The Importance of a Food Systems Approach to Low and Middle Income Countries and Emerging Economies: A Review of Theories and Its Relevance for Disease Control and Malnutrition

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Our review explores the changing food production, distribution and consumption environment in low and middle-income countries and emerging economies as a basis for framing how to study food systems in order to address public health issues of food safety and nutrition. It presents the state of knowledge on existing food systems science and its use in terms of sustainable actions for food safety and public health. The review identifies a knowledge gap in food system mapping and governance, with value chain mapping of key commodities often missing. Despite a number of initiatives, the application of food systems methods is highly variable in scope and quality. Most analyses concentrate on specific commodities, rarely taking into account the need for a whole diet approach when looking at nutrition or the assessment of a range of infectious agents and their interactions when looking at food safety. Of the studies included in the review there is a growing observation of "informal" food systems, a term used inconsistently and one that requires revision. "Informal" food systems link to the formal sector to provide food security, yet with trade-offs between economic efficiencies and food safety. Efforts to improve food safety are hampered by inadequate food safety capacities and a lack of policy coherence leading to: inadequate investment; fragmented food quality control systems; weak or non-existent traceability mechanisms; weak foodborne disease surveillance; obsolete food regulation; and weak regulatory enforcement. In-depth food systems assessments can complement risk analysis to identify risky behaviors and understand institutional settings in order to improve codes of practice and enforcement. Methods for looking at food safety from a food systems perspective are emerging, yet existing nutrition and food systems science are not advancing sufficiently in response to nutritional public health problems. There is an urgency for improved understanding of the structure and drivers

of the food systems, for better planning of changes that leads to nutrients access and healthy levels of eating. It is proposed that countries and international institutions provide an atlas of food system maps for the key commodities based on an agreed common methodology and developed by multidisciplinary teams.

INTRODUCTION

Global trends in human health indicate that while health overall is improving through higher levels of health expenditure (Dieleman et al., 2018), increased medical knowledge and better targeting of resources, there are continuing problems of undernutrition, emerging issues of food borne diseases and increasing overweight and obese populations (Walley and Wright, 2010). These trends vary regionally; and although food borne diseases have been well-controlled in many settings, they remain problematic and emerging in some regions (Havelaar et al., 2015). At the same time, food related non-communicable diseases (NCDs) have reached epidemic levels in many urban settings and are affecting health outcomes (Raleigh, 2018; OECD, 2019). The way food systems are currently guided and allowed to evolve across the world contributes significantly to the problems outlined. We argue that current government structures undermine the abilities to guide food systems in achieving the goals of efficient food supply, minimizing public health impacts and managing environmental problems. A food system that simply focuses on the supply of cheap and plentiful food for people and the provision of jobs for workers, may in the short term be politically palatable but it is not sustainable: it can create significant food-borne and food-related epidemics. A new paradigm is required where the food system becomes a core part of our health systems with policies and actions associated with this change.

If we are to respond in a proportionate manner to evolving health risks there is a need to have a better understanding of how our food systems operate and adapt to changing social and economic signals. We simply have to get better at describing and quantifying the food systems we depend on and to understand how these generate impacts on our health. These could be either direct impact, in terms of biological and chemical safety, the quantity and quality of the food that is made available to people or as a source of wealth and livelihood; but also indirectly through the numerous externalities in the environment, political landscape and other areas. This paper will examine the multidimensional nature of food systems, with a particular focus on its core theories and on their application for disease and nutrition control for emerging economies. We recognize the importance of food systems in our environment, but our paper will focus on their impacts on public health. It will illustrate how we have to start with the system itself if we are to better understand health and societal impacts of food. We will argue for moving from food system policies that emphasize efficiency alone to food system policies that emphasize health, because a well-functioning food system is the basis of a healthy population. The review will focus on animal source foods (ASF), which are essential for nutrition and well-being, especially in populations where access to protein is challenging.

VALUE CHAIN FRAMEWORK FOR FOOD SYSTEM ANALYSIS

Food systems are the combination of all activities, including people's interactions and networks that exist in a society for the transformation of primary resources into final goods, and their consumption and disposal thereafter. Within systems theory, a food system can be considered as a complex system (Mesarovic and Takahara, 2009), as each of its components can be classified as a system on its own. A food system study implies assessing the connections and interdependence of people and organizations across the system, to allow to: (1) determine system efficiency, (2) quantify externalities, (3) understand people's behaviors; (4) understand the evolution of food systems, (5) assess the consequence of changes (policy, intervention, or shocks), and (6) identify risk-hotspots and intervention target points. The importance of these objectives are indicated in **Table 1**.

Food systems can be extraordinarily complex, requiring strong multidisciplinary collaboration, an immense amount of data and resources, and a large variety of analytical approaches. In the context of value chain approaches to one health research, Antoine-Moussiaux et al. (2017) indicated the need to recognize and use complexity frameworks, such the one provided by Cilliers et al. (2013). Indeed, the authors argued that complexity is often addressed, unavoidably, in a reductionist manner, by reducing it to a number of essential elements. Yet, decomposing it destroys its system property, and biases the ability to study them. As a consequence, most food system studies focus on a specific commodity (vertical approach); a particular segment of the system, such as producer, markets or consumers (horizontal approach); and using a concrete problem (e.g., specific disease, nutrient, type of environmental impact, etc.). This in itself poses serious limitations, as it restricts the detection of potential negative consequences from recommendations or interventions in the systems.

So, how do we proceed to study the complexity of a food system? How far should we go in this analysis? There is no simple answer for this, but an understanding of the different core food system theories or concepts is fundamental. In economics, there are many areas that focus on the analysis of food systems, from supply chain analysis, market chain analysis, value chain analysis, commodity chain analysis or sustainable supply chain management, amongst others. A key element in the study of food

TABLE 1 | General objectives of food systems studies, and the consequences of meeting or not meeting these objectives.

