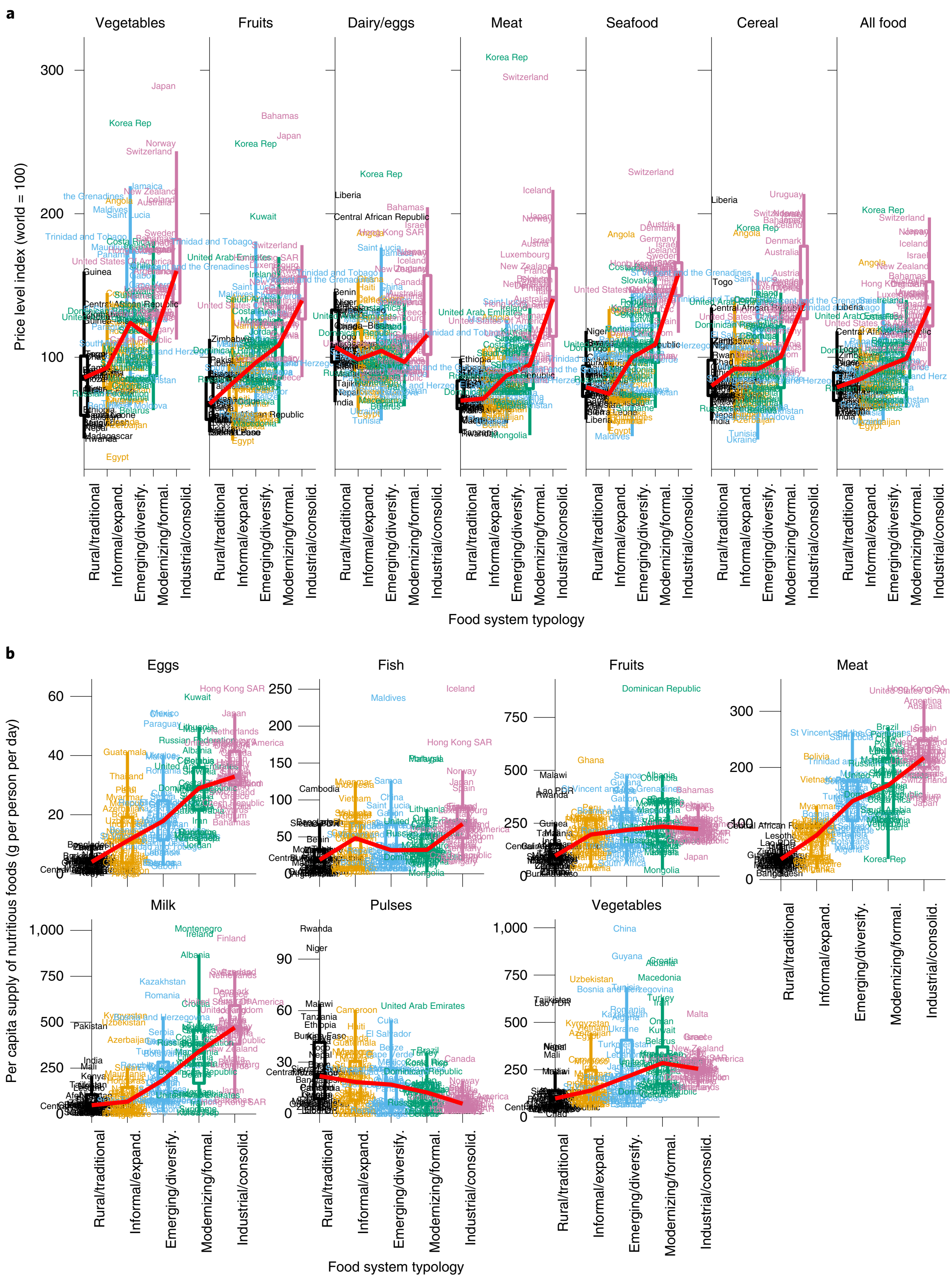


Fig. 3 | Prices and supplies of nutritious foods by food system typology. a, Food price indices. The data on food prices were gathered from the World Bank's International Comparison Program, and the data on GDP and international poverty lines were also obtained from the World Bank[129,130]. The food price indices are standardized measures of prices that can be compared across time and countries with different currencies. **b**, Nutritious food supply per capita by food group and food system typology (2018). The domestic supply of nutritious foods was obtained from FAOSTAT (2018)[131]. Supply includes domestic production and imports minus exports and any changes in stocks. The following item codes from FAOSTAT correspond to the domestic supply of nutritious foods (element code no. 645): eggs (item code no. 2949), fish/seafood (item code no. 2960), fruits excluding wine (item code no. 2919), meat (item code no. 2943), milk excluding butter (item code no. 2848), pulses (item code no. 2911) and vegetables (item code no. 2918)[10].

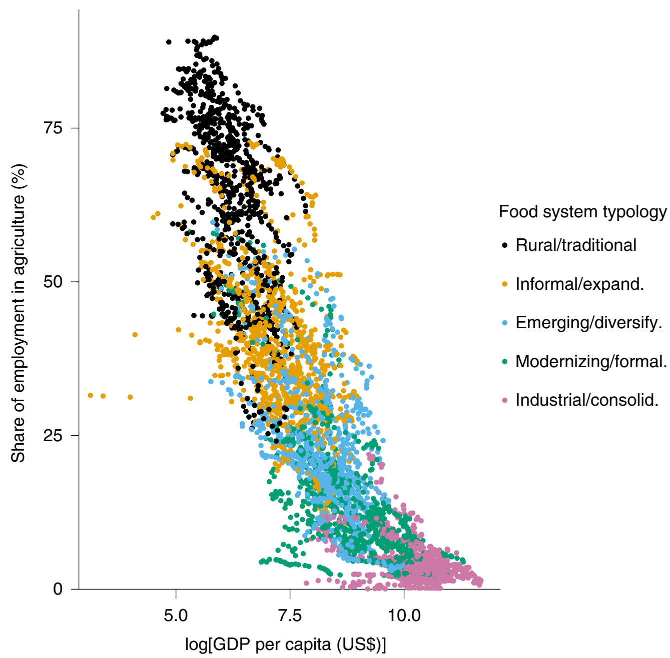


Fig. 4 | Structural transformation of economies over time by food system typology. The data on share of employment in agriculture and GDP per capita (using current US dollars) were sourced from the World Bank for analyses[129,133].

