THE CASE FOR INCREASED INVESTMENT IN FOOD SYSTEMS INFRASTRUCTURE IN LOW- AND MIDDLE-INCOME COUNTRIES

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ABOUT GAIN

The Global Alliance for Improved Nutrition (GAIN) is a Swiss-based foundation launched at the UN in 2002 to tackle the human suffering caused by malnutrition. Working with governments, businesses and civil society, we aim to transform food systems so that they deliver more nutritious food for all people, especially the most vulnerable.

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SUMMARY

This paper discusses the critical importance of expanding 'food systems infrastructure' as a necessary pre-condition for improving access to healthy and sustainable diets in low- and middle-income countries. It proposes a tractable definition of food systems infrastructure, highlights deficits that have yet to be addressed, and lays out a generic way forward to accelerate infrastructure accumulation.

Illustrations of infrastructure needs are provided for three categories of healthy food: fruits and vegetables, animal-source foods, and grains and pulses. In each case, production, distribution, and sales could all be expanded and facilitated if greater investments were made in developing the relevant infrastructure. This is likely to include both elements of infrastructure that are *not* specific to food, such as roads and digital infrastructure, as well as elements that *are* specific to food, such as refrigerated warehouses, markets, and on-farm irrigation. The absolute magnitude of the current infrastructure gaps is shown to be very large, especially in Africa south of the Sahara. Costs of developing this infrastructure are correspondingly substantial.

Efforts to transform food systems must consider infrastructure needs. Ideally, efforts to plan Food Systems Transformation Pathways should commission food systems infrastructure audits and prioritise the most important investments. Development finance institutions have a key role to play in mobilising the needed finance, as do stock exchanges in countries where these are operational.

KEY MESSAGES

- Infrastructure accumulation drives economic growth and reduces poverty; it is a pre-condition for increasing access to healthy diets from sustainable production.
- There are infrastructure needs across value chains, from production through to the final consumption in the home. These needs include both non-specific *and* food-systems specific elements.
- Current infrastructure gaps are very large. For example, only one of sub-Saharan Africa's 20 largest cities (outside the Republic of South Africa) has a modern wholesale market.
- For many low-/middle-income countries, an infrastructure investment bundle worth $300-400m could make a significant contribution to foods systems transformation if needs are carefully audited and prioritised.
- Development finance institutions and commercial stock exchanges can help mobilise the needed capital.

BACKGROUND AND OBJECTIVE

Infrastructure is perhaps the defining feature of modern living; we continuously enjoy the benefits of running water, electric power, buildings to work in, and roads, railways, ports, and airports to speed us from one place to another. Development economists have devoted decades to the exploration of the associations between stocks (or flows) of infrastructure and subsequent economic growth (for example, (1)) and have generally found substantial impacts on growth and poverty reduction. However, although food supply for most of the world's population rather obviously depends on the presence of adequate infrastructure—not least, because food production and consumption frequently are concentrated in different places, creating the need for a large food transportation industry—studies linking stocks or flows of infrastructure to dietary quality or nutritional status outcomes are limited and focus mostly on the urban built environment (e.g., (2)) rather than the full supply chain. This is in spite of the fact that that, for rural households at least, 'market access' (which is presumably heavily shaped by the presence of road and market infrastructure) tends to be positively associated with household dietary diversity (3).

This paper argues that modern infrastructure is needed throughout the food system in order to achieve the desired outcome of healthy diets for all including the most vulnerable. It is also needed for *sustainable* food production, mitigating climate change impacts and/or adapting to the challenges that climate change brings. These two considerations mean that infrastructure improvement is essential to achieve our mission at the Global Alliance for Improved Nutrition. Infrastructure investments need to start on the farm (mostly notably, irrigation and post-harvest storage facilities) and continue through into the consumer's home, where access to safe water and energy are essential inputs to household food and nutrition security. This paper argues that current stocks of 'food systems infrastructure' are grossly inadequate in most low- and medium-income countries and proposes that country-level audits of essential infrastructure need to be compiled across nutritious food value chains, with development finance mobilised to meet the gaps.

CRITICAL ISSUES

The nature of 'food systems infrastructure'

Infrastructure has been defined as 'the physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions' (7). The term appears frequently in the High-Level Panel of Experts report on *Nutrition and Food Systems* (8). In that report, 'innovation, technology and infrastructure' is considered one of the most important 'drivers' of food system changes, directly influencing both 'food supply chains' and the 'food environment'; these, in turn, influence consumer behaviour and hence diets. In the detailed commentary provided in the body of the report, particular emphasis is given to transportation infrastructure.