General objectives of food systems studies	System component to be discussed	Consequences of not addressing the objective	Outcome if addressed appropriately
Determining the efficiency of the system	Adequate use of resources (optimisation); efficiency of the reach of chains to all population groups where there is demand and/or need; Understanding of where and why the inefficiencies occur and their consequences	Overuse of resources; reduction in productoon; increase of wastage (and subsequent environmental concerns) and loss in quality; reduce competitiveness, profitability, and capacity to upgrade; inequality of distribution and food insecurity	Increase production and distribution; better access and affordability of products; increase profitability and capacity to upgrade and control risks; reduction of wastage and contamination
Quantifying externalities	Health, food security and safety, financial, social, and environmental externalities of food systems	Externalities are borne by the wider society and the costs are not internalized by the food system. In the case of public health this can lead to acute food borne disease, transmission of zoonotic pathogen, and poor nutritional outcomes	Government and industry better able to prioritize investment and regulation or policies to minimize negative externalities. Capacity to monitor effectiveness of interventions or policies. Transparency of real cost of production and incentive generation for change
Understanding people's behaviors and purposes	The reasons for the existence of any given food chain and the activities within it. Identify who and why people undertake risky behaviors in the food system	Policies and their implementation to manage risk, food safety or nutrition, have a low probability of success. Public health problems continue and money to manage them is used inefficiently	Better understanding of effectiveness of potential interventions or policies in the food system. Allow to generate changes that increase stakeholders and consumer satisfaction for participating in the chains
Understanding the evolution of the system	Understand past changes and how and why the current system has evolved to its current format. Detect and predict trends, and their potential consequences	Not knowing the factors that have driven past changes will restrict the capacity to generate effective policies or interventions. Risk of generating changes that can threaten existing cultural and societal order. Not able to prevent food system failures, insecurity, risks or health impacts	Better planning and control of food system changes and growth. Allow for the prevention of food system risks, and better preparedness. Ensure future sustainability of the food system
Assessing the consequences of changes	Consequences of shocks (e.g., disease, climate, etc.), interventions, policies or other changes in the system (e.g., changes in technology or people preferences)	Lack of capacity to inform decision on policies or interventions. Lack of preparedness to system shocks, increase system vulnerability and risk of health, financial, livelihood and environmental losses	Better inform decisions on interventions and policies. Better preparedness to system shocks creates a more sustainable food system
Identifying the potential risk-hotspots	Identify actual and potential risk-hotspots, quantify their magnitude and their consequences when removed or controlled	Limited ability to plan and implement mitigation actions that are successful. Public health does not improve with chronic problems and deteriorates with acute ones	Support the identification of suitable target points for interventions to ensure cost-effective use of resources Improved public health outcomes

systems, however, is that this needs to go beyond the knowledge of the flows of commodities and the identification of the type of activities and people. In this section, we argue that value chain analysis provides a powerful framework for the study of food systems. It may be referred to, in simple terms, as the value addition activities of a commodity throughout the supply chain. However, the analysis and implication of 'value generation' provides a large number of connotations that give way for in-depth understanding of the food system. In the first instance, it requires an analysis of the value of a good or commodity to the different people in the system and the reasons for such value. The value should not only be regarded as financial value, despite this being the original intention and the most frequent use of this analysis. It can also consider value in terms of nutritional, social (e.g., religious) or individual welfare, health, quality, or any other characteristic. Many of these values, but not all, will be however reflected in the prices of inputs and goods. Understanding the value of products helps to realize the reasons for these or specific commodity chains to exist. Yet, non-price valuation of commodities is often missing in food system research. Secondly, it determines the capacity of a chain to

satisfy a demand. Chains that are able to generate a product with unique value will be able to gain market access and comparative advantage. Thirdly, to generate and maintain this value, people and organizations require intense coordination of activities, capacity to influence and access a to multitude of factors (capital, infrastructure, adequate policy and social environment, etc.), which may represent a barrier for many stakeholders.

A food system analysis therefore requires an understanding of value generation through food usage (or waste) and the implications of that use. However, it could be argued that the same approach is valid for any type of system (such as cars, phones, university degrees, etc.). So, what makes the food systems in emerging economies different? Although there are many commonalities on how a system can be studied, food systems analysis is distinct because:

- The large majority of end products represent an essential source of nutrients, to which access could be considered as a basic human right. Food systems design should aim at guaranteeing the basic nutritional coverage (food security maximization), as opposed to systems for most non-food

commodities which are designed for profit maximization. As such, they represent one of the systems with higher policy interventions.