Tajikistan has a rural and traditional food system and is a landlocked country where 72% of the population resides in rural areas. Despite this, more than half the population can afford a healthy diet. A closer look into Tajikistan's food system profiles reveals several reasons for the increased affordability of healthy diets[34,35]. First, major land reform in the late 1990s changed farm size profiles, leading from the unequal distribution of corporate and subsistence farms to a more even distribution of farm sizes. This land reformation led to increased agriculture and livestock productivity while also substantially increasing rural household incomes[35]. Furthermore, it shifted cropping from cash crops such as cotton and tobacco to vegetable and fruit crops. Second, food prices for the staple crops are integrated across domestic markets within the country[34,36]. Third, social safety net programmes such as cash transfer and school feeding programmes have had relatively high coverage and are well targeted[34,36]. Lastly, household incomes are supplemented by remittances, which contribute 37% of the country's GDP[34].

The case of Egypt, a country with an informal and expanding food system, presents a puzzle because the data do not provide a clear picture of transition. The food price indices of nutritious food groups (Fig. 3a) are much lower than in many other countries with informal food systems. Yet only a small proportion (16%) of the population can afford a healthy diet. Low food prices for staples might reflect the subsidy programme that has formed the pillar of Egypt's food policy and social safety net for several decades, though this programme has recently been reformed to improve targeting towards vulnerable groups[13,37,38]. However, other food group prices are also lower, probably explained by the increase in productivity and adoption of technological innovations in Egyptian agriculture in the past 50 years[39]. The unaffordability of a nutritious diet means that wages and incomes are quite low for the majority of the population, even amid reasonable food prices for staples and nutrient-dense foods. Nearly one third of the population also experiences moderate food insecurity; even though food prices are much lower than in many other countries, incomes are still insufficient for much of the population to secure enough food[13,15].

Affordability is determined by the process of transition. The increasing affordability of nutritious diets from rural and traditional food systems to industrial and consolidated systems (Supplementary Fig. 1) happens in large part as a consequence of structural transformation and related changes to incomes, diets, urbanization and the modern food industry that has arisen to meet the demands of the increasingly wealthy, urban and time-constrained consumers[3,40–44]. Structural transformation refers to the process by which labour and total economic activity are reallocated from low-productivity sectors, predominantly agriculture, into higher-productivity manufacturing and services sectors.

Figure 4 shows the established pattern of structural transformation in which the share of the population employed in agriculture declines with GDP. Although the agricultural economy continues to grow and contribute to the overall economy during this transition, it does not grow as fast as manufacturing and services, contributing to increasing differentiation between rural and urban areas. The decline in the share of agricultural employment is accompanied by an often-slower decrease in the economic importance of agriculture to the total economy. This is spurred by changes in land and particularly labour productivity (Supplementary Fig. 4), allowing labour and capital to move to more lucrative sectors.

Higher incomes increase demands for goods and services[45,46]. Convenience takes greater importance in food preferences as wage workers have less time, creating demand for convenient retail (supermarkets) and for processed and prepared foods[43,47,48]. As incomes increase, demand for diet quality also increases (including increased demand for animal-source foods, fruits and vegetables), and the share of food spending as a percentage of total spending and the share of food spending on staple foods both decline[49,50]. Beyond incomes, living standards and human welfare generally also increase (Supplementary Fig. 5).

In contrast, no clear patterns emerge in levels of inequality (Supplementary Fig. 6), suggesting that addressing issues of equity within (and beyond) food systems and implications for the access to and affordability of food require explicit attention in each context. The historical challenges encountered by the lagging latecomers to structural transformation, and the more challenging context they face today, suggest that their processes of structural transformation—and thus food system transformation—may not follow the same pattern as that of countries further along in the transformation process (Supplementary Fig. 7). This suggests future unique and heterogeneous patterns of food system transformation.

With a declining workforce in agriculture, landholdings tend to become more consolidated (Fig. 5). Machinery and inputs (for example, improved seeds and fertilizers) increase the output per worker (labour productivity). Technology improvements increase land productivity and facilitate specialization that increases farm revenues. Supplementary Fig. 4a shows an increase in labour productivity at similar levels of land productivity across the typology. In the rural and traditional group, relatively smaller increases in labour and land productivity have occurred in the past two decades. Figure 5 shows that average land sizes are larger in the modernizing/formalizing and industrial consolidated categories, consistent with the pattern just described; though, within each typology, there is substantial heterogeneity in land distribution[42,51].

Supplementary Fig. 8a shows the reduction in agri-food system employment as a share of total employment moving across the typology. This primarily reflects the reduction in the share of the workforce in primary agricultural production as the role of agriculture within the agri-food system diminishes across typology (Supplementary Fig. 8b). This process generally occurs with a lag in which, for a substantial period, the share of employment in agriculture exceeds the share of agriculture in GDP, making the agricultural sector less remunerative and the sector where poverty remains concentrated. Within agri-food system employment, the

Fig. 5 | Distribution of landholding sizes (2005) by food system typology. The data on mean farm sizes across all agricultural commodities were sourced from Herrero et al. and categorized by country and food system typology[137]. Each bar represents the proportion and distribution of farm sizes. The pink gradient represents larger farm sizes, from 50–100 hectares to the darkest pink representing over 1,000 hectares. Green represents smaller farm sizes, with the darkest green representing under 1 hectare.

proportion involved in agricultural production declines, and the proportion involved in food services and processing increases as countries move from rural to industrial and consolidated (Fig. 6 and R.A. et al., manuscript in preparation). The proportion comprising agricultural workers also declines as countries move from rural to industrial and consolidated. Where people work in food system jobs in other parts of the value chain, wages are lower than in other non-food sectors of the economy, and job quality and stability are also inferior to those in many other sectors[8,52–55].

Furthermore, the degree of informality of jobs in food systems probably differs across the typology, and informal work (especially work that does not have any required permit or work authorization) provides for much more insecure livelihoods, vulnerability and potential income volatility[56–59]. Therefore, even beyond agriculture, those who work in food systems are more likely to be disadvantaged economically than workers in other sectors[60,61]. Even while part of the food system, small-scale farmers, labourers and those working in the food system are often not able to access affordable diets due to lower incomes.

