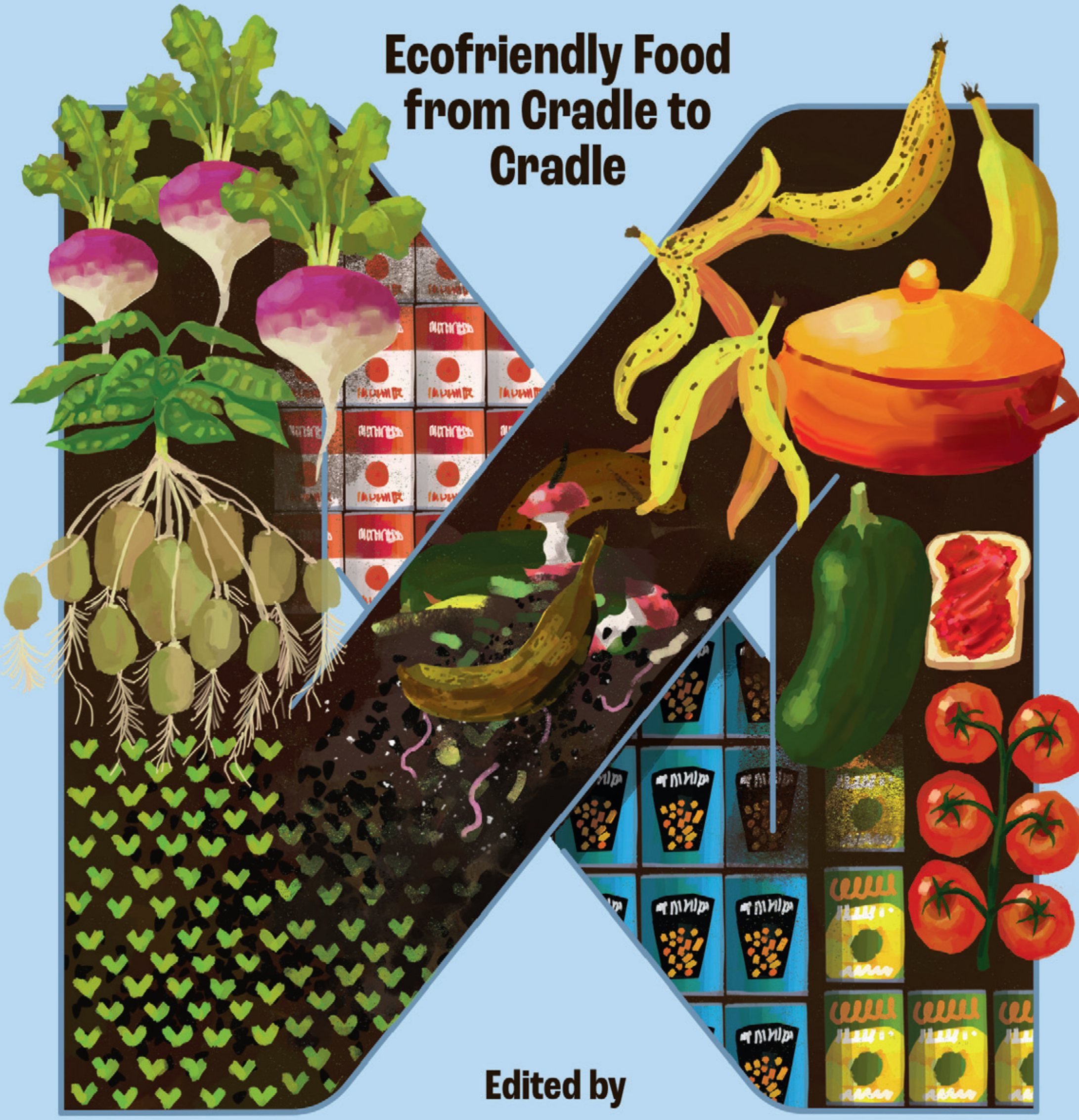
FEEDING TOMORROW ECOLOGICALLY

Ecofriendly Food from Cradle to Cradle



Edited by

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To everyone who practices eco-friendly living.