- Food systems represent an environment for pathogen emergence, maintenance and their direct or indirect transmission between humans and animals. Major human disease risks can originate from the food system (Aiyar and Pingali, 2020), a key example being the emergence of new influenza viruses (e.g., the H1N1 swine flu pandemic in 2009). Hence food system designs should aim also toward health maximization, while ensuring profits and maintaining livelihoods.
- Food production is the major utilizer of habitable land, and hence has direct consequences on environmental degradation and generation of conflict, leading toward more intensive production system (Gregory and Ingram, 2014). Furthermore, the system is highly dependent on and vulnerable to the environment, with climate change having a complex impact on food systems. These environmental shocks can not only affect prices and food availability, but also have an impact on the quality and safety of products (references) (Sonja et al., 2012; Myers et al., 2017). As agricultural value chains become increasingly globalized, environmental or political shocks in one area can generate consequences in food production and consumption in other areas.
- They are directly associated with animal welfare through factors such as intensification of farms, increased length of chains (implying longer transportation times of animals), generation of new livestock diseases or increase frequency of existing diseases, lack of quality of animal feeds and other One Health concerns (e.g., loss of habitat due to environmental degradation caused by food systems).
- They represent the most important manufacturing sector in terms of GDP for the majority of countries. In emerging economies, such as India, it generates over 40% of total employment, while in rural West Africa up to 80% of jobs are in the food economy (Allen et al., 2018). Hence, food system disruptions have immense consequences on people's wealth and livelihoods.
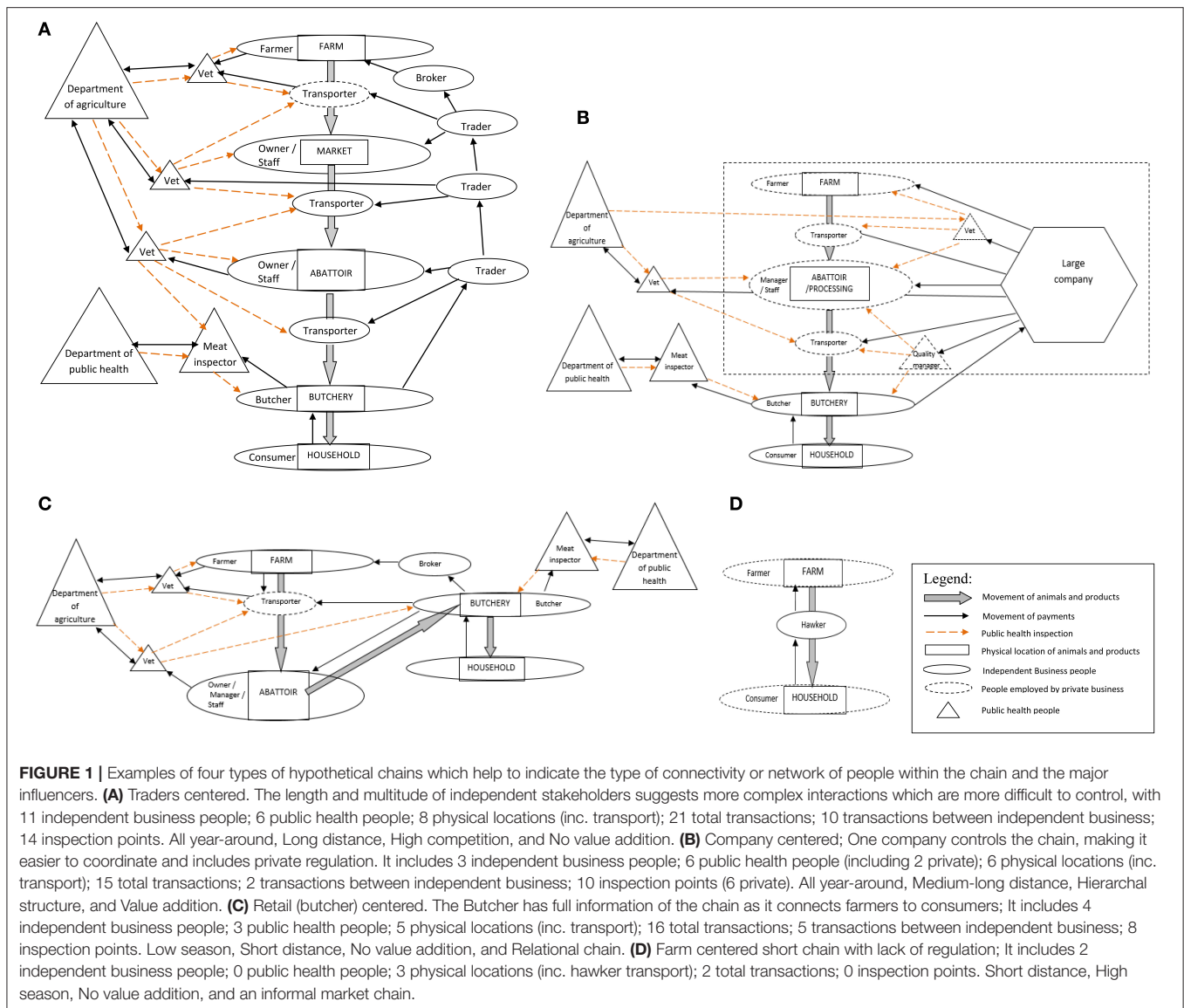
In order to address these distinctions the basis of food system analysis needs to involve mapping the system, understanding its governance, determining the equity across the system and identifying if there are barriers to entry and access. These core elements represent the backbone information with major utility in investigating the nutritional, health, welfare and environmental situation and impact of interventions.

Food System Mapping

Numerous methodologies are available in value chain studies (Kaplinsky and Morris, 2002; Attaie and Fourcadet, 2003; Hellin and Meijer, 2006; FAO, 2008, 2011a; Kerr et al., 2015; Alarcon et al., 2017a; Antoine-Moussiaux et al., 2017; Stein and Barron, 2017). Mapping aims to provide identification of all stakeholders, institutions, goods (including waste) and activities, their flow and situation (geographical, performance, etc.) in order to establish the structure of the food system. It can also provide a representation of the flow of other key

elements throughout the system, such as the flow of capital or information. It should include a quantitative assessment of flows, to allow for the understanding of the relative importance of each component. Diagrammatic representation of flows are normally a key necessity to facilitate understanding. These system maps should indicate the flows in several dimensions: geographical, temporal, between people or organizations, socio-economic status and can even provide a representation of the distribution of power. **Figure 1** provides some examples of food chain mapping based on differences in structural configuration, power distribution and highlights public health inspections. These maps are extremely powerful for understanding and deciding on how to effectively implement interventions, and our own experience is that policy makers in the food system respond well to them. However, as complexity is added, there is an there is an increased challenge for these maps to fulfill their purpose of generating clarity. For this reason, many food system mapping exercises tend to provide an oversimplification of the system, which may potentially lead to the avoidance of key crucial information for their effective use. Common failures, which apply to both formal and informal food systems, are:

- The lack of differentiation of people working in the food systems. Large traders will have access to different types of clients and may operate using a strict internal set of private standards. Differentiating in terms of size of operation may allow to account for these factors, but should not be the only criterion. Similarly, ethnic or income differences will highly influence behaviors and operations. Ethnographic analysis should therefore be an essential component of a food system analysis. An example of such differentiation can be found in Kiambi et al. (2018, 2020) where dairy traders in Nairobi were differentiate based on their level of association, and each presenting significant differences in chains and operations.
- Lack of chain differentiation, especially in terms of power distribution or socio-economic environment. Some chains may have the same structure, but be operated with a different set of rules and purposes (e.g., ethnicity specific, urban vs. rural, etc.). An example of chain differentiation is shown in Murungi et al. (2021) when describing pork value chains in Nairobi. In this work the chains for different abattoirs, urban and peri-urban areas and also for large corporations were differentiated and provide insight into differences in power distribution.
- Lack of quantitative data indicating the importance of flows. Understanding the importance and magnitude of the flows allows to understand implications of chain disruption and system vulnerabilities (Alarcon et al., 2017a).
- Not considering by-products and waste disposal throughout the system. These sub-systems are normally understudied, but may have an important role on food security [i.e., low income population depending on offal (Alarcon et al., 2017a)] or food safety and disease transmission (for e.g., through manure or abattoir waste) (Hassell et al., 2019).
- Food system maps tend to provide a picture of the system at one point in time, and therefore often fail to capture their evolution and their modification between seasons or festive

