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Perspectives from CO+RE

Perspectives from CO+RE: How COVID-19 changed our food systems and food security paradigms

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1. Background and drivers

Within a few weeks the world has changed, at the time this text is written (May 2020) more than 3.5 million people have been confirmed cases of COVID-19 and estimations propose up to a hundred times the number of actually infected. A third of the global population is on lockdown and a large part of our global economic activity has stopped. Food and access to food has played a visual role in portraying the impact of the outbreak on our society, with images of empty supermarket shelves appearing in mainstream media. In some countries closed schools resulted in many children not having access to free meals and mobilised a number of charities. While parts of the world are now exiting lockdown and measures start relaxing the near future remains uncertain with more waves of the pandemic expected. Given that there is currently no evidence to show that transmission of COVID-19 could occur through food or food packaging there has been limited discussion on the issue, implications and potential future scenarios within the wider food science community.

Within the food research community, up to the pandemic crisis the discourse has been dominated with design and manufacture of healthy and safe foods. The main issues are relevant to sustainability, circular economy, energy and water efficiency, climate friendly practices of products and processes. Efficiency has been the focus, but resilience has not been a significant issue so far. The term food system resilience has been defined by Tendalla (Tendalla et al., 2015) as '*capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances*'. We believe that in the future we will continue to see similar pressures in the food system, e.g., comparable pandemics, effects of climate change on food production, and that resilience will become of major importance.

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This commentary aims to present a reflection from the past, considering the present situation to provide thoughts on the actions needed to ensure resilient food systems.

2. How it started

In December 2019, China reported a series of pneumonias of unknown cause in what would evolve as the COVID-19 pandemic. The exact origin of the virus causing COVID-19, SARS-CoV-2, is not clear and is a matter of current investigation (Andersen et al., 2020; Mackenzie and Smith, 2020; Huang et al., 2020). COVID-19 has been classified as a new zoonotic disease that has been transmitted from animals to humans. Zoonoses are infectious diseases that spread from animals to humans and they are caused by viruses (e.g., Ebola, SARS-CoV), bacteria (*Salmonella* spp., *Yersinia enterocolitica*), fungi (*Basidiobolus ranarum*, *Lacazia loboi*) and parasites (e.g., *Toxoplasma gondii*) (Coronavirus, 2369). In the case of COVID-19, similar to SARS, wild animals are considered to be the original hosts which then infected other animals (present in wet markets), which transmitted the disease to humans (Zwijacz-Kozica et al., 2010; Perlman, 2020; Zhu et al., 2010).

3. What we thought of food before COVID-19

Modern agricultural practices and urbanisation of the global population has led to complex food supply chains, often requiring long transportation of raw materials (e.g., staple commodities such as wheat, maize, corn, soybeans and oil seeds) and facing significant environmental/sustainability challenges as well as decay in quality. Long supply chains (in terms of both distance and time) require the addition of a range of links in the chain that can impose significant risks and loss of control.

Food manufacturing presents a vibrant sector in developed and developing countries accounting typically for 12% of the GDP. In the EU (including UK) it is the largest manufacturing sector employing an estimated 4.72 million people and with a turnover in excess of €1.2 trillion according to Food & Drink Europe (2019). The sector is diverse with a large number of SMEs and micro SMEs (more than 285,000 companies in the EU). About 0.9% of the companies contribute to almost 50% of the activity, by any metric (e.g. volume of foods produced, employment, and turnover). This has been well recognised, as typical food supply chains are large, vertically integrated, and owned by multinational public and private corporations with a high degree of product diversity (Huff et al., 2015). This has also led to "bottle necks" in the food chain that might be problematic from a resilience perspective. In Fig. 1, a schematic of the UK food chain, as a typical chain in the western world, is shown. One can see a "bottle neck" appearing in supermarkets/suppliers with a relatively small number of organisations controlling a large part of the foods consumed. Further to this bottleneck, more than 80% of food is delivered through the global supply chain with a major focus on low cost and high efficiency. Products and supply chains with emphasis on environmental and social sustainability criteria are gaining momentum but still represent a very small fraction of the total volume.