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Contents

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Preface

This volume serves as a catalyst for feeding tomorrow ecologically. Closing the food cycle from cradle to cradle can only be achieved through collaborative and integrated efforts from all involved parties. **Graham T. Reader** breaks the ice and confronts us with the fact that there is enough food to feed all humanity in Chapter 1, "Engineering's Role as a Partner in the Food Supply Chain: From Farm to Plate and Beyond." The challenge is in sharing food with those who are starving and realizing the United Nations' Sustainable Development Goal in providing adequate nutritious food for all by 2030. Armed conflicts, natural disasters, geography, and severe weather events are factors causing starvation in parts of the world. Reducing food waste and food losses can mitigate the problem significantly, and thus, **Graham T. Reader** encourages engineering involvement at the start of the food supply chain and carrying this from farm to plate, and beyond.

Fertile soil is a necessity for bounteous harvests to feed tomorrow. **Yulin Hu** and **Quan He** relay that biochar is a solution in Chapter 2, "Application of Biochar as a Soil Amendment for Ameliorating Soil Properties." It contains macronutrients and micronutrients; both are essential for soil fertility and plant development and growth. The chapter details how biochar improves a soil's physiochemical properties and microbial community. The ability of biochar to enhance crop yield and quality lends to better harvests and accelerates the transition toward eco-friendly and sustainable agriculture.

No food can be produced without water, and scarce water must be reclaimed to feed tomorrow. This is the topic of Chapter 3, "Water Reclamation Technologies for a Sustainable Agri-food System: The Water-oriented Living Lab of 'La Axarquia' (Spain)." In this chapter, **Antonia María Lorenzo López**, **Alfonso Expósito**, and **Julio Berbel** enlighten us that reclaimed water, along with the nutrients it contains, are key ingredients for more sustainable agri-food systems. Water circularity implies cradle-to-cradle tracing of both water and nutrients. They present five frontier projects in the Water-oriented Living Laboratory of La Axarquia, showing empirical evidence proving the realization of water reclamation for sustainable food production.

Continuing on agricultural, food, and nutrition security, the title of Chapter 4 is "Sustainable Farming to Achieve Future-Proof Food Security." **Mohammad Shokati Amghani**, **Valiollah Sarani**, **Moslem Savari**, and **Hamed Sheykhi** argue that the global food system must undergo transition considering decreased productivity of certain crops and a rapid increase in demand for processed foods.

They review the disadvantages, limitations, and practical challenges of sustainable agriculture in relation to future food security. They propose land consolidation, precision agriculture, cropping patterns, climate-smart agriculture, and family farming as solutions.

Esraa E. Ammar, **Abubakr S. Sallam**, **Shrouk Ekramy**, **Nouran A. EL-Shershaby**, and **Xiaobo Zou** assert that feeding tomorrow is a holistic approach to improving food production, delivery, and consumption while addressing present and future challenges in Chapter 5, "The Evolution of Feeding Concepts and Technologies: Past, Present, and Future." Sustainable practices, technical improvements, and legislative reforms to further food security, sustainability, and universal access to nutritious food for future generations are highlighted.

Good policies are required to enable the realization of sustainability goals such as SDG 2: End Hunger. In Chapter 6, **Beth-Anne Schuelke-Leech** addresses public policies for supporting sustainable food systems, "Policy Formulation and Implementation for Sustainable Food Systems." Sustainable growth, environmental sustainability, and socially just sustainability are some definitions of sustainability, and they do not all mean the same thing. Furthermore, the policymaking process and the ideology that contextualizes this process influence what policy alternatives are considered. It is thus unsurprising that policymaking requires compromise.