FIGURE 1 | Examples of four types of hypothetical chains which help to indicate the type of connectivity or network of people within the chain and the major influencers. **(A)** Traders centered. The length and multitude of independent stakeholders suggests more complex interactions which are more difficult to control, with 11 independent business periods; 6 public health people; 8 physical locations (inc. transport); 21 total transactions; 10 transactions between independent business; 14 inspection points. All year-around, Long distance, High competition, and No value addition. **(B)** Company centered; One company controls the chain, making it easier to coordinate and includes private regulation. It includes 3 independent business people; 6 public health people (including 2 private); 6 physical locations (inc. transport); 15 total transactions; 2 transactions between independent business; 10 inspection points (6 private). All year-around, Medium-long distance, Hierarchal structure, and Value addition. **(C)** Retail (butcher) centered. The Butcher has full information of the chain as it connects farmers to consumers; It includes 4 independent business people; 3 public health people; 5 physical locations (inc. transport); 16 total transactions; 5 transactions between independent business; 8 inspection points. Low season, Short distance, No value addition, and Relational chain. **(D)** Farm centered short chain with lack of regulation; It includes 2 independent business people; 0 public health people; 3 physical locations (inc. hawker transport); 2 total transactions; 0 inspection points. Short distance, High season, No value addition, and an informal market chain.

and non-festive periods". or modifications during different periods in the year due to festivities or seasonal supply issues.

• Failure to add the regulatory bodies and financial services involved, including their levels of influence.

In emerging economies, mapping these systems is particularly difficult because of the lack of data availability, increased importance of informal chains and a lack of clear coordination of the chains. For example, some commodities such as poultry are difficult to map as most stakeholders are independent and operate on an informal basis, without clear associations or registration, and with no clear estimation on number of people or businesses involved in each node or no estimates of the overall consumer base reached (Carron et al., 2017; Onono et al., 2018). Hence, identifying adequate key informants who know about the system is a key challenge. Several studies have, however, provided useful examples of food system mapping in emerging economies. Alarcon et al. (2017a,b), Carron et al. (2017), Kiambi et al. (2018), Muloi et al. (2018), Onono et al. (2018) and Murungi

et al. (2021) illustrate clear examples of detailed mapping of ASFs value chain systems operating in the city of Nairobi, Kenya. These form a body of work used to identify structural vulnerabilities and inefficiencies, but also as a framework to research disease transmission and control. Currently, one of the largest UK funded research project on animal health for LMICs, the UK GCRF One Poultry Hub project, focuses on the mapping and the typology of poultry production and distribution networks in Vietnam, Sri Lanka, Bangladesh and India as a fundamental pillar to understand emergence and management of disease risks and for the development of healthy sustainable food systems[1] (Hennessey et al., under review)[2]. Mcleod et al. (2009) provide a review of FAO mapping reports for the poultry sector in

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Africa and Asia and their implications for policy to control High Pathogenic Avian Influenza. The study also highlights the importance of such maps for communication reference to experts and stakeholders. Indeed, most value chain maps lay the background for general interventions. As an example, Deka et al. (2019) provide a very detailed mapping analysis of the informal dairy value chain in Assam, India. It was done as a framework to inform and design interventions to facilitate agribusiness rural transformation. Neves et al. (2014) mapped the beef value chain in Brazil, but focussed on financial transactions, and estimated that the sector generated $167.5 billion in 2010. Recently, maps have also been used to develop system dynamic models to assess the impact of policy interventions (Naziri et al., 2015; Dahlanuddin et al., 2017; Ouma et al., 2018; Rich et al., 2018).

However, despite the numerous research projects, adequate food system mapping for the majority of commodities in emerging economies (but also in high-income countries) are missing. Mapping has been done by different institutions using different methodologies, and with large differences in quality. We argue that there is a need for countries to provide an atlas of food system maps for the key commodities (e.g., beef, poultry, eggs, or milk). These should be performed by large multidisciplinary groups of researchers, supported by government and industry. These maps would need to be updated periodically (e.g., every 5 years), to effectively capture the evolution of dynamic systems. They should be developed using an agreed methodology for effective comparison. The benefits of having such maps would be tremendous, for research purposes, but also for industry development, predicting trends and effects of shocks and policies. Furthermore, there is some resistance by journals to publish food system mapping research as often a specific focus is required, and hence most studies are published in the form of long institutional reports, with few being peer reviewed in scientific journals. Such work needs to be promoted and supported in the academic publishing industry to ensure its quality.

Food System Governance, Equity, and Upgrade

Analysis of food system governance provides an understanding of coordination and power asymmetry variance of the different chains across the system. Several major publications provide key guidelines for the study of governance. Gereffi et al. (2005) established a clear classification of chains according to their degree of coordination and power distribution. This is based on three key factors: (1) the complexity of knowledge transfer between firms required for their transactions; (2) the capacity to codify and efficiently transmit this information; and (3) the capabilities of suppliers to meet the requirements of buyers. Kaplinsky and Morris (2002) indicate that analysis of governance should also consider the type of norms in the system, identification of rule-makers and followers, analysis of incentives and sanctions, the legitimacy of power of stakeholders and the mechanism to exert this power. The governance structure, together with facilitating or obstructing factors (such as policy and economic environment), will directly influence the capacity of stakeholders to innovate and to improve the system or upgrade. For this, four levels of upgrading were defined:

process, product, functional, and chain upgrades. The authors further indicates that the analysis should be combined with an understanding of equality, such as the assessment of profit or gender distribution along the chain. A deep analysis of these factors will allow better understanding of people's behaviors and the reason why disease or food security risks exists (FAO, 2011a). Velde et al. (2006) show an efficient application of these theories for the investigation of the role of entrepreneurship in value chains of non-timber forest products in Bolivia. Their investigation highlighted the importance of these government factors in the development of innovative marketing and its spread along the value chains.