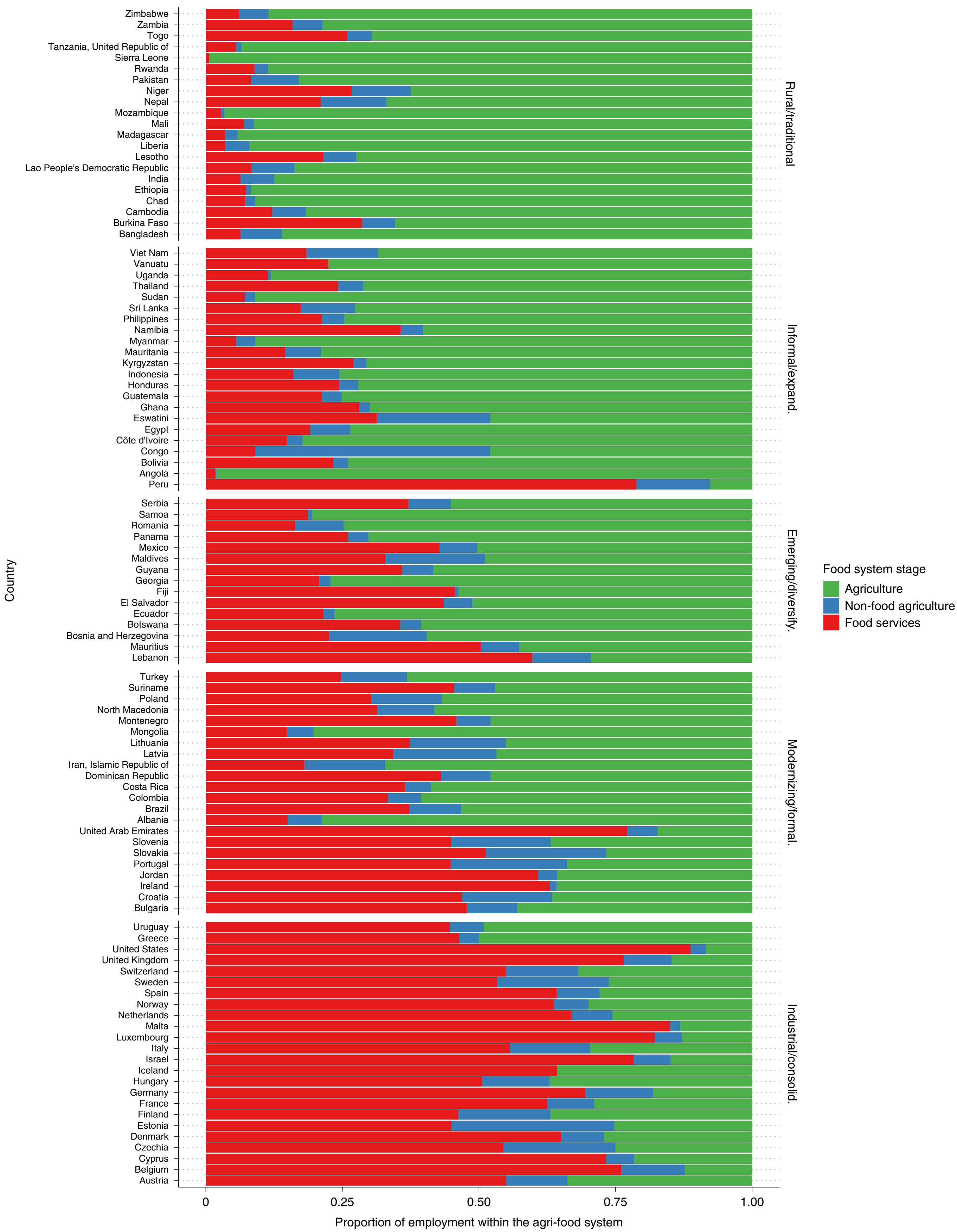
Livelihood and land outliers. The food systems of several outlier countries depart from the general patterns, primarily explained by policy choices. Albania, for example, has a modernizing and formalizing food system but has a much larger share of the population employed in the food system than other countries in that group (Fig. 6 and Supplementary Fig. 8a). Small farms still predominate, in contrast to most other countries in that typology (Fig. 5). This is partly due to Albania's land reform of 1991, which redistributed all former state farms and agricultural cooperative land from the Soviet era on a per capita basis to every rural person[62]. In practice, this policy resulted in land fragmentation and insecure land tenure due to conflicting claims on land from pre-collectivization inheritance with the post-communist reallocation. Studies have attributed the low level of land market transactions and land consolidation to this tenure insecurity and unclear property rights, leaving the majority of Albanians to rely on small-scale farming or to leave farmland abandoned in favour of non-farm opportunities, including international migration[62–65]. This lends some explanation of why 44% of the population are estimated to be unable to afford a recommended diet, more than any other country in the same modernizing and formalizing group[11].

Ecuador offers a contrasting story. It too has a larger share of the workforce employed in agriculture and food systems than other countries with emerging and diversifying food systems, but land sizes are larger than in most other countries in this group. Policymakers there have historically prioritized traditional export agriculture to drive economic growth[66]. This policy orientation favours large-scale farms and agribusiness (for example, bananas, broccoli and flowers), the monoculture production of staple foods (rice, maize and potatoes), palm, cattle and, more recently, the manufacturing of value-added food products[67,68]. As a result, there are many more wage jobs in agriculture. Agricultural jobs in Ecuador are of higher quality than in most other places in several ways: they are more stable (low precariousness), are directly hired (not through contractors or intermediaries) and provide equal opportunities for women[67]. As such, agricultural wage jobs are seen as desirable jobs for most rural people, where other opportunities are scarce due to substantial land inequality[67]. Small-scale farms (family-operated farms occupying less than 10 ha) account for only 12% of the total agricultural area in the country; they are farmed predominantly by indigenous people, who comprise 76% of the country's farmers and who supply a large share of domestically consumed food[69–71]. Without access to sufficient land to farm at a lucrative scale or to improved technologies, most small-scale farmers in Ecuador depend on non-agricultural income sources to supplement what farming can produce or earn[68,69]. Only 18% of the population are estimated to be unable to afford a healthy diet (Fig. 1), in line with the median level for countries in the emerging and diversifying group, but those who are poor are more likely to be small-scale farmers and of indigenous heritage[70].