All designs should be in harmony with their environment, and agricultural systems are no exception. This is the discussion of Chapter 7, "Harmony by Design: Fostering the Green Engineering Revolution for Sustainable Agriculture." **Abhishek Anand**, **Monika Jain**, **Bishal Mukherjee**, **Suman Dutta**, and **Manish Kumar Naskar** explain the pivotal role of engineering in revolutionizing agriculture toward an eco-friendlier paradigm to feed tomorrow. Engineers can facilitate precise management of water, fertilizers, pesticides, etc. with the help of advancements in precision agriculture, sensor technologies, and automation. They also highlight regenerative farming practices and advocate engineering beyond the farm gate, to food waste reduction and supply chain efficiency improvement.

It follows that a nature-based design system, permaculture, should replace chemical-dependent monocultures of conventional industrialized agriculture as put forth by **Timothy C. Leech** in Chapter 8, "The Permaculture Alternative and Its Potential for Addressing Global Food Scarcity." **Timothy C. Leech** argues that permaculture can particularly address the United Nations SDG 1. No Poverty and SDG 2. No Hunger. Socioeconomic and policy barriers are among the challenges to overcome for widespread adoption of permaculture.

Chapter 9 discloses, "Toxicity in the Green Growth Transition in Africa: Reality Versus Utopia." **Nyong Princely Awazi** sheds light on the green growth transition in Africa, promoting sustainable development, reducing environmental degradation, and enhancing the well-being of communities. With green growth advancements, toxicity in greening notably engenders food security through cultivation of crops for biofuels. **Nyong Princely Awazi** calls on African countries to adopt a holistic approach that integrates environmental protection, public health, and social equity considerations into their green growth strategies. This is also a relevant message for all countries around the globe.

David Cameron asserts that "The economy is the start and end of everything. You can't have successful education reform or any other reform if you don't have a strong economy." With that, we conclude the book with "Analyzing the Circular Economy of the EU Countries: Evidence on Environmental and Sustainable Development Perspectives" as Chapter 10. The question is how we know if the implementation of a measure yields the desirable outcome. **Fazıl Gökgöz** and **Engin Yalçın** explain that a circular economy aims at balancing resource usage and waste and can provide valuable information to assess the successful development of sustainability improvement initiatives. They evaluate the circular economy efficiency of the European Union countries by invoking bootstrap data envelopment analysis. The results reveal variations in efficiency across countries, with Germany, Austria, and Belgium leading in terms of recycling rates and years.

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Chapter 1

Engineering's Role as a Partner in the Food Supply Chain: From Farm to Plate and Beyond

Graham T. Reader

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Abstract

As the global population continues to grow, there will inevitably be demands for more food. Moreover, among the key elements of the United Nations' Sustainable Development Agenda is the provision of sufficient quantities of nutritious food for all by 2030. Presently, the world actually produces enough food for all, so to meet future requirements could mean just doing more of the same in terms of food production. However, aggregate global sufficiency does not translate into individual adequacy for all, so while many have an abundance of food, others are starving. This situation is the result of a combination of many factors from armed conflicts, natural disasters, geography, and severe weather events to the state of national economies, population demographics, and the vagaries of political interventions. These causes are amplified by the sizable amounts of global food waste (FW) and post-harvest food losses (FLs). Engineering alone cannot ensure the eradication of global hunger, but engineering's continuing involvement and improvement at the start of the food supply chain (FCS), i.e., the sowing, growing, and harvesting, could play a major role. Unfortunately, there is a general lack of awareness of how engineering has been, and continues to be, involved in the production and acquisition of food to its processing and consumer availability, i.e., farm to plate. This paucity of awareness is also evident among many engineering communities. In this chapter, some insights are provided into engineering's role in agriculture together with some remarks on sustainable food production