In emerging economies, governance of animal source food systems remains largely unorganized and based mostly on market or relational chains, with independent traders and livestock and wet markets often being the dominant influencer. The organized chains (or often called formal chains) are frequently of hierarchical types and directed to high income consumers in these countries. Yet these two systems are often interlinked at the production stage, where there is competition for resources. This is apparent in Kenya through the analysis of both the dairy (Kiambi et al., 2020) and the ruminant meat sector (Alarcon et al., 2017a). In the latter study findings show that the informal sector accounted for 90% of meat consumption in Nairobi. The formal sector was found to depend on the supply from independent traders that operate in livestock primary markets, and hence without control on the source of animals. Although little competition between both systems exists at consumer level, the study highlights that new business models used by large companies which are able to successfully distribute and sell processed meat products, such as beef sausages, to low income consumers. The situation however contrasts with other emerging economies such as Brazil, which has been able to develop comparative advantage for meat production based on enabling policies and on increased land availability and foreign investment. As a result, strong international meat packer companies have risen in the country. These however compete also with informal channels representing 40% of the Brazilian meat market. "Unfair" competition from these informal markets (unfair due to norm-and tax-evasion mechanisms), have led the major (Azevedo et al., 2004). India, the largest consumer of milk in the planet, has seen its dairy system transformed, which allowed them to become a net exporter of milk This has been achieved through changes in policies, and a rise of cooperative systems (Kaur and Singla, 2018). Yet again, it was estimated that 70–75% of the milk consumed in the country is still produced and distributed through informal traditional sectors, which give opportunities for small producers and traders to generate income (Kumar, 2010). Rapid population pressure and food security issues currently forces these informal chains to emerge or increase in size, while at the same time intensification of farms in formal and informal chains occurs, and in particular in densely populated areas. Although these help to provide food to low-income households, they generate an increased risk for disease transmission. Kiambi et al. (2020), provides a clear example of the impact of chain governance on food safety practices along the Nairobi value chain, and the interactions between informal and formal sectors. Furthermore, in several countries government

regulation structure and legislation are based on other developed countries [e.g., Kenya and Indian legislation for food safety are in their majority based on historical British legislation (Joireman, 2006)] and therefore fail to meet the particularities and challenges of their current food system. There are therefore clear trade-offs on the changes of governance in the systems in emerging economies that are related to food security, food safety, poverty alleviation interventions, and economic development objectives that have to be clearly considered. More efforts are needed to include governance analysis of food systems when tackling disease or food security issues. In this respect, participatory approaches that can focus on co-design and identification of innovations along the value chain may represent an effective way forward (Govoeyi et al., 2019; Häsler et al., 2019). In addition, the meaning of the term "informal" system tends to vary between studies. The International Labor Organization (ILO, 2015) defines the informal sector as "all economic activities by workers and economic units that are—in law or in practice—not covered or insufficiently covered by formal arrangements". The definition does not cover the illicit activities, such as illegal trade of commodities. The illegal trade suggests the denomination of illegal or underground value chains, which may play an important role in some countries, especially associated to bush meat value chains that have major consequences on wildlife conservation (Kamins et al., 2011; Souto et al., 2019). The informal chains in food systems are however conceptualized as those chains generally operating by a multitude of home-based stakeholders without formal contracts (so without legal back-up systems) and with some level of non-compliance with regulations; or simply as those chains composed of small size operators and not being part of large corporations or processors network (Birthal et al., 2016). We argue that the lack of clarity on the definition of informal food chains, and the potential repercussions of this denomination, at market or societal level, requires a careful review and usage of this term.

FOOD SYSTEMS AND PUBLIC HEALTH

Consumption of animal source foods brings public health risks through biological, chemical and mechanical hazards. In 2015, the World Health Organization Food Borne Disease Epidemiology Reference Group (FERG) quantified the role of food in the burden of disease, and found that food borne disease burden globally is comparable to that of the major infectious diseases, and that diarrhoeal agents are a major cause of mortality (Havelaar et al., 2015). Overall, the 33 million Disability Adjusted Life Years (DALYs) lost to food borne disease primarily affect children under 5 (40% of global burden), and people in low income settings. Food borne disease is thus a major public health problem, a problem of equity and has a generational impact on health. In support of this observation of the health loss due to food borne disease, Henson et al. (2018) report that the productivity losses due these diseases was US$ 95.2 billion a year in low and middle income countries alone.

A striking feature of the FERG programme of work is the lack of high quality input data from those countries suffering the greatest burden of disease (Devleesschauwer et al., 2015; Torgerson et al., 2015). A lack of formal, published studies representing these countries and regions is at the root of this, highlighting the urgent need to focus attention on food borne disease studies and, concurrently, on understanding the systems that supply food to the many millions of people who do not have choice in what they are able to afford to consume.

Where Does Disease Risk in Food Originate?

The complexity of food systems as explained earlier, is an exemplar of the One Health approach—considering human health, the health of the source animals and the environment in which production and transport takes place (Antoine-Moussiaux et al., 2017; Amuasi et al., 2020). As mentioned above, in most low income countries and emerging economies, informal food systems dominate the food landscape, while they are highly formalized and structured elsewhere; both formal and informal structures generate public health risks, though the management of those risks differs by system (Roesel and Grace, 2014; Alarcon et al., 2017a; Kiambi et al., 2020). These structures may also intersect at multiple points; food production may occur in the informal sector, some elements of the transport and distribution system may be shared with the formal sector, and, crucially from a food safety perspective, products may flow from one system to the other, such as in to the informal sector after rejection from the formal sector (Kiambi et al., 2018). These cross-overs tend to occur particularly in urban settings (Alarcon et al., 2017a).

In rapidly evolving developing cities, populations are growing fast (Montgomery, 2008) and the demand for cheap animal source foods is high (FAO, 2011b; Hatab et al., 2019). It is estimated that in sub-Saharan Africa, 55% of the total population will be urbanized by 2050 (Henson et al., 2018), and to meet the food demands of this non-food producing population, production systems and animal husbandry practices are changing at an unprecedented rate as production moves from largely fragmented smallholder production to intensified operations—a major driver for zoonoses emergence. It has been noted (Henson et al., 2018) that "food safety concerns generally become more important in transitioning lower-middle-income countries that are experiencing rapid demographic and dietary change, giving rise to dynamic and visible food safety hazards." In Uganda, for example, the demand for pork is increasing at 150% per year, and for milk at 100% per year. Across developing countries, value chains of major food safety concern are commercial poultry and eggs, intensive dairy, pork, and red meat.