Through implementation and rigorous enforcement of robust quality control measures, food companies (with a major contribution from key manufacturers and distributors) have contributed to providing safe food at affordable prices. Since Nicolas Appert invented canning as a way to preserve agricultural products for extended periods, there has been a range of technological innovations in processing, transportation and cold food chain. The technological innovations combined with access to inexpensive energy (i.e. fossil fuels) have allowed for the development of complex food supply chains. Currently, global megacities with population densities higher than 20,000 people per km^2 are sourcing foods from the rest of the world. It should be noted that there have been questions about the environmental impact of food chains and the true cost of food if the economic effects of impact to the environment is included. Large food organisations have leveraged their scale often to create efficient, centralised operations and a complex supply chain system. The emergence of new sensing, automation and digital technologies in the context of Industry 4.0 (i.e., fourth industrial revolution which aims at integrating cyber-physical systems, the internet of things, industrial internet of things, cloud computing, cognitive computing and artificial intelligence in manufacturing technologies and processes) are promising to provide even greater efficiencies and flexibility. Increasing efficiency in the food industry has minimised inventories (even for non-perishable items) leading to an "on-demand" system with high dependence on effective transportation. In the context of resilience, one would have to revisit the impact of such manufacturing and supply chains, especially during a pandemic similar to COVID-19.

As defined by Folke (2006), resilience is the requirement for flexibility and adaptability as well as the capacity to absorb market and environmental shocks and still maintain a fully functioning food supply chain. One of the greatest challenges in crisis planning is developing food systems that are sufficiently resilient to continue functioning. Buldyrev

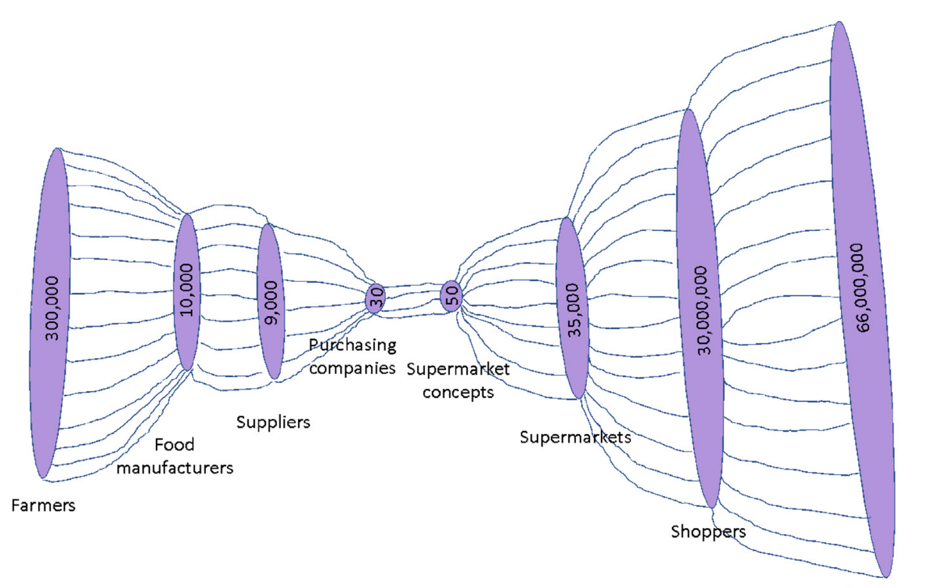

Fig. 1. Schematic of the UK food chain as a "representative" for the western world. Numbers represent the number of actors at each of the chain, size of each part of the chain is getting smaller to represent the relative number of actors.

et al. (2010) highlights that a fundamental property of interdependent networks is that failure or degradation in one system may cause the failure of other dependent systems. The same stands for food networks, as for example failure in either the manufacturing, or transportation, may cause the failure to food supply. For example, food industries that rely on import and export face challenges as raw materials might be difficult to source.