Feeding Tomorrow Ecologically, 1–48

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1. Introductory Remarks

As the world is embarking on numerous pathways to achieve an ecologically-sound global habitat for a sustainable future, it is important to consider the core criteria that will need to be satisfied to realize this ambitious agenda. One of these core criteria is the provision of food for current and future human populations. In their many forms, engineering and technology play key roles in the various activities involved in the food production and supply chain systems. However, to fully appreciate these actual and possible roles it is first necessary to gain some insights into the global, national, and regional activities which provide the end-product, i.e., food. As with many human activities, global approaches to food production processes and systems are not homogenous, a result of many different factors affecting not only how a nation feeds its population but how they provide the wherewithal, e.g., finance, infrastructure, education, and natural resources, to produce the food. Whatever problems exist presently, these will be magnified in the future because, as the global human population increases, so does the need for more food. In this opening section, an overview of some of the many factors involved in the complex nature of food supply chains (FSCs) is given together with the changes being made, or suggested, to improve the efficacy of food production.[1]

The advent of agriculture and the development of mechanical tools, especially since the invention of the self-propelled farm tractor, have significantly enhanced the human's ability to produce more food. However, while engineering, technology, biotechnology soil sciences, and agricultural chemistry all have had increasing roles in the production of food, other factors, particularly geography, ever-changing weather patterns, climate, regional socio-economic factors, politics, wars, and armed conflicts, continue to impact significantly the many processes involved in the production and supply of food. This is especially the case on the African continent (ISAAA (International Service for the Acquisition of Agri-biotech Applications), 2014; Suri & Udry, 2022). Human survival depends on access to food along with freshwater, air, and shelter. Indeed, even with access to water and air, humans can only live a few weeks without food. Generally, the quality of human physical health is closely associated with the provisions of nutritious and sufficient food together with drinkable water, breathable air, and adequate shelter (Office of the High Commissioner Rights, n.d.; Reader, 2022; UNEP, 2022).

Not surprisingly, as populations became more settled and less nomadic their necessary food supply came to be more reliant on crop growing. To meet the growing demand, the size of the agricultural work force had to increase such that for most nations agriculture was the dominant industry. For those communities in

[1]Abbreviations and acronyms are defined when they first appear in the text.

the fortunate situation of being able to cultivate surplus food, the accompanying agricultural trade provided a significant revenue stream. Consequently, until the dawn of industrialization, 75% or more of workers, including slave labor, were employed to feed the populace. Since the industrial revolutions the global percentage of agricultural workers has fallen dramatically to 27%, particularly in rich countries (Roser, 2023). Maybe this is one of the reasons why there appears to be a general lack of awareness of the importance of farming, especially among growing urban populations and mainly in developed countries. Additionally, according to recent articles, there needs to be greater awareness among all consumers regarding the virtues and advantages of sustainable healthy and nutritious food (Guiné et al., 2023; FAO et al., 2020).

To counteract the ostensible lack of public understanding regarding food quality and quantity it is likely that this has resulted in the increasing use of phrases such as "Farm to Fork," "Farm to Table," and especially "Farm to Plate." These descriptions have become popular taglines in food industry product branding and marketing as well as in the literature emphasizing the virtues of rural tourist destinations (Tourism Essex, 2017). Such epithets are also used by international agencies to headline their pathways and planning strategies to achieve universal sustainable and affordable food production (FAO, 2024a; Milicevic & Nègre, 2023; Wesseler, 2022). In their literature, the food marketing media frequently involves schematics and animations of the many food chain processes which can provide easy to understand features of FSCs and their management whereas agency websites and open-domain reports offer more intricate representations of the individual steps that are taken to supply food to consumers.

These illustrations could be useful in drawing attention to the roles engineering and technology play in food production for student and practising engineers not pursuing careers primarily in the agricultural and biosystems disciplines, but there is little evidence of such instances in the curricula of mainstream engineering programs apart from industrial engineering offerings. There is then a dearth of awareness within the general engineering community of the rudiments of food production reflecting what is also the case in society at large. So, whether at home, in a restaurant or other eating situation, it is likely that whatever form of food is provided its origins are rarely questioned or even considered. Furthermore, although supermarkets and grocery stores frequently label their food products with their place of origin the journey the food has taken from the source is not espoused. This is not surprising since the FSC and its management can be palpably complex and to add the specific details onto every individual food item would be a monumental task. The situation can be appreciated as shown in a relatively simplified schematic of a FSC as shown in Fig. 1.1.