Most sub-Saharan African efforts to improve food safety are hampered by inadequate food safety capacities, lack of policy coherence, inadequate investment, fragmented food quality control systems, weak or non-existent traceability mechanisms, weak foodborne disease surveillance, obsolete food regulation, and weak regulatory enforcement. Consumer access to information is, however, not lacking and food safety scares are now routine, focussed on chemical adulteration of meat and milk, aflatoxins, and antibiotic contamination of meat and milk. Populations demand higher quality, although they may not have purchasing power to make food sourcing decisions (Cornelsen et al., 2016). Dealing with these issues requires integration of

public and private sector interests, and an analysis of food safety risks across the value chains concerned.

Where Do Animal Source Food Safety Risks Originate?

The production level can be a source for introduction of pathogens to animals that will become food, of contamination and of emergence of pathogens with potential to infect humans. As an example, *Taenia solium* is a parasitic helminth that causes neurocysticercosis in humans and is the food borne parasite with the highest burden of disease (Havelaar et al., 2015; Torgerson et al., 2015). Infection of pigs, which results in infection of pork meat, occurs when a cycle of pig/human transmission takes place in farming environments where pigs have access to human feces containing *T. solium* eggs (Pray et al., 2017; Thomas et al., 2017). When poorly cooked, the meat from these pigs presents a disease risk; given that the demand for pork is growing in many urban areas, transmission to humans may occur far from sites of production (Akoko et al., 2019).

Another example is through the growing usage of antibacterial compounds in small-holder farming. As these farmers intensify (Chaiban et al., 2020), their operations may outgrow their ability to maintain hygienic environments, and antibiotics may be used to compensate for this poor hygiene (Robinson et al., 2016, 2017). In addition, antibiotics may be used for growth promotion, or simply be more widely available through private sector markets (Chauhan et al., 2018). In some instances, antibiotics may be added to products such as milk as a preservative (Singh and Gandhi, 2015). Consumers around the world [e.g., Ha et al. (2019)] express concern about these and other chemical hazards in food, but direct impacts on health are often hard to quantify (Phillips et al., 2004).

Points of slaughter are significant sites for contamination of the food supply, and for intense occupational exposure between workers and animals from farms (Swai and Schoonman, 2009; Cook et al., 2017a,b). All sites where food products are handled and transported present a degree of risk. Sites of primary processing, such as slaughterhouses or milk bulk collection points have intense opportunity to amplify risks with cross contamination, but the broader transport system, processing plants, packaging environments, etc. also do, particularly in informal market systems where private or public sector oversight on handling practices may be lacking. Of particular importance is the recently brought to light risk associated with informal market systems in Asia and Africa, so called "wet markets," and the risks of transmission of novel pathogens though the food system (Riou and Althaus, 2020). One hypothesis for the emergence of COVID-19 is through mixing of species at such markets, which provide opportunities for homologous recombination of viruses (Wardeh et al., 2021). Yet, these markets which sell fresh food are currently essential for food security for millions of people (Huang et al., 2015), and similar fresh food markets are increasingly popular as an alternative to vertical retail systems in many settings (Buman et al., 2015). While some have called for "wet markets" to be banned, there is clearly scope for these

important nodes in the food chain to be better managed to reduce food safety risks.

Several other risk factors have been proposed for disease emergence (Binder et al., 1999). They include issues of access to healthcare, international travel, population growth, climate change, land use change, urbanization (Hassell et al., 2017). Many of these issues come together in complex formal and informal food systems (Amuasi et al., 2020). The food system itself is an interface between the environment and consumers, farms and urban dwellers, etc.

The importance of the contamination of food by biological and chemical means is creating major health and economic impacts. Poor food hygiene limits societal outcomes through increased levels of diseases, lowering the value of products and limiting trade with attractive markets. Understanding where the main points of risk are across the food systems requires the carefully description and understanding of that system using the tools described earlier. These provide information on the likelihood of food contamination and spread, and the human behaviors associated with the practices that are problematic. Since information allows for far more effective and targeting measures of control.

FOOD SYSTEMS AND MALNUTRITION

Food System-Related Malnutrition and Potential Responses

Poor quality diets (low in fruits, vegetables and fiber, with excess intake of meat and protein, sugars, fats and oils, refined grains, and processed foods), have been identified as the top risk factor in the global burden of disease (Forouzanfar et al., 2015). Overall, the burden from NCDs represented 62% of the DALYs lost globally in 2017. A further 2% of the DALYs were lost due to nutritional deficiencies[3]. Concerns are particularly placed in the diets of the poorest, with the expansion of cheap nutrient-poor calorie-rich and often ultra-processed foods (such as savory snacks, sugar-sweetened drinks, or confectionery), not meeting international recommendations on salt, sugar and fat levels (GNR, 2020). As countries develop economically, the prevalence of being overweight appears to increase among the poorest, while the wealthiest stay mostly unchanged (Templin et al., 2019). Urban dwellers are particularly susceptible to these nutrition transition dietary shifts (Hawkes et al., 2017). Indeed, a recent systematic review and meta-analysis that investigated diets in urban Ghana and Kenya found low consumption of fruits and vegetables (52%), and high consumption of sugar-sweetened beverages (40%), other unhealthy foods (29%) and ASFs (69%) (Rousham et al., 2020). Since deficient diets are not simply a result of personal choices, but also a failure of food systems as a whole to provide healthy sustainable food as an accessible and affordable choice for all, there is a need for more equitable transformation of these food systems (GNR, 2020).

To tackle the multiple burdens of malnutrition simultaneously, diverse diets rich in nutrient-dense foods (i.e., ASFs, fruits, vegetables, and pulses) are essential, particularly

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[3]www.ourworldindata.org/burden-of-disease.

in young children and pregnant women. ASF concentration and bioavailability of nutrients is often higher than in plants (Grace et al., 2018). The EAT-Lancet commission has put an explicit focus on ASF intake on the grounds of sustainability and of negative health implications, and called for a dramatic consumption reduction (Willett et al., 2019). The main health reason was the existing association between high intake of processed red meat and chronic diseases (Rong et al., 2013; Cui et al., 2019). However, there is limited evidence on the risk posed by most ASFs (Soedamah-Muthu and de Goede, 2018; Afshin et al., 2019) and ASF as a whole are not currently considered as a main driver of the burden of overnutrition in low- and middle-income countries. This highlights the danger of drawing global scale conclusions and comparing groups in high-income countries with countries where access to nutrients, and particularly to ASF, is far more precarious (Mozaffarian, 2016). Recent evidence suggests that other ingredients might be more harmful for NCDs, such as added sugar or high salt levels (GAIN, 2020). The Global Alliance for Improved Nutrition (GAIN) recently concluded that consumption of red meat should be reduced where it is high, but that it remains an important source of nutrients, and their reduction should not risk undernutrition among the most vulnerable (Rong et al., 2013).