In terms of innovation and growth the sector is in a state of flux. Before the pandemic large food manufacturers reported a relatively slow growth (<3%) while some SMEs reported growths of up to 10%. Innovations with high growth emerge around new propositions, e.g. plant-based foods, which are emerging from risk-taking start-ups. One could speculate that the food sector is moving to an innovation model similar to the one from pharma, where small SMEs develop technologies and then are acquired by multinationals. There are also changes in the way consumers "interact" with food. For example, 30% of the calories are consumed outside the home (in the western world) and the average household in the US spends about 20 min in preparing food. At the same time, consumers spend increasingly longer time online (e.g. in the UK the average time spent online was 21 h per week in 2015, 50% of which with a smartphone), which has a direct impact in determining their food preferences (e.g. through information flow, adverts) and practices. A number of lifestyle online platforms promise to provide personalised advice to maintain personal health. Digital technology is impacting the research arena, offering increasing opportunities for data acquisition and handling.

Rapid urbanisation of marginalised sections of our population with limited access to services including housing, transportation, education, healthcare and energy, has resulted in whole areas without ready access to fresh, healthy, and affordable food often referred to as food deserts (USDA, 2019). These communities may have no food access or are served only by fast food restaurants and convenience stores with few healthy affordable options. Poor access to healthy food options, whilst presenting as a deficiency of certain nutrients, can also result in obesity and increased instances of non-communicable diseases such as type 2 diabetes (Doval et al., 2019), often referred to as the double burden of malnutrition. Diets rich in energy from refined foods, high in sugar and fat, are often affordable but lacking in essential macro-and micro--nutrients. Food insecurity and food deserts, as forms of inequality, have severe consequences both in terms of physical and mental health (Doval et al., 2019; Delhey and Dragolov, 2014; Inoue et al., 2013; Cannuscio et al., 2013) that result from the complex social dynamics at play in marginalised urban areas. The issue of food insecurity is intrinsically multidimensional and emerges from a combination of material (access) and intangible (socio-economic) factors (Wang et al., 2018). Ensuring a healthy diet available to all citizens is a major challenge for the future.

Increasingly, the scientific community has focused on issues around designing and producing not only safe and healthy food but approaches offering improved sustainability. The themes covered in the recent global food conferences, e.g., International Congress on Engineering and Food (ICEF 13, Melbourne, September 2019), European Federation of Food Science and Technology (EFFoST 33, Rotterdam, November 2019), Institute of Food Technologists (IFT annual meeting, New Orleans, June 2019), have increasingly addressed sustainability of our foods supplies but less so with regards to food resilience.

To further investigate the "state of the art", we performed a literature search for journal articles in Scopus on "food supply" and "resilience" and "security", aimed at identifying the key concepts that have been targeted in the last 5 years. The intention was not to perform a detailed literature analysis but to inform a higher-level analysis on the interrelationship between key challenges, requirements, and potential solution enablers. The obtained results were analysed through the graph network bibliometric visualisation tool VOSviewer (VOSviewer.com; Centre for Science and Technology Studies, Leiden University, The Netherlands). The tool was employed to build network graphs of terms employed in article titles and abstracts (Fig. 2). The key visualisation features are determined by scores and weights and are visualised with bubbles and connectors. High scores correspond to more frequently used terms and are depicted with larger bubbles. Thicker connectors correspond to more frequent co-occurrence of terms. Trimming out weak connections and infrequent terms, the Scopus picture illustrates key terms and their relationships in three main clusters. The green cluster brings together terms closely linked with food supplies and their production ecosystem. Key terms such as disruption, capacity, availability, and vulnerability denote the uncertainty around the food supply chains. The blue cluster is mostly about regulation and the customer. Key issues here are public health, trust, and safety. The red cluster brings in an interesting connection between technology enablers (internet of things, hyperledger/blockchain, sensors, rfid cloud platforms, packaging) and critically important features (traceability, transparency, efficiency, product quality). The reverse supply of food waste is also linked to this cluster.