Some commentators distinguish between 'hard infrastructure' (physical networks) and 'soft infrastructure' (institutions). While not in any way wishing to minimise the importance of institutions, this paper focuses on 'hard infrastructure' as a clearly measurable output of public and private investment. Commonly referenced types of hard infrastructure include energy infrastructure, transportation infrastructure, water infrastructure, telecommunications, and waste management infrastructure, among others.

Within each of these categories, there are many elements (roads, power networks, mobile phone connectivity, etc.) that benefit multiple sectors and are not specific to the food system. While it is easy to see why a lack of road infrastructure, for example, could limit the availability and affordability of nutritious foods, these types of infrastructure are expected to be high-salience national development priorities and do not generally require additional arguments to justify investment. The same is likely true for '21st century infrastructure' supporting digital value chains, for which there is strong end-user demand and a viable commercial business model. On the other hand, there are additional infrastructure elements that exclusively serve the purpose of producing and marketing food. These include grain silos, abattoirs (slaughterhouses), and produce markets, among others. The nature and relevance of these elements is best understood by unpacking the supply chains of specific groups of nutritious foods. It is critically important to focus on the *entire* value chain (and not agriculture alone), including inputs, farming, aggregation, processing, and marketing. For example, China's agricultural development strategy, and consequently its success, was centred on three key pillars: land, roads, and aggregation warehouses, which served as the foundation for the entire value chain (9). Box 1 offers an example of the impacts of critical food system infrastructure failure.

BOX 1. WHAT HAPPENS WHEN CRITICAL FOOD SYSTEM INFRASTRUCTURE FAILS?

A dramatic illustration of the critical importance of food systems infrastructure came to the world's attention on August 4th, 2020, when a massive explosion destroyed the port of Beirut, its grain silos, and large sections of the surrounding neighbourhoods. In a net food importing country, the explosion destroyed 15,000 MT of grains and left the country with less than one month of grain reserves (4). Economic output immediately fell across Lebanon, but particularly sharply in Beirut (5). National food price inflation continued an upward trajectory prompted by the Covid-19 pandemic and reached nearly 200% by October of the same year (https://microdata.worldbank.org/index.php/catalog/4497). A survey of households in Beirut province conducted between December 2020 and March 2021 found that three quarters of households were experiencing severe food insecurity (6). Although the port explosion was only one of many crises affecting Lebanon in recent years, it dramatically exposed the vulnerability of the country's agriculture and food distribution to a sparse, decaying, and poorly managed network of transportation infrastructure.

In the following sections, we focus on nutritious foods contributing to a healthy diet, as laid out in (10). Specifically, we focus on foods inherently high in nutrient value (fruits and vegetables, animal source foods) and on fortified foods of enhanced nutritional value.

Fruit and vegetables

A stylised supply chain for fruits and vegetables indicating major infrastructure needs is shown in **Figure 1**.