To efficiently assess how the highly dynamic food systems can best contribute to leverage nutrition equitably and deal with trade-offs, a systems approach is needed (Gillespie et al., 2019). A strategic mechanism to address the nutritious food access gap is the promotion of inclusive agri-food value chains for nutrition (i.e., profitable for everyone involved, and linked to equitable markets) (Allen et al., 2019). These identify entry points for interventions targeting the supply and demand of nutritious foods, as well as approaches and policies to increase the smallholders income, reduce loss and waste or promote an enabling environment for nutrition (FAO, 2016). In low- and middle-income settings, specific challenges exists related to high costs of distribution, inadequate infrastructure, food quality requirements, lack of foods safety regulations, rapid transformation of the food systems (from traditional and informal, to modern production and retail outlets) and of the preferences and demand. These are not well understood—including their role in nutrition (Allen et al., 2019). For example, a recent study in Kenya suggested that the spread of supermarkets in emerging economies could be influencing dietary habits and contributing to rising population numbers of overweight people and obesity (Demmler et al., 2017; Qaim, 2019).

In addition, it has recently been found that affordability of nutritious foods might be a more serious barrier to resolving malnutrition than commonly thought, which warrants urgent policy attention (Headey and Alderman, 2019). To make healthy sustainable food the most accessible, affordable and desirable choice, options such as supporting shorter supply chains for fresh-food delivery programmes, increasing public investment for healthier food products, implementing comprehensive regulatory and policy frameworks to ensure availability of healthy foods or working with the food industry to encourage production and marketing of healthier food products, have been identified (Mozaffarian, 2016). Furthermore, there is a need for information

on the role of the smallholder farmers and the informal sector (and the nutritional pros and cons of different value chains); on the emerging problems of less regulated chains from a food safety point of view; and on whether production costs of better nutritionally balanced food might reduce its accessibility to the poor and vulnerable. With regards to costs these need to consider prices of food and also the transactions costs of access points of sale. As such, we return to an imperative, which is to understand the complex nature of the networks that link food production to consumers.

Application of Value Chain Studies and Interventions to Address Malnutrition

In the past, nutrition approaches to food systems have focused on rural development, dealing with commodity-specific short, direct and local value chains, failing to capture the interactions amongst value chains or to understand more complex urban and frequently international food systems, where multiple stakeholders converge. Value chain analysis rarely undertakes a whole diet approach or assesses carefully the rest of the diet and the potential effect of interventions on dietary substitution. Changes in the access to or in the desirability of one specific commodity, promoted by value chain interventions or external factors such as health concerns (e.g., food safety scares) can lead to important substitution effects, in turn influenced by the characteristics of their respective value chains. Such substitution foods can have substantially higher, lower or similar nutritional quality than the substituted or displaced foods, thus, value chain availability can have tremendous consequences for nutrient intake. Understanding the nutritional impact of the elimination or the modification of certain value chains, for both the stakeholders and the final consumers, as well as the alternative value chains available, is essential for policy-making to improve nutrition. Assessing in detail multiple value chains is nevertheless a massive undertaking that most projects cannot afford, and given the dynamic nature of value chains and the heterogeneity in methodologies, separate studies of different value chains are not always comparable. In practice, assessing in detail the whole system is impossible, but agreeing on well-established tools and methods may help to address this. Also, Gelli et al. (2015) established a typology to characterize and frame the objectives of specific value chain interventions. The evidence on successful value chain interventions to leverage nutrition is limited (Allen and de Brauw, 2018). This is due to the difficulties when considering: (1) more functional outcomes like child stunting, which can respond to a number of different factors other than food systems (e.g., water and sanitation, education, gender issues), and (2) the potential for scaling up value chain interventions, which is not often researched and analyzed in a thorough way.

Several large programmes have attempted to tackle some of these challenges (yet, the evidence is patchy and some of the data are difficult to analyse and interpret). An example of such a programme is LANSA (Leveraging Agriculture for Nutrition in South Asia), implemented in India, Bangladesh, Afghanistan and Pakistan, with high undernutrition rates. The programme attempted to understand the effectiveness of potential pro-nutrition food value chain interventions (e.g.,

dairy sector, fortification schemes, etc.) to inform food system policies (Henson and Humphrey, 2015). They concluded that these value chain-based interventions did not always achieve the desired nutrition goals and that to change in the right direction, food system interventions require a clear nutrition objective, adapted to the specific population dietary constraints. They also found chief trade-offs in trying to align commercial objectives and nutrition requirements. Modifying the design and implementation of agri-food system interventions and developing capacity and leadership for evidence-based decision-making becomes then an important step.

Value chain work is often led by safety, quality and economic considerations; rarely by specific societal nutritional needs. The Urban Zoonoses project in Nairobi attempted to link the nutritional status of the low income households with animal source food value chain analysis in order to identify potential food systems interventions to leverage nutrition of most affected households. Identification of which commodities can help fill the relevant nutrient gaps was assessed through Optifood (Dominguez-Salas et al., 2016; Vossenaar et al., 2017), but other approaches such as the Cost of Diet (Deptford et al., 2017) are also available. This targeting can also be improved through better understanding of cross-price elasticities of demand and drivers of food choice (Cornelsen et al., 2016). However, establishing efficient linkages between household nutrition and the numerous value chains remains very challenging. New innovative research methods to effectively provide these linkages simultaneously, for multiple value chains are still required.