Beyond affordability, food system objectives remain unmet. While food affordability is high, food system objectives to minimize environmental and climate change consequences and to improve nutrition and health outcomes are not being met. Figure 7 shows the proportion of greenhouse gas (GHG) emissions from each of the eight food system supply chain stages (land-use change, production, processing, packaging, transport, retail, consumption and end of life) across the five food system typologies, using FOOD-EDGAR estimates[72]. In general terms, land-use change and production practices constitute the primary sources of GHG emissions of all categories. However, as food systems transition from rural to industrialized, the shares of these two main sources of emissions change. Land-use change, driven by cropland and grassland expansion, is the key source of emissions in countries with rural and traditional food systems (in line with agricultural extensification). This category of emissions diminishes in relative importance as countries increase yields of commodities due to agricultural intensification through increases in fertilizer use, yield varieties, water control and improvements in land use policies and tenure laws. As countries industrialize, they use more energy, transport, processing and packaging throughout the value chain, which translates to higher emissions from these sources. Production emissions remain a substantial component, primarily from fertilizers and manure management, as well as methane from enteric fermentation from ruminant livestock. These emissions sources, while remaining large, diminish their shares relative to post-production emissions.

Structural transformation drivers have led to nutrition transitions as countries have industrialized and urbanized[73–75]. Urbanization and changes in employment demographics, especially for women working outside the home, have increased demands on time while changing physical activity levels. This has created a higher preference for convenience foods that are often highly processed and contain excessive sugar, salt and saturated fat. In addition, with increased urban incomes, preferences for and consumption of animal-source and ultra-processed foods increase[76,77]. While these dietary shifts have led to lower micronutrient deficiencies among the affluent urban population, in the longer run, they have also led to a substantial rise in cardiometabolic diseases due to imbalanced and unhealthy diets and lower physical activity[78–83]. One limitation of the present study is that in concentrating on food group proportionality, we do not consider differences in food quality, such as level of processing, that others have identified

Fig. 6 | Share of the workforce employed in agri-food systems (2009–2020) by food system typology. The workforce estimates were obtained from the International Labour Organization using International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4 across a range of activities including agriculture production, food processing and service, and the manufacture of non-food agricultural products that were deemed to fall under the definition of agri-food systems (R.A. et al., manuscript in preparation)[133–135]. These economic activities were pre-determined on the basis of ISIC codes if they fell under agri-food system definitions, which include employment in agriculture, processing, value chain and services, transportation, and retail (authors' calculations). The three categories are defined as follows: 'agriculture' employment includes activities related to agriculture, forestry and logging, and fishing; 'food services' refers to any activities related to the manufacture of food products and beverages, as well as food and beverage services; and 'non-food agriculture' refers to the manufacture of tobacco products, textiles, leather, wood (except furniture), paper and related products.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Zambia
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Sierra Leone
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Pakistan
Niger
Nepal
Mozambique
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Lesotho
Lao People's Democratic Republic
India
Ethiopia
Chad
Cambodia
Burkina Faso
Bangladesh
Rural/traditional
Viet Nam
Vanuatu
Uganda
Thailand
Sudan
Sri Lanka
Philippines
Namibia
Myanmar
Mauritania
Kyrgyzstan
Indonesia
Honduras
Guatemala
Ghana
Eswatini
Egypt
Côte d'Ivoire
Congo
Bolivia
Angola
Peru
Informal/expand.
Serbia
Samoa
Romania
Panama
Mexico
Maldives
Guyana
Georgia
Fiji
El Salvador
Ecuador
Botswana
Bosnia and Herzegovina
Mauritius
Lebanon
Emerging/diversify.
Turkey
Suriname
Poland
North Macedonia
Montenegro
Mongolia
Lithuania
Latvia
Iran, Islamic Republic of
Dominican Republic
Costa Rica
Colombia
Brazil
Albania
United Arab Emirates
Slovenia
Slovakia
Portugal
Jordan
Ireland
Croatia
Bulgaria
Modernizing/formal.
Uruguay
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Industrial/consolid.
Country
0
0.25
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Proportion of employment within the agri-food system
Food system stage
Agriculture
Non-food agriculture
Food services

Fig. 7 | Country-level breakdown of GHG emissions within food systems by food system typology (2015). The data on food systems emissions by country over time were sourced from the FOOD-EDGAR model and categorized by country and food system typology[72]. The different colours denote various food system components, and length of each bar indicates the proportion of emissions attributed to that food system components. For example, dark grey indicates emissions from land use / land use changes.