In many developed countries, the number of workers in the agricultural sector, especially in Europe, as a percentage of a national labor forces is now far lower than it was at the start of the 19th century Industrial Revolution. For example, in France at that time almost 60% of the labor force was employed in agricultural activities, but by the start of the present decade, this has fallen to 3%; in the United Kingdom (UK]), the current percentage is about 1% (Roser, 2023). The main

Fig. 1.1. A Schematic Representation of Typical Food Supply Chains.

reasons for this dramatic decline are mechanization, automation, and biochemical interventions such as synthetic fertilizers, pesticides, insecticides and genetically modified resilient raw materials, e.g., seeds. Globally, the labor force size decline has not been quite as dramatic, but it has fallen from 44% to about 25% over the last three decades. Nevertheless, in some countries of sub-Saharan Africa, like Uganda and Nigeria, the levels of agricultural employment today are greater than they were in France and the United Kingdom, five to six centuries ago. To some extent, these differences are also examples of geographical impacts on food production as soil in temperate climates is usually more inherently fertile than in other climatic regions (Arnfield, 2024; Sowell, 2023).

The global heterogeneity of fertile soil location is also manifest in other forms of food production such as "capture" or "wild" fishing. In locations where high concentrations of photosynthesizing organisms exist the fish stocks are at their most abundant. The most productive area is the pacific northwest with the northern Pacific Ocean providing more capture fishing than anywhere else (Hilborn, n.d.). In general, the oceans account for almost 90% of the capture fish the remainder being freshwater fish found in lakes and rivers. However, the demand for fish has long outpaced the amount that can be captured. The three main reasons for this are population growth, the increased per capita consumption of fish products, and non-sustainable fishing practices (FAO, 2018). To make up the deficit between demand and supply, fish farming, a form of aquaculture, has become increasingly popular and, in terms of the amount produced, it is now equivalent to that captured, with the Food and Agriculture Organization of the United Nations (UNFAO) forecasting an even greater share by 2030 (FAO, 2024b).[2]

A more or less equivalent strategy for enhancing land-based food production has been the increased use of large-scale greenhouse facilities (Ashton, 2024). It is worth noting that both land and water food production is not solely for human consumption as domesticated animals, i.e., pets, livestock, and beasts of burden, also need food. Moreover, not all crops, whatever their sources, are used for food purposes, including bioenergy, household cooking and heating, and clothing. Indeed, clothes are made from certain type of fish and animal skin. Additionally, fish, shellfish, and aquatic plants are also used in the production of fertilizers for use on land. Overall, the "bio-economy" of products from non-food agricultural sources, such as "Fuel, fibers, starch, oils, solvents, dyes, resins, proteins, speciality chemicals and pharmaceuticals," many of which are replacements for fossil-fuel based versions, are creating new industries and significant employment opportunities as well as new markets for farmers, especially in developed countries (European Commission, 2018; Farm Europe, 2017; OECD, 2009).

The term "farm" used as a noun or verb outside of its use in food production has numerous connotations, e.g., farm-team in the sports sector (Merriam-Webster, 2024). However, its use is more frequently associated by the world at large with

[2]Aquaculture is "the breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in all types of water environments," according to the National Ocean and Atmospheric Administration (NOAA) of the United States.

the agricultural production of food for human and animal consumption although the descriptions "wind-farm" and "solar-farm" are becoming more familiar to the public.[3] The diversity in the use of "farm" labels is also echoed in the ways different national and international agencies define agricultural farms into "consistent" groups so that the wide range of collected data can be more readily compared, e.g., size, revenue, and ownership (Garner & O Campos, 2014; Gov.UK, 2024; USDA, 2024a). While these data are useful for governments in assessing the impact of their agricultural sectors on the country's economy, when collated on a global basis by the UNFAO, it makes crucial contributions to several indicators used to assess progress toward the realization of the Sustainable Development Goal (SDG) to end global hunger by 2030, i.e., SDG 2 (FAO, 2023; UN, 2023).