In some of the animal value chain analyses conducted in different countries [e.g., pig in Vietnam (Nguyen-Viet et al., 2019) and Uganda (Roesel et al., 2019), fish in Egypt (El Tholth et al., 2015), dairy in Tanzania (Haesler et al., 2018)], a novel integrated and systematic assessment of associated nutrition and food safety risks and opportunities was introduced. It combined qualitative participatory rural appraisal approach and survey data in producers and consumers, with food sampling and value chain mapping. The approach collected data on hazards; value chain structure and risk points; food hygiene, production, handling, preparation and consumption practices; nutrition security; perceptions and beliefs around food safety and quality; feeding practices and cultural and social norms. This allows better comprehension of the links, trade-offs, weaknesses, opportunities and co-benefits of food safety and nutrient intake and disease (Haesler et al., 2018).

Food System Shocks and Nutritional Impacts

The unprecedented global pandemic of Covid-19 has (as has previous Ebola outbreak in some African countries) brought into focus the fragility of food systems in low- and middle-income countries. Some important consequences have been: food environment disruption, derived from the restriction of movement of people to access or produce food; the income decline and subsequent reduced capacity to afford food (fuelled by price hikes); or the lesser food availability as a result of the ban of wet markets and the interference with flows of foods, which is particularly notable for fresh products (UN, 2021). In low- and middle-income settings, markets rely importantly on

the informal sector; and governments may not have enough resources for social protection interventions and to support recovery. This implies that the risk of dietary diversity reduction, shift to cheaper poor quality foods, and malnutrition is more severe and likely more long-term. In turn, people with underlying conditions, including both undernourishment and NCDs are at increased coronavirus vulnerability (Headey et al., 2020; Mertens and Penalvo, 2020). Prediction models for disease control do rarely take into account these downstream effects on nutrition, hence potentially being ignored in the decision process. These type of shocks can also trigger strong migration flows to rural areas, shifting the pressure to those value chains that are often unstable and from which highly nutritionally vulnerable populations can be dependent on. However, the exact impacts of the food systems disruption on the nutrition status have not been sufficiently studied, in a way to assess which mitigation measures are likely to have deeper nutritional consequences. In any case, Covid-19 is reshaping the economy, society and politics, and is an opportunity to rethink food systems, and build more local, resilient, efficient, sustainable, safe and nutritious value chains. This requires strong national and supranational leadership, engaging with the broad range of stakeholders to implement holistic One Health approaches that consider the interactions and interconnectedness.

Recommendations of Food System Approaches for Nutritional Outcomes

Food systems need to change but the evidence on how best to adapt value chains to nutrition needs is limited. Moving forward with research, we need to identify ways to integrate and clarify the currently fragmented information, among currently disjointed but much interconnected disciplines, and among value chains. Suitable interdisciplinary metrics and methods, well-matched to link value chain efficiency or disruption with nutritional outcomes, are imperative. Understanding better the power groups, the incentives and the profit distribution can also help shape and align food systems in the positive direction, to optimize public health, distributing the right food for the right people through the right channels. Currently, for many nutritionally vulnerable groups, this will still be the informal channels. The value chain analysis can also help identify entry points to make high-quality diets more available, affordable and appealing. For the consumers, easier tools to characterize the healthiness of foods, which seems at present more developed to reflect Westerner concerns (such as NCDs (e.g., traffic light labeling on sugar, salt, (saturated) fats and calories) or additives) and do not always clarify relevant aspects of undernutrition (e.g., provision of essential micronutrients). Multi-country, interdisciplinary, comprehensive value chain analysis to diagnose complex problems should be promoted by donors and funders (Haddad et al., 2016).

SOLUTIONS TO THE CHALLENGES

Food systems are constantly adapting to changes in the social and economic circumstances. The pace of these changes has accelerated in the last 30 years in response to a combination

of an increased human population and that a larger proportion of people are in urban settings. This has made food systems both more complex, diverse and geographically lengthy with consumers divorced from the land where food is produced, and in many cases also removed from the processing of food before it reaches the home for consumption. There is much success in the change with food availability improving both in terms of quantity and affordability. However, there are downside. Some people still have poor access to sufficient food and undernutrition continues to be a problem. Others have enough to eat in terms of quantity yet the nature of the diet available is generating problems of overweight and obesity. Finally, the new food systems that are livestock orientated have thrown up new challenges in terms of biological and chemical safety as systems get longer and risks of moral hazard increases. The impacts of the double burden of malnutrition and the food safety aspects are slowly becoming recognized and are being quantified. With food safety our tools such as risk analysis need to be supported with in-depth assessment of food systems in order to identify risky behaviors, understand the institutional settings and establish better codes of practice and enforcement. The area of malnutrition is trickier as our existing tools on nutrition and food systems science are not yet being merged, yet there are new studies that indicate the complexity. These problems are in urgent need of solutions, and will require better understanding of the drivers of the food systems and the need to incorporate codes of practice and enforcement which ensure that everyone has access to food that can provide sufficient nutrition in a way that leads to healthy levels of eating. These two areas are probably our biggest challenges in the next decade, solve these and our populations will see another boost in the reduction of health loss across societies, ignore them and we will see an increasing trend of food related NCDs. To address these challenges, countries should generate food system maps for the key commodities (e.g., beef, poultry, eggs, or milk) based on an agreed common methodology. This methodology needs to be agreed by high level international organizations and countries governments, with participation of the industry and the research community. Consistent and systematic production of these maps can be used as a monitoring tool for more effective planning of local and global food systems, and as essential baseline for research in nutrition and food safety. Furthermore, to accelerate the combination of understanding of food systems and public health we need the recognition that food systems are integral to health and that food systems policy have to be aligned with health policy and vice versa.

In order to assess some of the broader questions of public health impacts through food safety and nutrition there needs to be interdisciplinary research that reflects the diverse dimensions of the food system from: consumption behavior (related to household economics and social research); value chain analysis; policy analysis; nutrition science; and gender research. The difficulties of such an interdisciplinary undertaking have been thoroughly discussed (Bromham et al., 2016), yet they can be overcome if we accept the need for systematic and regular application of food system science as outlined in this paper. The information generated will provide unique windows into where problems are generated with respect to food safety and nutrition, and will allow us to identify who needs to be involved to generate solutions and how policy should be shaped to support these processes. Overall such methodology adoption will help us to have food systems that optimize resource use and minimize public health problems for all.

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All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. PA, EMF, PD-S, and JR have participated in the development, review, writing and revision of the different sections of this work. PA and JR have provided overall coordination for the work.

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