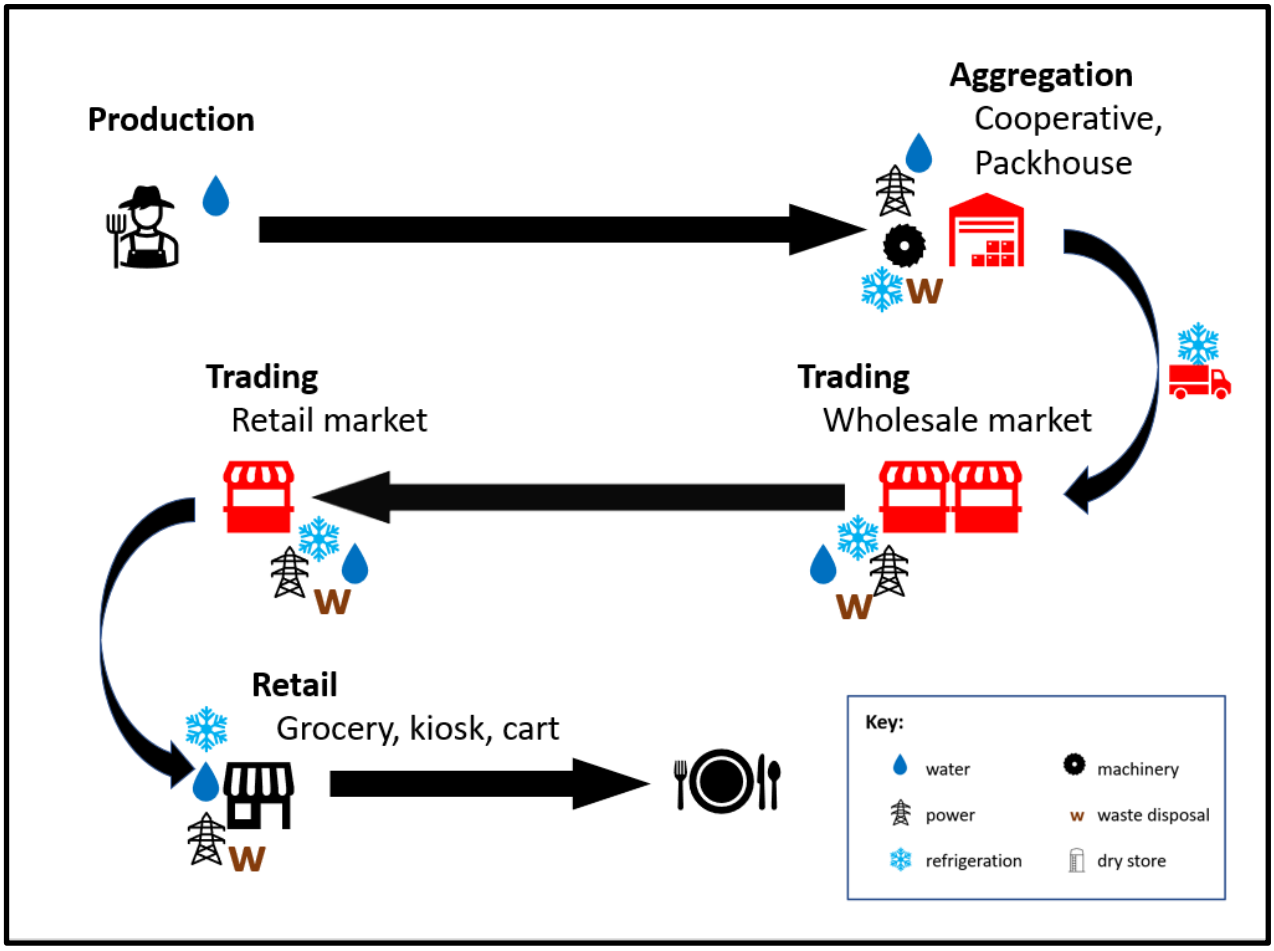

Figure 1: Stylised supply chain for fruits and vegetables.

Although some fruits, such as bananas and mangos, are rain-fed, other fruits and most vegetables require significant inputs of water and can only be produced at scale on irrigated farms. The largest such farms are likely to benefit from investing in on-farm cold storage, as this reduces post-harvest loss prior to transport to market (11). All subsequent stages of the value chain require product protection (e.g., crating and off-ground stacking areas) and cold storage, with long-distance transport best accomplished in refrigerated trucks. Inadequate handling along the supply chain results in losses from post-harvest to distribution, averaging 22% of physical quantity (12), with consequent gaps in availability and increases in cost. Efficient operations

involve local producers bringing their produce to a central point (a 'packhouse') where it is aggregated, cleaned, sorted, and graded. Some produce may be cut, pulped, or dried and then packaged. In most low- and middle-income countries, the vast majority of fruit and vegetables are traded in retail markets (13), which require appropriate storage and waste-disposal facilities; failure to upcycle compostable waste from markets leads has significant environmental, health, and economic costs. Large urban centres with many retail markets benefit greatly from having a wholesale market that consolidates different supply routes and avoids excessive congestion on inner-city roads, as well as promoting price transparency and standardisation of quality (14). Laboratory capacity is required to ensure quality control and food safety standards at all points along the supply chain, and mobile networks facilitate the exchange of up-to-date market information.

Animal-source foods

A stylised supply chain for fish indicating major infrastructure needs is shown as **Figure 2**. Wild fish is best aggregated at landing sites along the coast (or lake/river shore), where processing such as cleaning, fileting, freezing, drying, and packaging can be undertaken. These steps require dedicated buildings, with power, water supply, refrigeration, and appropriate waste-disposal facilities. In low- and lower-middle income settings, fish is usually sold either in markets (where dried fish is especially common) or in specialist stores or supermarkets that require freezer capacity. Moving fish nearly always requires refrigerated transport; this is only not needed if the fish has been carefully dried and packaged.

Other animal-source foods have different requirements. Meat supply chains (including poultry) require abattoirs for the safe and humane slaughter of the animals. Cutting of meat (butchery) may be done at the abattoir or at a subsequent stage in the supply chain. Dairy supply chains require milk collection centres close to the foci of production, and dairy processing is both power- and water-intensive. Both meat and dairy supply chains require laboratory capacity for quality control and food safety safeguarding, and, as for fish, most transport must be refrigerated. Biowaste, especially from meat processing, constitutes a very significant risk to human health and requires advanced infrastructure to manage safely (see, for example, (15)).

Egg production requires less infrastructure for distribution as fresh eggs do not require refrigeration. However, even medium-scale egg production requires power to keep the chickens cool, plus water and appropriate accommodation for the birds. Many lower-income countries do not have the necessary inputs for egg production, so eggs and/or chicks must be imported from abroad. Young chicks are highly vulnerable and require dedicated services throughout transportation and during border control procedures to avoid mortality.