This particular SDG has 5 national and 3 international targets associated with 14 indicators (tier classification ref). Although there are established international methodologies to collect, assemble, analyze and report the identified data used in the assessment of the indicators not all countries regularly obtain the necessary data. In these cases, the associated indicators are labeled "Tier 2" whereas if more than 50% of countries participate in the acquisition of the target measurements, the indicators are defined as being "Tier 1" (United Nations Statistical Commission, 2024). In global terms, Tier 1 indicators and target valuations are more comprehensive in quantity and quality than Tier 2. Unfortunately, many of the Tier 2 indicators are connected to productively, sustainability, and revenue pertinent to the small-scale agricultural endeavors that are the primary focus of SDG 2. As with all SDGs, each target and indicator has a custodian agency or agencies who compile, verify, and submit data to the United Nations Statistics Division (UNSD) after it has been validated and approved by the countries concerned. These agencies are usually a part of the UN organization, e.g., United Nations Children's Fund (UNICEF]) or the UNFAO, but reputable and authoritative international bodies, such as the World Bank (WB) and the Organization for Economic Co-Operation and Development (OECD), are also involved.

While the SDG data are crucial in assessing the progress toward meeting the sustainable development targets, they are but a subset of the extensive data collected by government agencies such as in the European Union (EU), the United Kingdom and, especially, the United States, regarding agriculture and the food industry in general. All these data are helpful in characterizing the changing nature of FSCs and emerging agricultural industry cultures, e.g., "Smart Agriculture" and "4th generation Agriculture" (De Clercq et al., 2018; Sayegh, 2023; Shalimov, 2023). These insights can also enable the identification of new opportunities for the development of an even wider range of engineering disciplines and technology innovation partnerships with the agriculture and food industries, particularly improvements in productivity and land-use efficiency. For example, if automated self-driving on-road vehicles can be readily manufactured, why not similarly operated farm vehicles? Moreover, developments in artificial

[3]Including food for household pets.

intelligence (AI), machine learning, and the Internet of Things (IoT) promise to revolutionize the effectiveness of many human activities, so why not apply them to food production and the many elements of the FSC (Agriculture Sector, 2023; Javaid et al., 2024; Lomasky, 2024; Manyika & Bughin, 2018)? Such eventualities are further discussed in Section 1.3.

Over the past half-century, the economic sectors of today's richer countries have been transformed by the advances in, and use of, engineering, technology, biological sciences, and supply chain management to being industrial, manufacturing and service-based as opposed to agricultural (World Bank, 2019, 2024a). However, the economies of countries with low income per capita, as measured by their Gross Domestic Product (GDP), are still dominated by their agricultural sectors (Suri, 2011; Suri & Udry, 2022). Is this because of the lack of political will to embrace technology and provide crucial infrastructure, e.g., roads, affordable energy, or the lack of the ability of governments to acquire the financial resources needed to provide such facilities (Ruzzante et al., 2021)? Similarly, farmers in these countries do not have access to the level of investment capital necessary to purchase, lease, or rent advanced agricultural equipment. Advanced agricultural technologies can be costly.