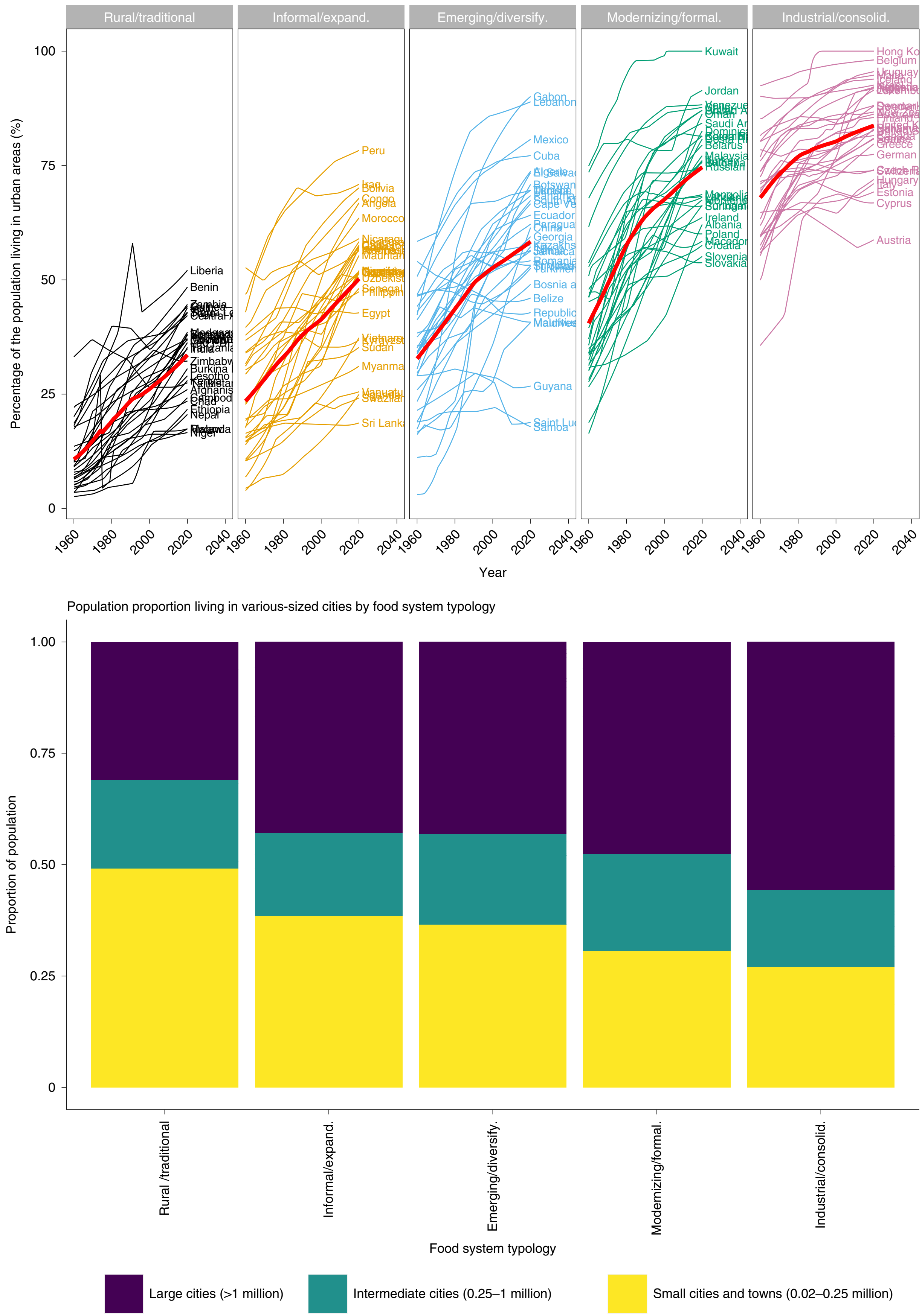

Fig. 8 | Rates of urbanization from 1990 to 2020 and proportion of the urban population by typology in 2015. The data on urbanization are from ref. [140], and the data on populations in different-sized cities are from ref. [136]. The red line in the top panel indicates the mean urbanization rate by typology.

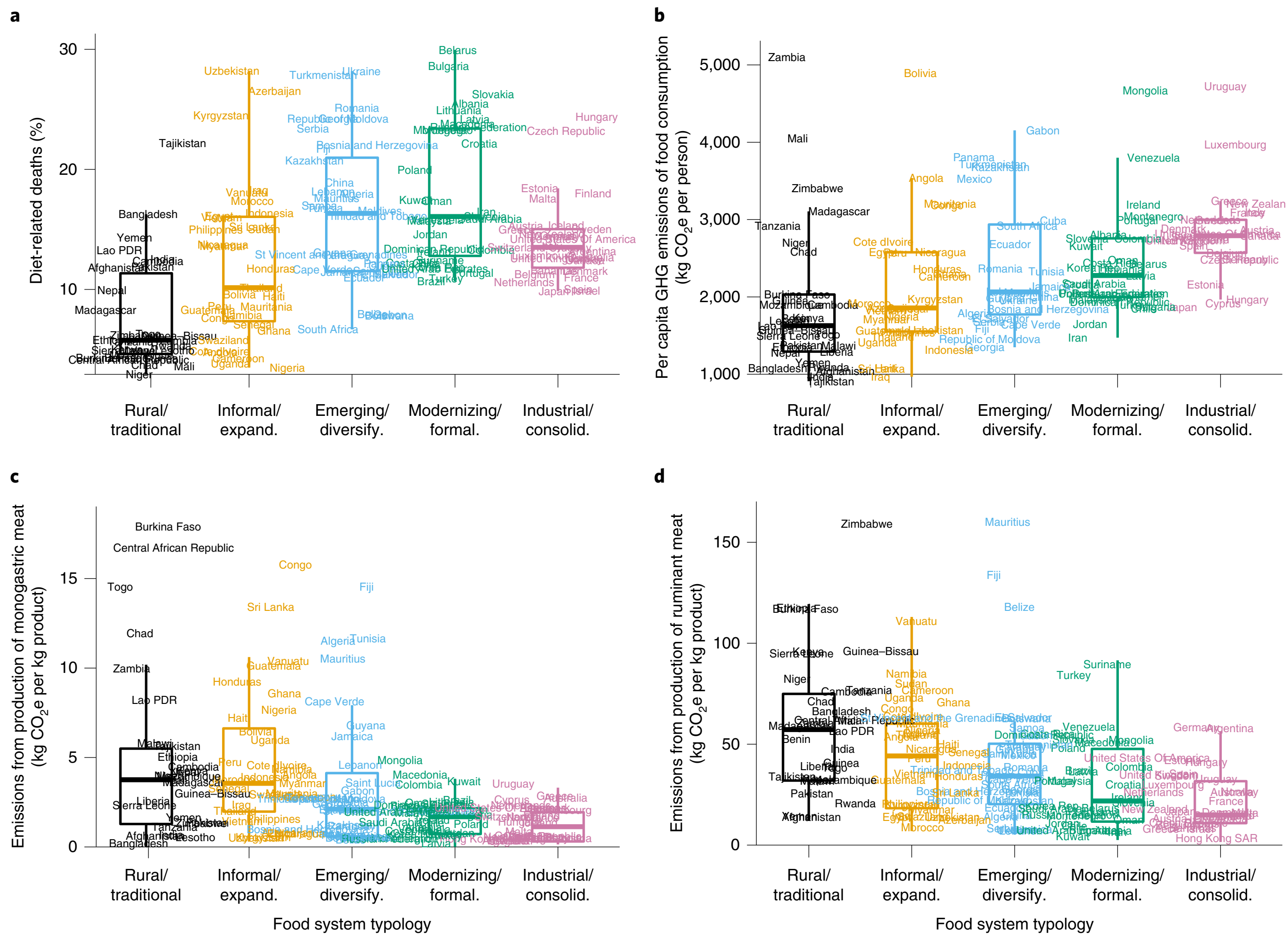

Fig. 9 | Food-related health and environmental impacts by food system typology. a, Percentage of deaths attributed to dietary-related risk factors obtained from the Global Burden of Disease (2019). **b**, Ecological footprint of food consumption (kg CO_2e, 2010, shown without extreme outliers). **c**, Emissions per kilogram of monogastric meat (poultry and pig, shown without extreme outliers). **d**, Emissions per kilogram of ruminant meat (cattle, goat, sheep and buffalo, shown without extreme outliers). Supplementary Fig. 10 shows these same figures with the inclusion of extreme outliers. The calculations are based on data from refs. [72,86,88,129,131].