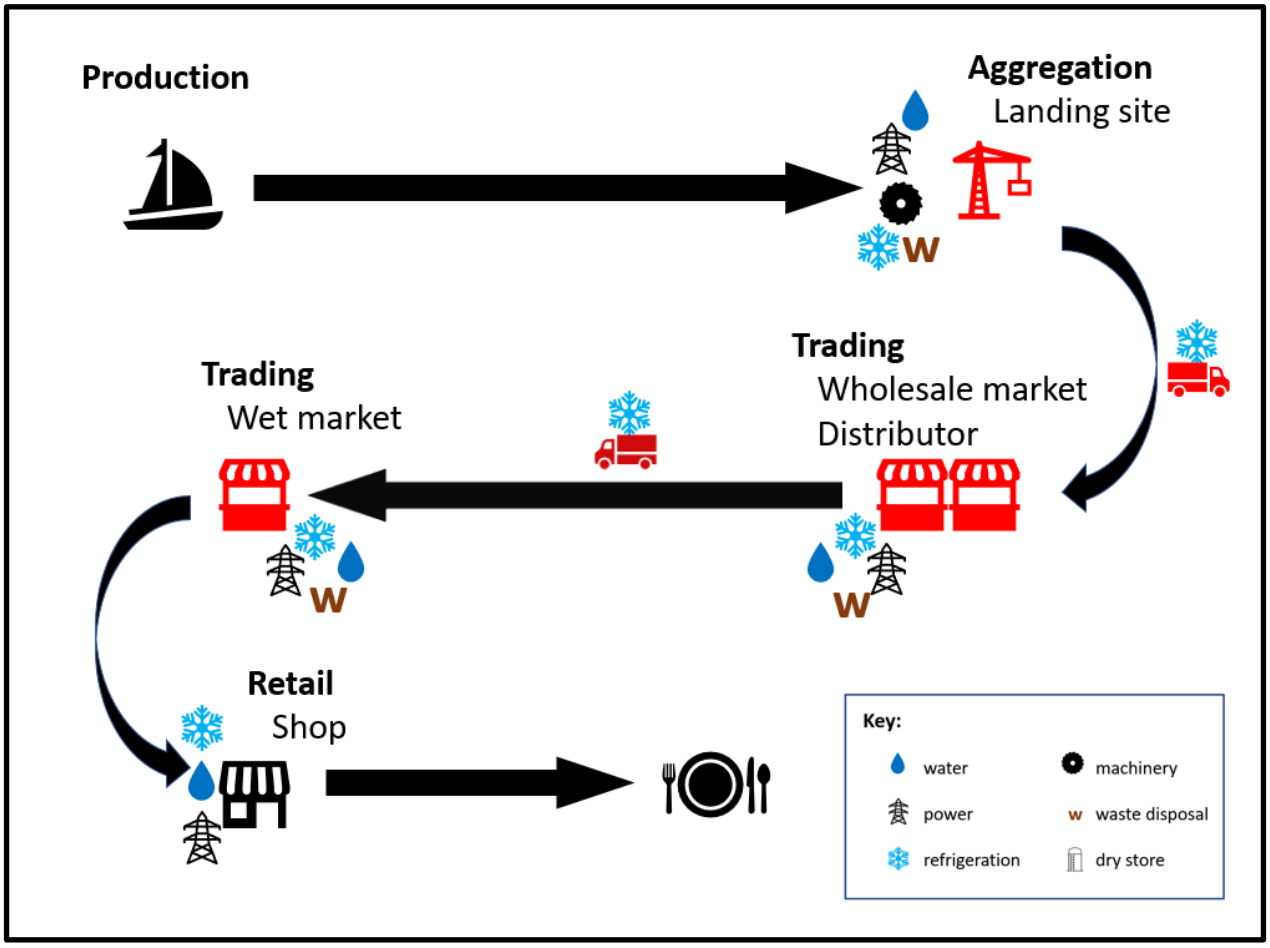

Figure 2: Stylised supply chain for fish.

Grains, pulses, seeds, and nuts

Grains, pulses, seeds, and nuts are generally traded dry. A stylised supply chain indicating major infrastructure needs is shown as **Figure 3**. Because grains and pulses are staple foods, the quantities traded are enormous, and extensive infrastructure (e.g., silos, grain stores) is needed along the supply chain to control humidity and vermin. Failure to ensure appropriate storage can lead to hazards such as aflatoxin contamination, which can be near universal in some settings. It is estimated that up to just under 10% of production is lost post-harvest through distribution (12).