Overall, the emerging picture is that of an increasing role of technologies, such as processing, packaging, connectivity, sensing for monitoring and cloud (platform) information systems infrastructure strongly linked to key requirements (traceability, transparency, effectiveness, product quality). However, resilience aspects of the food supplies are yet to be tightly connected with such technology enablers and they are closely linked to the production side of food supplies. This implies that there is significant room for capitalising more on the technology enablers and not only on the production side of food supply to improve the resilience of food supply chains.

4. State of the food system today –during COVID-19

During a pandemic, it becomes more evident that a value chain is in fact an economic and social reality as reported by Caiazza and Volpe (2012; 2014).

In many countries, the media reported consumers stockpiling food products with images of empty supermarket shelves and strained online deliveries unable to cope with demand. Most catering services were closed resulting in remarkable food waste and economic losses. As the situation evolves alarming reports emerged from major food producers about broken food chains and consequently wasting of good foods (The Guardian, 2020). While records indicate that on average (at least for the middle class) 50% of food was purchased before the pandemic from supermarkets and 50% from food services, now almost 100% has moved to supermarkets. It is worth mentioning that to a large extent food chains coped with the increasing and changing demand. Another observation is that truck traffic for food in France which accounts for 30%, has been reduced by 60% since the lockdown measures, meaning that more or less the remaining 10% are for delivery of online shopping by big incorporations.

Reports also show a clear change in consumer behaviour or purchasing habits. There is some evidence that consumers did not "stockpile" to the extent that it was previously thought, there was an average increase of ~15% on the consumer spent in each visit, while there is a decrease in the number of visits. This change might be a result of more people preparing meals at home for themselves and their families. According to The Nielsen Company (US), LLC. (2020), sales of products like shelf-stable milk and milk substitutes (particularly oat milk) are up by more than 300% in US dollar growth during the current pandemic. Other items seeing increases in product sales are for example dried or canned beans, canned tuna, pasta and fruit snacks that have a long shelf life. It anticipated that sales of frozen foods, specialty products, and meat will also increase. Daily cooking at home created the need for different types of food products. Spanning from long shelf-life and convenience; to luxury and indulgence. Consumer practices have changed as a result of physical distancing (also communicated as social distancing), e-shopping and infrequent shopping become common; takeaway and home delivery become an alternative to closed restaurants. An overall increase in the use of on-line platforms to order food, share recipes and substitute social interactions around food are apparent.