as important components of a healthy diet[78,84,85]. Figure 8 summarizes the urbanization trends in the past few decades and the current proportion of urban residents by city size. The lower panel of Fig. 8 (Supplementary Fig. 9a,b) shows a larger proportion (>60%) of the urban population residing in intermediate-sized (0.25–1.0 million people) and smaller cities (0.2–0.25 million) in countries with rural, informal and emerging food systems compared with countries with consolidated and industrialized food systems, highlighting the need for better access to health systems, food environments providing healthy diets and more employment opportunities in these secondary cities. Urbanization will continue to be a major driver of food systems changes in these typologies.

Figure 9a shows the country-level percentage of mortality attributed to dietary risk factors such as diets high in sodium and red meat, coupled with low fruit, vegetable, whole grain and legume intakes[86]. The median percentage of deaths attributed to dietary risk factors increases from 5.7% in countries with rural and traditional food systems to 16% in countries with modernizing and formalizing food systems. Central Asian countries have higher diet-related mortality despite the high supply and intake of fruits and vegetables. This is probably due to other co-existing risk factors such as poor access to health care and high smoking and alcohol intake rates[86,87].

Nutrition transitions have a large environmental impact, driven largely by the increased demand for animal-source foods. Figure 9b illustrates the increase in the per capita ecological footprint of food consumption as countries' food systems transition[88]. While the consumption of animal-source foods increases from rural and traditional to industrialized food system types, GHG emissions per kg of meat decrease due to better feeding, health and management practices and changes in livestock systems. The efficiency of production increases from subsistence to commercial and industrialized systems[89]. Figure 9c,d shows this phenomenon for GHG emissions intensities related to different types of animal-source food production, which show clear declining linear trends with the food system typology. Regardless of the stage of transition, the differences in emissions intensity between monogastric (pork and poultry) and ruminant (beef, sheep and goat) meats are large; the median is 4 kg CO_2e per kg of meat among monogastric animals and 52 kg CO_2e per kg of meat among ruminant animals, indicating that the source of animal protein matters for climate impacts. Substantial increases in livestock production efficiency have led to a sustained increase in the domestic supply of meat in countries with modern and industrial food systems and, in some cases, have led to the overconsumption of animal-source foods, including higher-emitting ruminants[74,90].

Sustainability outliers. Bolivia's poultry industry offers a case study of achieving a commodity-specific transition leading to drastic shifts in land-use changes, meat prices, food safety challenges, affordability of diets and marketing of food choice—all of which were primarily driven by historical inequality and power asymmetry. At the dawn of independence in 1826, Bolivia's government denied citizenship to the entirety of its indigenous inhabitants, which constituted 80% of the population, to control land ownership[91]. In the 1890s, another substantial dispossession of indigenous land occurred when those in power systematically took over more arable land[91,92]. By 1950, 95% of the farmlands were owned by 8% of the population, with notably large parcels of farm sizes (>500 acres)[93]. Successful land reformation for more equitable land distribution occurred in 1953 (but only for men). However, this reform was not complemented with appropriate forestry management policies, which led to worse environmental outcomes[94,95]. Figure 5 illustrates that Bolivia is still an outlier in the share of large farm sizes compared with other countries with similar food system typologies using data from 2015. Furthermore, as shown in Fig. 7, Bolivia has the highest proportion of food system emissions related to land use and land cover change and production. It also stands out as an outlier for per capita food system emissions (Supplementary Fig. 10b). This is primarily due to a rise in soybean farms and processing plants, driven by investments from Brazil[96–98]. The profits made from the soybean industry were used for investments in the poultry industries, especially to purchase hatcheries and feed, which led to skyrocketing growth in chicken production between 2005 and 2015. Though increased efficiency and production drove down meat prices, poor regulations on sanitation and veterinary standards resulted in food safety concerns among international consumers. This limited exports and thus saturated internal markets, further decreasing the price of chicken[99,100]. Bolivia has the lowest meat prices for its food system typology while also having the highest meat supply per capita (76 kg per person per year) compared with other countries in the same typology (Fig. 2). The soaring domestic supply of chicken was complemented by the marketing of chicken to stimulate consumption[99,100]. Thus, in Bolivia, 75% of households can afford a recommended diet compared with the median of 67% for other countries within the same food system typology (Fig. 1)[11,13].

The United States offers another perspective on long-term food system transitions, where the high supply and affordability of a recommended diet have not translated to positive health and environmental outcomes (Fig. 9b and Supplementary Fig. 10a). Supplementary Fig. 6 illustrates rapidly rising inequality in the United States since the 1990s; this country currently has the second-highest level of inequality among countries with industrial and consolidated food systems (with a Gini coefficient of 41.4 compared with the median value of 32.4 for other countries in that group). While a recommended diet is affordable for 98.3% of the American population (Fig. 1), high levels of inequality and social inequities create barriers to translating affordability into widespread consumption of healthy diets[101]. Such inequities in the food system are reflected in widely observed population-level diet-related health disparities[102–107]. On the production side, US agriculture employs less than 1% of the population, 75% of whom are Latino despite making up less than one fifth of the US population[108–110]. Farmworkers face substantially higher poverty rates, food insecurity and poorer health outcomes, compounded by social and legal barriers to accessing health and other public services, occupational health hazards, low wages and poor job quality, including forced labour[101,110–114]. A recent report on the *True Cost of Food* estimates that the US food system's human health and environmental externalities (impacts on external actors from the food system that are not incorporated into the cost) are as much as $2.1 trillion[115]. These consequences are borne in part by farmworkers through, for example, extremely low wages and lack of access to health care and other social services, and by child and forced labourers, as well as in the form of environmental consequences such as pollution and soil degradation[114–116]. On a systems level, the current food supply in the United States is not aligned with its dietary guidelines, yet if all Americans met those guidelines, the increase in fruit and vegetable consumption would increase GHG emissions and probably increase the reliance on unfair labour practices that are prevalent in these value chains[101,114,117–120]. Despite having had an extended food system transition for more than a century (compared with ~15–35 years in African countries and ~25–50 years in Southeast Asian countries), policymakers have not made explicit policies that prioritize positive health or environmental outcomes, nor have they dealt with the apparent trade-offs or addressed systemic inequities in US food systems[101,121].