A number of important grains (wheat, maize, etc.) are milled before final sale to the consumer. The flour milling industry in Africa has experienced significant growth over the past few decades. Flour milling companies require reliable transport, energy, water, and telecommunications infrastructure to support their operations. For instance, Dangote Flour Mills in Nigeria benefits from its proximity to a major expressway, while Premier Flour Mills has invested in its own gas pipeline, and Seaboard West Africa Limited flour mill in Senegal is located near a fibre optic cable, providing high-speed internet connectivity for its operations. Tatu City Industrial Park in Kenya offers shared waste management services to the flour milling companies located in the park. For rural areas with weak infrastructure, unreliable electricity and

low consumer demand, innovations in solar technology and modular mills show promise. They are powered by solar panels and designed to be portable, with capacities of up to 90 kg per hour (16). Another innovative solution, called a mobile mill, micro-mill, or 'mill-in-a-box', is designed to be energy efficient and can be powered by electricity or solar energy. These mills use shipping containers to house the bulk of the structure and can process up to 2 tons per hour; they use 20-30% less energy compared to traditional mills and include all the necessary equipment for processing grains, including cleaning, grinding, and packaging.

Milling provides an opportunity to add additional minerals and vitamins, enhancing nutritional value at minimal marginal cost (17). For this to happen, millers need to be equipped with the necessary dosifiers (which release appropriate amounts of vitamins and minerals into the flour) and mixers. Extensive laboratory capacity is required to ensure the safety of grains and pulses and, where mandatory, to monitor compliance with fortification.

Oil grains follow a similar process.

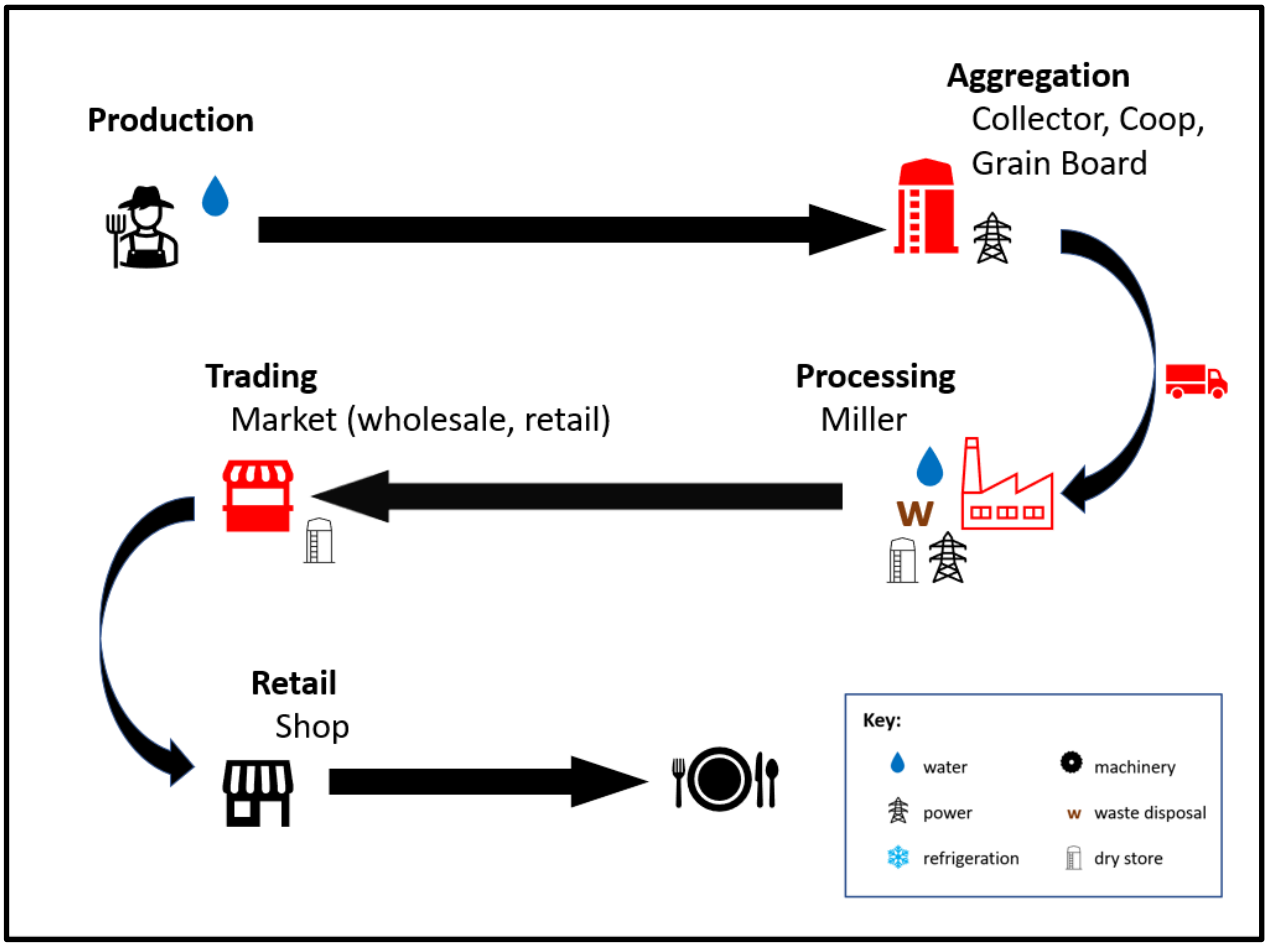

Figure 3: Stylised supply chain for grains and pulses.