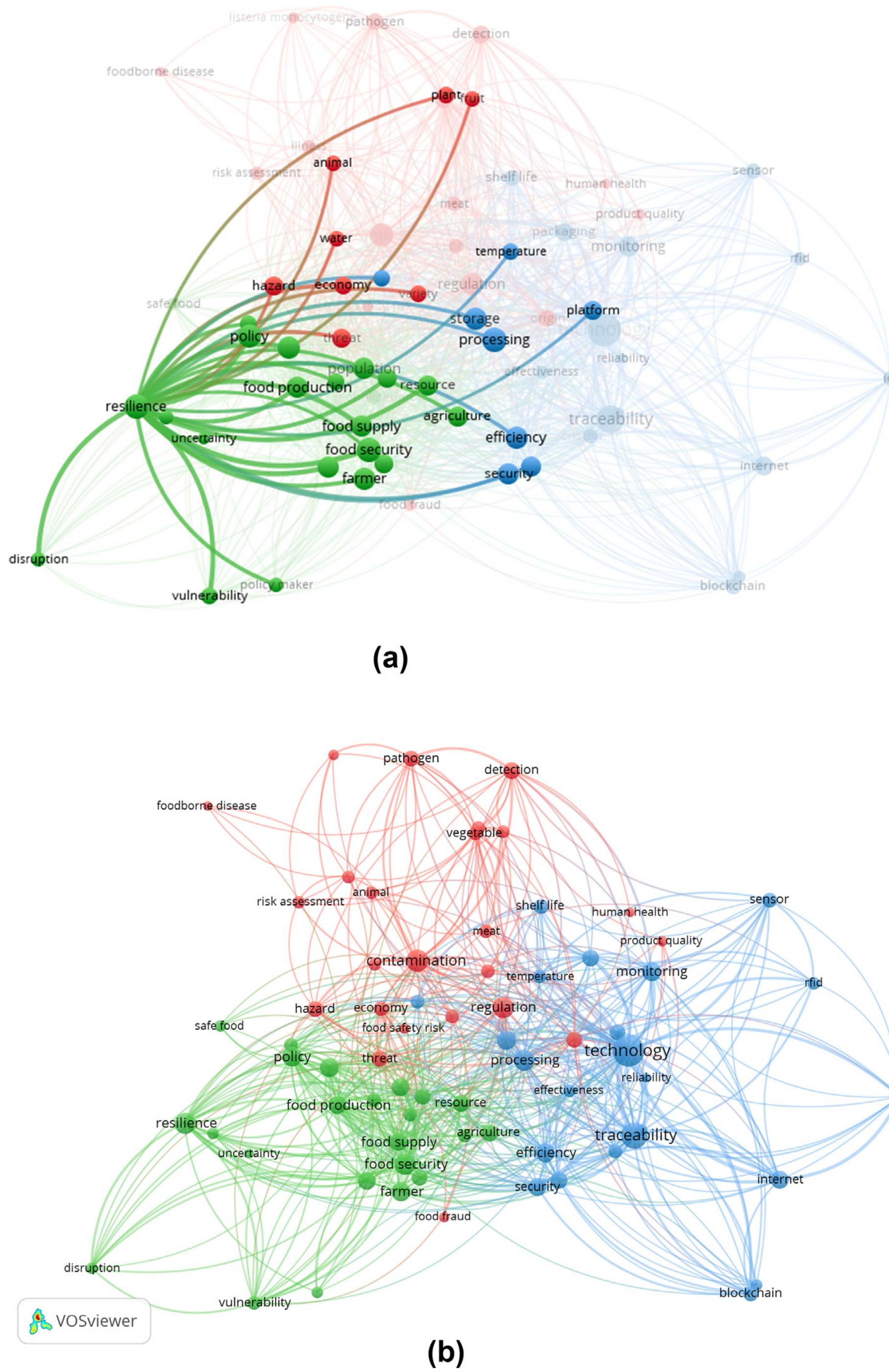

Fig. 2. Network analysis of journals published in Scopus for the last 5 years for "food security" and "resilience" (a) "resilience" relationship; (b) fully connected graph of all key terms. Size of the bubbles represents more frequently used terms while thicker connectors correspond to more frequent co-occurrence of terms.

An interesting case might be the flour, one of the basic products that abruptly came into short supply on the supermarkets' shelves, especially in the UK, but also in other European countries as well as Australia and New Zealand. According to Waugh, the UK produces around 90,000 tonnes of flour weekly, with the majority being sourced by commercial bakeries and other food manufacturers (delivered either in tankers or in 16 kg or 25 kg bags) while only 4% is sold through shops and supermarkets. The current metrics about 3,000 tonnes of flour a week, equivalent to two million 1.5 kg bags or a bag of flour every 14 weeks for each household in the UK has dramatically changed. Home baking became common and a family activity resulting in a lack of flour and yeast in the supermarkets. At the same time, there does not appear to be a lack of bread and baked products on the supermarket shelves. Flour does exist in the food system not necessarily in the form that consumers want it, demonstrating the potential of improvement in the format, e.g. packaging products are offered.