Discussion

The pursuit of sufficient calories for billions of people at an affordable cost has largely been successful[5]. As countries have become more prosperous, they have increased agricultural production efficiencies, consolidated production processes, reduced transaction costs, increased value added to agricultural products, increasingly participated in trade and a globalized economy, and effectively moved large agricultural populations to better jobs in other sectors and cities[122]. Additionally, many people have been able to afford higher-quality diets[13]. However, these patterns of transition have come with substantial costs, trade-offs and compromises. The vast majority of people living in rural and traditional countries, and over three billion people globally, cannot afford a nutritious diet[13]. Moreover, affordability has not always translated to accessibility or actual consumption of a healthy diet. Hunger and poverty are on the rise, and obesity and diet-related diseases are rising as well[15,123]. Inequality is still rampant and unattended[124]. Environmental degradation has increased beyond safe limits by many metrics, and climate change is leading us towards a major catastrophe[7,125,126]. These are the current and potential future failures of food system transitions.

The reality of current food system transitions across the typology is far from a sustainable food system transformation. Such a transformation towards sustainable food systems will require addressing these challenges directly and setting a global agenda with equity, nutrition and the environment at its core[127,128]. In many cases, this agenda will challenge historical trends and processes that have led us to where we are today. The future will not look like the past and indeed cannot look like the past if we are to achieve sustainable food system transformation. Latecomers to the process of structural transformation face a very different world and a much more challenging economic context. The very process of food system transitions incurred by countries further along with structural transformation and the negative environmental and nutritional outcomes they engendered has changed the parameters of success for future transitions. This, coupled with variation in performance across countries within the five categories of the typology, suggests that we will see unique and heterogeneous patterns of food system transition.

This paper highlights general trends in food system transitions. However, the country outliers within every metric suggest that there are salient cases of best performance at each stage of transition and that policymakers at the country level make choices that matter. Across the six case studies, effective policies include reliable and well-targeted safety nets, school feeding programmes, equitable distribution of land with appropriate environmental management and tenure policies, and creating employment that provides increasing incomes relative to food prices to achieve affordable, nutritious diets. Reducing the consumption of unhealthy diets, increasing access to health systems and incentivizing sustainable production practices are key to meeting both the health and environmental objectives of food systems. More in-depth country-level case studies are needed to identify the range of effective solutions necessary to move food systems towards achieving equity, health and environmental objectives, as well as identify the political economy tensions that hinder progress towards sustainable food system transformation. This study also calls for learning from examples, identifying best practices and benchmarking transition processes to develop targets for improvement. Additionally, it is important to examine how the drivers of food system transitions change and interact over time, comparing these relationships within countries and between countries, as they may inform how food system shifts occur in the future. Creating more sustainable transition roadmaps will require a robust approach based on multidisciplinary science and the involvement of a broad range of stakeholders with different views and values.

Methods

Data. The datasets used in these analyses were mainly publicly available and are summarized in Supplementary Table 1. The data on the CoRD were obtained from the 2020 and 2021 publications of the *State of Food Security and Nutrition in the World* report published by the Food and Agriculture Organization of the United Nations (FAO) as well as the background technical report by Herforth et al.[11,13,15]. The data on food prices were gathered from the World Bank's International Comparison Program, and the data on GDP and international poverty lines were also obtained from the World Bank[129,130]. The food price indices are standardized measures of prices that can be compared across time and countries with different currencies.

The affordability of a healthy diet was obtained from the 2020 *State of Food Security and Nutrition in the World* report, published jointly by multiple United Nations agencies and calculated by Herforth et al.[11,13]. The healthy reference diet is defined by local food-based dietary guidelines in each country. Food-based dietary guidelines are produced by countries' national agencies, sometimes in collaboration with international expert agencies (such as the United Nations World Health Organization and FAO), and describe a culturally appropriate healthy dietary pattern to guide consumers and institutions in their dietary choices and meal planning. The cost of this diet (measured around the world as the CoRD using local dietary guidelines, food items and prices) can be compared to incomes to measure the affordability of the diet that meets dietary guidelines in each time and place[11]. To assess affordability, the CoRD is constructed by the median cost of the healthy diet compared to median incomes under the assumption that 63% of income is spent on food[11,13].

The domestic supply of nutritious foods was obtained from FAOSTAT[131]. Supply includes domestic production and imports minus exports and any changes in stocks. The following item codes from FAOSTAT correspond to the domestic supply of nutritious foods (element code no. 645): eggs (item code no. 2949), fish/seafood (item code no. 2960), fruits excluding wine (item code no. 2919), meat (item code no. 2943), milk excluding butter (item code no. 2848), pulses (item code no. 2911) and vegetables (item code no. 2918).

The data on labour and land productivity for all countries were obtained from the United States Department of Agriculture[132]. Labour productivity is defined as the total value of crop and animal production using 2004–2006 global average farmgate prices, in US$1,000 purchasing-power-parity dollars divided by the number of agricultural workers who are above 15 years of age. Land productivity is defined as the total value of crop and animal production using 2004–2006 global average farmgate prices, in US$1,000 purchasing-power-parity dollars divided by 1,000 hectares of rainfed-cropland equivalents, which include rainfed cropland, irrigated cropland and pasture and are weighted by relative quality[132].

Share of the workforce in the agri-food system was obtained from the agri-food system working group at FAO. Briefly, these were estimates obtained from the International Labour Organization using ISIC Revision 4 across a range of activities including agriculture production, food processing and service, and the manufacture of non-food agricultural products that were deemed to fall under the definition of agri-food systems[133–135]. These economic activities were pre-determined on the basis of ISIC codes if they fell under agri-food system definitions, which include employment in agriculture, processing, value chain and services, transportation, and retail (authors' calculations). The following three categories are used in Fig. 6 and Supplementary Fig. 8: 'agriculture' employment includes activities related to agriculture, forestry and logging, and fishing; 'food services' refers to any activities related to the manufacture of food products and beverages, as well as food and beverage services; and 'non-food agriculture' refers to the manufacture of tobacco products, textiles, leather, wood (except furniture), paper and related products. The country-level agri-food system employment data, along with the detailed methodology, are part of an FAO working group analyses (R.A. et al., manuscript in preparation).