In a rich country such as Canada, known for its agricultural acumen, the farming communities had debts of almost US$110 billion in 2023, representing more than a 25% increase over a 5 year period (The Ivey Academy, 2023; Statistics Canada, 2024). However, over the same period the value of farm real estate has increased by close to 50% to US$540 billion within a total agricultural asset value of US$680 billion (Statistics Canada, 2024a). As produce prices have also increased the solvency and return on investments have balanced the liabilities of Canadian farmers. The annual GDP of similar sized countries, by population, such as Angola and Uganda are lower than the debt load of Canadian farmers yet while agriculture only accounts for 1.4% of Canada's GDP, for Uganda it is 24% and 15% for Angola (World Bank, 2024a). If technology is to be used as a core strategy to improve agricultural productivity in low-income countries, then enormous financial investments will be needed, but where will the money come from? According to the World Bank, the annual development assistance and foreign aid provided to the numerous countries which constitute sub-Saharan Africa, a region with a population 30 times greater than Canada's, peaked at slightly less than US$60 billion in 2020, an amount equivalent to about 55% of Canadian farmers' debt-load (World Bank, 2024b). Perhaps a less ambitious use of engineering and technology would be appropriate for low-income regions?

While there appears to be a general lack of public awareness regarding the complexities of the global agricultural industry, there is also a paucity of appreciation among farmers regarding safety standards. Working in the agricultural sector is "one of the most hazardous occupations worldwide" (McNamara et al., 2019). According to a UN report, at least 170,000 agricultural workers are killed annually, which is twice the rate of workers in other sectors, and these figures are likely an underestimate (Elver, 2018). What role does engineering, especially concerning accidents involving agricultural machinery, play in this unsettling situation? On a global scale statistical attribution of the causes of these fatalities is difficult to quantify mainly because of the scarcity of accurately reported data. A limited survey of Irish farmers found that about 32% of fatal accidents were associated with farm machinery while Canada, which has a comparatively robust system for industrial accident reporting, identified that 66% of agricultural fatalities over the period 2011–2020 were machine related (Belton & Drul, 2023; McNamara et al., 2019).

However, in Canada, for the same time period, there were over 30 times more deaths in road accidents than among agricultural employees, but, in terms of scale, the per capita rates of death are far higher in the farming environment.[4] This is a common occurrence in many developed countries such as the United States, the United Kingdom, Italy, and other EU countries, yet, according to the International Labor Office (ILO), the situation is far worst in less developed countries (ILO, 2011; Merisalu et al., 2019). Nevertheless, it is noteworthy that, in a 2019 analysis of fatal agricultural injuries from 1992 to 2015 in the United States it was estimated that engineering developments had led to a reduction in the number of fatal accidents by over 60% (Issa et al., 2019). In addition to physical accidents associated with technology, there are many other health and safety issues that are frequently encountered in agricultural work environments such as the lack of personal protective equipment (PPE) for workers using chemicals – pesticides, herbicides, and fertilizers (Liebman & Augustave, 2010; Molina-Guzmán & Rios-Osorio, 2020). Moreover, in lower income countries, facilities for many farm workers such as adequate provision of food, drinking water, and sanitation and disease protection are limited (Elver, 2018; International Labour Office and United Nations Conference on Trade Development, 2013; Lord, 2023a, 2023b). The claims that agricultural employment can be dangerous are clearly justified. However, the situation maybe even worse than the statistics imply as a number of part-time, temporary, and seasonal workers, who are often migrants, are regularly undocumented (Drenon & Debusmann, 2024; Rosenbloom, 2022).

The use of engineering devices, often in combination with chemical agents and bio-scientific technologies, depending on the particular environment, e.g., terrestrial or water-borne food acquisition activities, all have one main objective which is to improve agricultural productivity. While these factors may result in the production of greater amounts of food, they do not necessarily make food more affordable to the consumers, especially if the rate of population growth exceeds the rate of production increase. Affordability, whether it be for housing, energy or food, is a major societal problem worldwide and presents daunting challenges for governments regardless of political ideology. If solutions are to be found, then the most crucial step is to eliminate general poverty. Thus, the main aim of the UN's Sustainable Development Agenda is to eliminate poverty in all its forms (UN General Assembly, 2015). Although policies and commitments were established by many governments following the passing of three UN resolutions in 2015 – the climate change accord [Paris Agreement], Sustainable Development Agenda [Transforming Our World], and disaster risk reduction [The Sendai Framework] – the COVID-19 pandemic,

[4]Based on the official number of agricultural employees and the country's total population.