One of the major issues that COVID-19 has revealed is the issue on food insecurity faced from a large part of the population. The social measures that were in place, e.g. school meals, family/grandparent support, to a great extent have been stopped as a result of the lockdown. This has put the most vulnerable parts of our societies in significant (food related) risk. Induced unemployment contributed tremendously to food insecurity for the low-income households. Charities and other community-oriented support services e.g. food banks or incentive financial measures in some countries have been activated to address the issue, but this remains an issue causing significant concern.

5. What to watch

At a primary production level, small-scale farmers should be supported to both enhance their productivity and market the food they produce, e.g. through e-commerce channels. The effective implementation of short food supply chains during the lockdown could offer an additional mechanism to cope with the issue of food resilience. The agri-food chain is labour intensive and can be affected from limitations in the workforce due to infection and/or limited ability to travel (Delhey and Dragolov, 2014). There should be efforts to allow for global trade and overall to minimise logistics disruptions, so that major staple commodities can be moved across countries.

Availability of food products is expected to directly affect the nutritional habits of consumers. It would be worth ensuring that diets during this crisis provide the necessary macro and micronutrients. For example, vitamin D deficiency in the time of lockdowns is expected to have an impact on consumers' immune system. The consumers are also expected to take additional measures to protect their health by implementing Good Hygiene Practices at a delivery stage not only when preparing the food, e.g., disinfecting practices of purchased products – packed versus unpacked.

One of the important issues is to ensure the wellbeing of the less privileged, e.g. through access to safe and nutritious foods. This will require multiple actors across the chain to work together to ensure access to foods as well as financial support. For example, FAO recommended that governments will need to carefully manage inflation to reduce the risk of inflating food prices (Cullen, 2020).

6. The day after: manufacturing for resilience

This will be an opportunity to re-examine our Food Systems through the notion of resilience. Increasing resilience will require enriching the current food system with shorter supply chains creating a richer ecosystem of foods as well as taking coordinated actions across different actors.

Hecht et al. (2019) identified the following 10 factors that may contribute to organisation-level resilience in food supply chains: formal emergency planning; staff training; staff attendance; redundancy of food supply, food suppliers, infrastructure, location, and service providers; insurance; and post-event learning. Implementation of any changes towards a more resilient future for foods requires that key stakeholders, including industry, policy makers, governments, as well as the consumer, all have an active role.

6.1. Food producer/manufacturer

It is important to identify the logistic-retailer bottlenecks for different food chains to propose intervention strategies. These could include a number of different actions, such as:

- A richer food ecosystem to allow for resilience, especially if one part of the "system" does not work. These systems could implement the development and application of use of locally sourced foods; (i) disruptive technologies for food distribution (e.g., IoT, drones, etc.), and following physical distancing (ii) e-commerce apps for ordering and delivering, (iii) voluntary delivery peer-to-peer of the food product through sharing of information and transport routes to also reduce costs, etc.;
- Use of automation to cope with a smaller number of people available to work both at primary production as well as at food manufacturing level and distribution;
- The layout of our workplaces, manufacturing facilities and retail will need to be transformed to ensure safety of workers as well as customers;
- Complementing existing chains, where possible with local production systems connecting agriculture, processing and valorisation/reuse of waste. Future scenarios should include considerations for water and energy resources.

In this new world of travel restrictions and decreased international trade, manufacturers will have to rely on more local manufacturing. Food manufacturers are likely to distribute their resources to use local facilities, where local raw materials can be used. This strategy may lead to a significant job creation but any environmental/sustainability benefits should not be taken for granted and they will need to be re-assessed and evaluated (Edwards-Jones et al., 2008). Urban agriculture is often presented as a solution; it may have a positive contribution towards resilience but will not suffice to provide the current staple crops.