CURRENT GAPS IN FOODS SYSTEMS INFRASTRUCTURE IN LOWER-INCOME COUNTRIES

The Economist Intelligence Unit includes a measure of agricultural infrastructure as part of its Food Security Index database. The Agricultural Infrastructure Index is available through the Food Systems Dashboard (www.foodsystemsdashboard.org), with the latest data mapped in **Figure 4**. As expected, the highest levels are seen in North America, Europe, East Asia, parts of the Middle East, and Australasia. Lower-income countries generally show considerably lower values, with especially low values in Niger (Africa), Nicaragua (Central America), and Laos (Asia); these countries have index values of just 22-29, compared to 100 in countries such as Canada, France, and Austria.

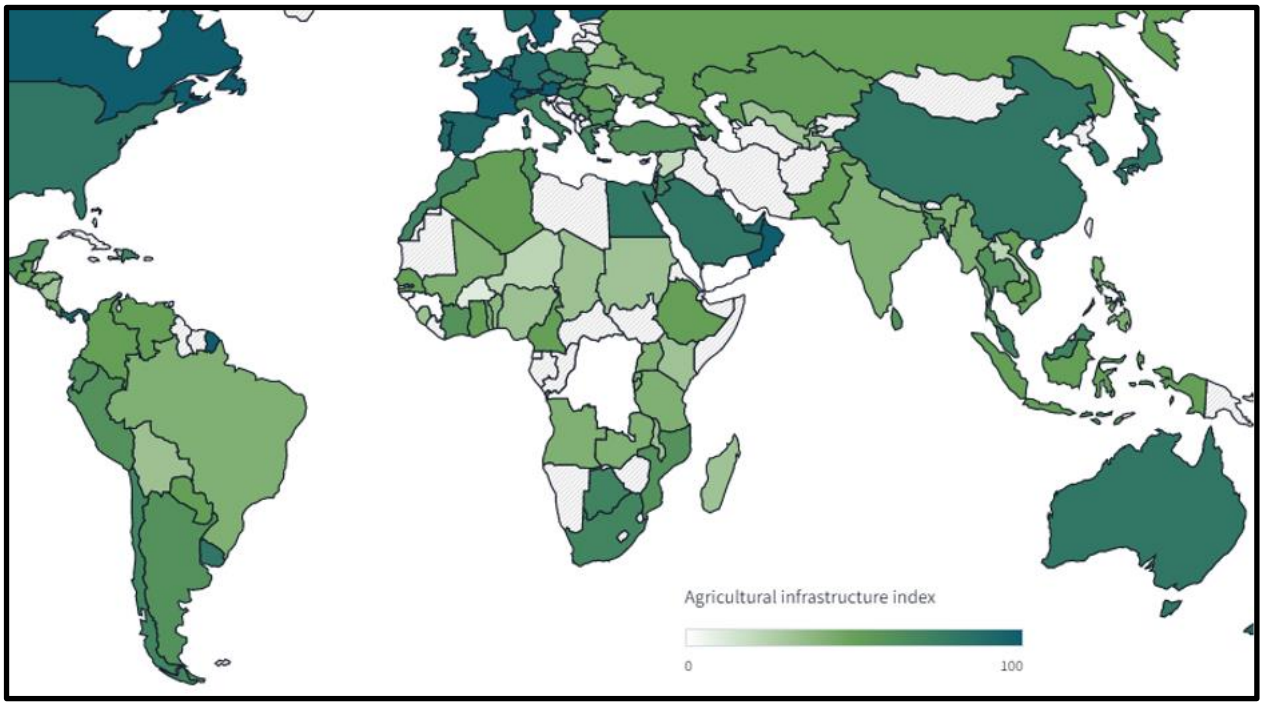

Figure 4: Map of countries showing their levels on the Agricultural Infrastructure Index. (Reproduced from www.foodsystemsdashboard.org, permission not required).