Of note, the available data on employment in the downstream value chain segments of food systems are not sufficiently disaggregated for the complete enumeration of food system workers outside of agriculture, agri-food manufacturing, and food and beverage services. Since employment and labour statistics are not ideal for the task of food system worker accounting, the estimated number of workers shown here is probably a lower-bound estimate in all food system types. For example, in places where much of the workforce is engaged in agriculture and the informal economy, there is probably some undercounting of farmers and informal food system workers. In other food system types where supermarkets, superstores and other retail venues that sell food products are prevalent, there is probably an undercounting of food system workers in retail settings, as they cannot be disaggregated from other retail workers and are therefore excluded from the numbers. Similarly, where people do multiple jobs (common in agricultural and informal economies as well as in the new 'gig economy' that spans all country income levels), most of the data only capture whatever is considered the primary job, and other jobs are missed from the accounting.

The data on the human development index and urban population ('SP.URB.TOTL.IN.ZS') were obtained from the United Nations Development Programme. The data on the Gini index were obtained from the World Bank Development Research Group (PovcalNet) using the indicator 'SI.POV.GINI'. The data on GDP per capita are also obtained from the World Bank, using the indicator 'NY.GDP.PCAP.CD', which reports in current US dollars. Information on population density across the rural–urban continuum was obtained from the supplementary dataset provided by Cattaneo et al.[136]. The data on mean farm sizes across all commodities were obtained from Herrero et al.[137] and are available upon request for research purposes.

The percentage of deaths attributed to dietary risk factors for each country were obtained from the Global Burden of Disease[86]. Food systems emissions by country over time were obtained from the FOOD-EDGAR model[72]. Emission intensities per kilogram of meat (kg CO_2e per kg) were extracted from FAOSTAT. For ruminant meat, the mean of emission intensity from cattle, sheep, goat and buffalo was calculated, and for monogastric meat, the mean of emission intensity from chicken and pig was calculated. The ecological footprint of food consumption was obtained from the JHU/GAIN food system dashboard, which was originally sourced from *Bending the Curve* by the World Wildlife Foundation[88]. The 'ecological footprint of food consumption' is a misnomer because it is based on the domestic food supply for each country and not based on actual food consumption patterns, since domestic supply does not equate to consumption. The footprint is a product of domestic supply and a global average environmental impact for each food product estimated from Poore and Nemecek[138]. Supplementary Fig. 10c–e illustrates the data with and without the top 10% of the outliers.

Food system typology. The goal of the typology is to describe the complexity of the food systems parsimoniously. The development of the food system typology was rooted in two global consensus-building processes and peer-review reports, which include the 2015 Global Nutrition Report and the 2017 High Level Panel Experts report on food systems[1,139]. Briefly, these reports identified a need to characterize food systems through a variety of evidence-based indicators associated with drivers of food systems. More recently, Marshall et al.[10] classified the food system typology using a simple quantitative method that ranked and scored countries using four chosen indicators: the share of dietary energy from staples, the percentage of the population residing in urban areas, the supermarket density per 1,000 people and the agricultural value added per worker. Stylized descriptions were also prepared for each of the food system types, on the basis of published literature describing food system transitions as well as comparisons of specific variables across the food system types[4,10]. The styled descriptions do not capture the dynamic and evolving nature of food systems. As mentioned earlier, there is no linear progression through time for food system transitions; some countries through war and conflict go back and forth in their food system transitions[84]. It is well recognized that food systems can be characterized across a continuum; thus, a limitation of the food system typology at the national level is that it does not capture heterogeneity within countries[1]. For example, within a country such as India, there might be multiple food system typologies for different regions.

Analysis methods. We merged the data obtained above with the food system typology using three-digit country codes. Exploratory analysis examining these trends across the food system typology was conducted in R4.1.2. We used box plots to illustrate the median as a central measure for indicators in each typology, as it may be less affected by outliers than the mean (especially in the case of India and China, where many of the indicators are driven by population size).

We selected the country case studies purposively on the basis of two criteria. First, we examined which countries were outliers across multiple metrics within a given message. Second, we selected a spread of outlier cases across all three messages that would include at least one country case example from each of the five food system types.

Data availability

Most of the compiled datasets used in these analyses are available publicly, such as from the FAO or World Bank. Please see Supplementary Table 1 for the exact sources. The datasets on farm sizes and employment in the agri-food system are available upon request for research purposes. Estimates on employment in the agri-food system will be available upon request for research purposes.

Code availability

The code to reproduce the analysis and figures is available from the corresponding authors on reasonable request.

Received: 17 December 2021; Accepted: 11 August 2022;
Published online: 19 September 2022

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Acknowledgements

We thank the following colleagues for their contributions to the paper and its evolution: FAO collaborators on the agri-food system employment team, especially E. Mane, R. Rivera, G. Caivano, Y. Gurbuzer, M. Benali, N. Chaudhary, N. Piedrahita and P. Conforti. We thank K. Waha and J. Palmer of CSIRO, who helped with the farm size datasets, and Q. Marshall and the Food Systems Dashboard team, who developed the typology and gave us the classification dataset. We also thank the Food Systems Economic Commission and the EAT foundation for their support. This work has been supported by the Food System Economics Commission, funded by the Wellcome Trust, grant agreement no. 221362/Z/20/Z R.A., K.R.S. and J.C.F. live in the United States of America and acknowledge that the country is built on stolen land from Indigenous Peoples and Communities and stolen labour from Black Americans, and neither of these groups have been compensated for these historic and ongoing injustices.

Author contributions

All authors conceptualized the study. R.A. did the analyses and drafted the methods. K.R.S. outlined the three main messages. J.C.F. drafted the introduction and the conclusion. K.R.S. and R.A. drafted message 1. K.R.S., B.D. and P.W. drafted message 2. R.A. and M.H. drafted message 3. All authors contributed to the interpretation of the results and to manuscript development.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43016-022-00588-7.

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Peer review information *Nature Food* thanks Barry Popkin, Peter Timmer, Robel Alemu and Monika Zurek for their contribution to the peer review of this work.

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