In recent times, short food supply chains, i.e. supply chains in which the number of intermediaries between farmer and consumer are minimal or ideally nil, and local markets have flourished in all EU countries, both in rural and urban areas. These represent an alternative to conventional longer food chains. Such food systems have the potential to respond to a number of needs and opportunities, both of farmers and consumers. The development of (different types of) short food supply chains (i.e., direct sales by individuals and/or collective direct sales, partnerships – community supported agriculture) is one of the approaches that could be followed (also in line with the Common Agricultural Policy of EU) in an effort to increase resilience and promote a more favourable framework for sustainable, local, healthier and ethically produced food. It would be of interest to re-examine the past to inform future food scenarios, e.g. how "traditional" self-sufficient societies operate, and if there are practices that can be translated and reapplied through technology.

Although the exact origin of COVID-19 is not known, a hypothesis has linked it to a wet market selling live wild animals, a problematic practice seen in parts of the world. In such markets, outdoor stalls are usually squeezed, displaying caged animals that may be slaughtered at a neighbouring butcher, and have their meat chopped and sold on customer demand. Wet markets are critical for sustainability and food security, providing fresh, affordable food for billions of people globally. However, they have been associated with negative health outcomes, to the point that WHO suggested to enhance regulation of wet markets.

The discussion around short food supply chains and local productions and the impact of COVID-19 pandemic, is an area of academic discussion (Cappelli and Cini, 2020). The current crisis generates interest in further exploring the development of collaborative short food supply chains, balanced with the need to regulate and ensure safety.

We should also continue our commitment to deliver sustainable food systems resilience and flexibility. Food will continue to have a major environmental impact (~17% of the total carbon footprint) and is highly dependent on fossil fuels. Future scenarios should involve a number of different economic, environmental and social parameters which are not currently considered in standard assessments, e.g., reduced labour availability (because of infections), and reduction of consumer buying power (as a result of sudden increase of unemployment). Life Cycle Sustainability Assessment (LCSA) methodology, the combined application of Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA), will come to front as the integrative and holistic approach to make decisions for promoting sustainable development.

6.2. Government/municipality

The current crisis has revealed that in our current interconnected food system co-ordinated action will be required. The current crisis has also potentially redefined essential services and goods. While there is currently an excess of oil one should wonder if we should treat food as a limited resource and maybe re-introduce reserves?

The malnutrition may become more of an issue to vulnerable populations which will need a more active intervention strategy, e.g. food donation activities. The role of the local authorities should also be active in the area of education. Different types of educational plans, which extend current guidelines by WHO, will need to be developed which could include: (i) education of households about food storage, (ii) education of households about the need for increased hygiene, (iii) education of households about the nutritional food requirements of short- or medium-term emergencies like the pandemic to reduce malnutrition and lack of nutrients that enhance the immune systems, (iv) education about balanced diets in periods of limited physical exercise. Even though whether or not COVID-19 was started at a wet market still requires further investigation, stricter regulations are no doubt needed to minimise health and safety risk to both consumers and environment.

At a fundamental level, food safety should be re-considered. It is now becoming clear that within a global food supply it is required to have robust yet realistic food standards where the use of information technology, e.g. blockchain, could provide some solutions.