As mentioned previously, there are key components of national infrastructure that are not specific to food but greatly impact food systems outcomes. Mobile telephony has expanded all around the world and is well tracked. 84% of the adult population of sub-Saharan Africa now live in areas covered by mobile broadband networks, though actual connection rates are less than half that level (18). Surprisingly, access to road infrastructure has been harder to assess, due to differences in national definitions of an 'all-season' road and sparse reporting. Nonetheless, it is clear that Africa is lagging far behind other regions of the world: while 99.5% of the rural population of the United Arab Emirates live within 2km of an all-season road, this falls to 54% in Nepal and 11% in Madagascar (https://datacatalog.worldbank.org/search/dataset/0038250). And those roads that do exist are not necessarily optimally located to facilitate movement of goods: Graff (19) has shown that significant welfare gains could be made from

reorganising road systems on the African continent. Meanwhile, 733m of the world's population live without access to electricity, of whom 568m are in sub-Saharan Africa (20).

Africa is similarly disadvantaged when it comes to irrigation, the single most important infrastructure investment for extending growing seasons and increasing crop diversity. Currently, only 6% of cultivated land in Africa is irrigated, and two thirds of this is concentrated in just five countries (21). This compares to 37% in Asia. South of the Sahara, it is estimated that the potential exists to increase irrigation fivefold.

Quantifying gaps in less generic elements of food systems infrastructure is challenging due to incomplete data. The following paragraphs provide 'guestimates' for three illustrative elements along the supply chain: milk collection centres; village mills with capacity to fortify, and wholesale markets.

Cold storage is an essential element of a modern dairy industry. Without it, there are high levels of spoilage (ultimately increasing consumer prices), seasonal supply spikes cannot be accommodated, and food safety is jeopardised. India provides a good benchmark for cold storage capacity in the dairy industry as dairy production in that country is organised into cooperatives and the National Dairy Development Board (NDDB) collects statistics on cold storage capacity. As of March 2021, the NDDB was reporting dairy plant cooling capacity of 89M L/d across the country (22). With an estimated 193M head of cattle in India (https://www.fao.org/faostat/en/#data), this means that there is enough cooling capacity to process ~0.5L/d/cow of milk (~2.4 L/d/cow if the denominator is restricted to female cows actively producing milk). If the same ratio were applied to sub-Saharan Africa, this region would need ~150M L/d of dairy plant capacity, yet many countries in the region have virtually no organised dairy sector. Kenya does have an organised dairy sector, with a milk collection centre capacity of 475 M L/y (23), but, by the same logic, it needs eight times more capacity than that. Such expansion is greatly limited by the penetration of electricity supply in rural areas and the challenges of creating a business model for safer milk.

Nearly 700 million Africans live in rural areas, and almost all consume a diet rich in grains (including maize, millets and sorghums, and teff, among others). Many take whole grains to a local commercial hammer mill, which is usually diesel powered and virtually never has capacity to fortify. Ideally, every village should have a modern, solar-powered mill fitted with a dosifier to mix vitamins and minerals into the flour. In fact, at a moderate efficiency of 60 kg/hour and assuming no more than six hours of operation per day and an average daily flour consumption of 450 g per person, the average village would require two such mills, for a total addressable market size of 800,000 mills (there are estimated to be ~400,000 villages in Africa).

Progress has been slow in setting up wholesale markets for nutritious foods. As noted by Tollens over 25 years ago, 'most major African cities lack specialised and efficient wholesale markets, even though their function is a critical factor in the effectiveness of any food marketing system' (14). Considering the 20 largest cities in sub-Saharan Africa (not including the Republic of South Africa), all of which now house more than 3 million inhabitants, there is little evidence that this situation has changed. Even

though some wholesale markets were established in colonial times, these have largely evolved into retail markets (e.g., Owino Market, Kampala) and/or collapsed or burned down (e.g., Kariakoo Market, Dar es Salaam). Some large markets combine retail and wholesale functions, frequently dividing the functions according to the time of the day, which fails to extract the full benefits of a modern wholesale market. Probably the most ambitious wholesale market project yet in sub-Saharan Africa outside South Africa is the *Centro de Logística e Distribuição* (CLOD) in Luanda, which began construction in 2009 and is intended to cover up to 400 ha with structures including a fruit and vegetable market, a meat market, a fish market, a meat cold store, a fish cold store, and an ice factory. However, the project is clearly not fully functional today (**Figure 5**). In Dakar, the Chamber of Commerce launched in 2022 a *Marché d'Intérêt National* in the port area of Diamniadio, ~170 km from the capital itself. This market covers 24 ha and includes shops, cold rooms, storage and packaging zones, specialist shops for poultry and for dairy products, and a phytosanitary laboratory. A transport hub has been constructed adjacent to the market. Abidjan, Douala, and Kinshasa have all announced the intention to construct modern hybrid (wholesale-retail) markets, but construction does not seem to be advanced.

Figure 5: Satellite image of the area intended for the Luanda wholesale market (CLOD), 2023. (Reproduced from Google Maps, permission not required).