6.3. Consumer

The lockdown resulted in an increase of home cooking and artisanal food production. This may create a new era following the revolution of convenient food products that are very common to Western markets, providing new opportunities for food manufactures, e.g. through digital technology for training. This will also impose new challenges in terms of ensuring hygiene while cooking at home. E-commerce shopping may become the norm for shopping, supporting reduction of any kind of transmitted viral diseases in places which are commonly crowded. Definitely online ordering and delivery are the most drastic change. Fairly sophisticated apps that work across platforms in real time will have to be developed. These new apps will also have to include the ability to judge list of ingredients, maybe even linked to nutritional information and advice. The platform needs to be attractive but also regulated so that it does not become merely a marketing tool for companies. Maybe we will witness the birth of regulatory affairs of online food resources. The information and claims presented in such platforms will need to comply with existing food regulations. If more people will be purchasing their supermarket food online, a new distribution system will need to be created. Home delivery could work, but maybe we will need small distribution centres all over cities. Orders would be brought and deposited in lockers, and consumers could pick them up during the day. These would include refrigerated and frozen units as well. Other approaches may include drive-in supermarkets where you have ordered online before. Either way, home delivery or pick up of pre-ordered products will be a big part of this new way of doing things. Since supermarket shelf space is always limited, maybe this new world of online shopping might democratise our food product choices and include new and novel products from smaller manufacturers. These small manufacturers would struggle to get the shelf space in normal supermarkets. Under these conditions, the supermarkets become distributors more than retailers, in the traditional sense of the word. The border between retail and distribution may become blurred at this point.

7. Concluding remarks

The 'unprecedented' times that the world is currently experiencing due to the COVID-19 pandemic may become more common in the future, considering for example that ecological catastrophes and climate change may increase appearance of zoonotic (or other) diseases in humans. (Patz et al., 2005; Alirol et al., 2011). Additionally, the frequency and intensity of disease cycles are expected to increase because of the high population density and greater ease of global transportation (Bhunnoo, 2019a).

The current situation has highlighted the importance of food security in times of shocks and crises. The COVID-19 pandemic is clearly challenging the entire food chain system. Restrictions of movement, including movement of (agricultural and other) labour and supplies, are likely to disrupt food production and food-related logistics and services, posing a challenge for the ability of the system to provide sufficient, affordable, and nutritious food for everyone. The consequences are likely to hit the poorest and most vulnerable members of the (global) society, deepening the gap of food inequality between populations and classes.

Food system is multidisciplinary and highly interconnected (Smith et al., 2015). A complex systems approach for food systems has the potential to address food security (Clancy, 2017), safety (WolfHall and Nganje, 2017) nutrition/quality (Abbaspourrad et al., 2017); manufacturing/distribution (Roos et al., 2016) with economics and social drivers. Systems can be built that would help decision making in industry and by public planners (Bhunnoo, 2019b). Food products are often multicomponent formulations that often require ingredients which are not locally available. Shortage of such ingredients could lead to significant challenges to food manufacturers. Therefore, it is conceivable also to build such systems at multiple scales, from industry to region, state, country and global levels (Bhunnoo, 2019b).

Building food systems that are resilient to shocks such as the COVID-19 pandemic requires collective action along the entire agri-food chain, including policymakers. Development of enhanced, robust agri-food chains will probably require a fine, complementary balance between the current, "global", food supply practices and other, "local", trends. Different scenarios would be developed and evaluated taking into account multiple parameters such as pandemic time duration; the global pandemic extend; resilience of different foods; their significance for nutrition and wellbeing. Industry should also identify the essential ingredients with the highest probability of shortage in case of a pandemic(s), and develop strategies for manufacturing their products with alternative ingredients (ideally locally available) or modified recipes which can fit with their production lines without investments. It is important to keep in mind that existing food supply chains are heavily dependent on fossil fuels making them vulnerable. Existing and new technologies, including digital and physical, are likely to play key roles in the operation and maintenance of these enriched agri-food chains, as well as in ensuring food safety and hygienic practices. The academic community is called to identify and discuss the relevant underpinning challenges openly. This requires an interdisciplinary approach that will involve disciplines from food-related sciences/engineering to social or computer sciences, as well as businesses, and policy/regulation representatives.

COVID-19 has fostered global flexibility. Universities have turned online within weeks, while physical distancing restrictions stretch the system to unknown territories. We expect that academics will respond to the COVID-19 disaster. With respect to foods, we expect to participate in focused conferences/sessions, special issues, or even face-to-face meetings if/when this becomes a possibility.

Credit author statement

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The authors declare that there was no conflict of interest to declare.

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