ESTIMATED COSTS

The Ceres2030 report on Sustainable Solutions to Hunger estimates that the total cost of eliminating hunger would be $33bn/year (24). This number does not consider other important food systems objectives such as achieving a safe and healthy diet or minimising environmental impacts, so it must be taken as a bare minimum level of investment. Nonetheless, the requirement is very significant, reflecting the high costs of building infrastructure. If a country were to commit to spending 1% of this amount ($330m), what might it be able to buy? Using unit costs typical for Africa, an illustrative bundle might consist of:

- 4000 ha of irrigation (new construction);
- Rehabilitation of 800 km of paved roads;
- Four value chain-specific projects, such as one medium-sized dairy processing plant or 4000 solar-powered mills; and
- One new wholesale market and the rehabilitation of ten traditional retail markets.

Clearly such a bundle would not resolve the infrastructure deficit of any but the smallest countries in Africa, but, if planned well, it could make a significant contribution to enhancing food and nutrition security of the most vulnerable groups.

CONCLUSIONS

This paper has shown that in order to deliver healthy and sustainable diets for all, including the most vulnerable, food systems require the backbone of a dense and robust network of hard infrastructure. This infrastructure includes elements that are not specific to food—such as roads, energy, and communications infrastructure—as well as other elements that *are* specific to food and may differ greatly depending on the particular value chain being considered. The two sets of needs are not independent of each other: a modern dairy industry, for example, requires cooling plants close to the areas of production, but these are impossible to set up in the absence of rural electricity provision. Similarly, cold transport facilitates the movement of perishable produce, but is of little use in the absence of roads. Investing in both types of infrastructure is a recommendation that is consistent with, but goes further than, the Ceres2030 report on Sustainable Solutions to Hunger (24); that report singles out irrigation (recommendation 7), roads, and storage infrastructure (recommendation 10) for the purposes of modelling the cost of transforming food systems.

Infrastructure deficits beset all low- and middle-income countries but are clearly far more acute in sub-Saharan Africa than in other regions of the world. While a few innovations, such as digital finance, have scaled up quickly in Africa, there remain many key elements of food systems agriculture—including irrigation, cold storage, and wholesale markets—that are almost entirely absent in large sections of the continent. These deficits set the stage for extensive post-harvest loss, interruptions in supply, biohazards, and unnecessary costs to the consumer. Failure to invest in food systems infrastructure also misses an opportunity to boost the incomes of smallholder farmers and other poor households, a key step to reducing food and nutrition insecurity. The

loss of health and economic well-being resulting from insufficient investment in food systems infrastructure should be—but isn't—the cause of widespread outrage. Rarely do events as egregious as the 2020 port explosion in Beirut ignite popular fury and draw international condemnation.

Resolving these challenges will require a concerted effort to analyse current challenges, prioritise the most important needs, and mobilise the needed resources. This could follow a three-phased approach:

Firstly, countries need to undertake a comprehensive **audit** of their food system infrastructure. Currently, information is scattered in grey literature that focuses on single value chains and does not attempt a holistic review of what is required to provide access to a healthy and sustainable diet, including for the most vulnerable.

Secondly, this baseline needs converting to a mapping of gaps, and the most pressing needs should be prioritised as part of national consultations on **Food Systems Transformation Pathways**, a key policy process emerging from the UN Food Systems Summit of 2021. Pathways that do not consider infrastructure needs cannot possibly deliver more and better food. The Pathways planning process provides an opportunity to view infrastructure within the context of the broader enabling environment: building wholesale markets, for example, implies a commitment to the formalisation of wholesale trade in food, which necessarily involves a range of other fiscal and regulatory reforms. Planning and coordinating investment across the value chain offers the best chance of realising benefits for the end consumer. Some infrastructure projects transcend national boundaries, and these will need to be championed by regional bodies.

Finally, **funds** need to be mobilised to pay for these infrastructure developments. Because of the high unit costs of infrastructure projects, international development finance institutions (DFIs) are best placed to both support the planning process and to provide access to affordable capital. Food systems advocates need to press DFIs to develop lending portfolios that prioritise food systems infrastructure. Stock exchanges—where operational—can also provide platforms to raise capital for infrastructure investments. The rapidly growing asset class, green bonds—fixed-income securities that are issued to finance projects that have positive environmental or climate benefits—can finance renewable energy systems or in regenerative agriculture. These investments have not only economic benefits but also large social and environmental benefits. Improving access to credit will encourage private investment in smaller value-chain specific projects.

Infrastructure takes years, if not decades, to build up. It may even be too late to save the food-related Sustainable Development Goals, which should be achieved by 2030. It is time to invest now to ensure that countries that became independent in the 1950s and 1960s are not still lacking in critical food systems infrastructure a hundred years later.

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