Ch 1 Studying agri-food supply chains: an analytical framework

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1 Introduction

Food supply chains are an essential part of our society. From the primary production of agricultural products to the retail and foodservice settings through which food products are distributed, these extensive supply chains provide a wide range of products to satisfy daily demands for human nutrition. In addition, these food supply chains also provide a significant contribution to the economy and to employment across the world (Beckman and Countryman, 2021).

We probably live in one of the most interesting times to study agri-food supply chains. Demand for food is expected to rise significantly over the next few decades, both as a result of population growth and even more so due to the rise in average income levels. Increases in agricultural food production (mostly due to improved yields) have so far been keeping up with increasing demand[1], even though food insecurity remains a major problem in many parts of the developing and developed world. Matching food supply and demand is thus one of the key global challenges for the future.

In addition to this challenge of rising demand, agri-food supply chains regularly have to deal with external events that can lead to significant supply chain disturbances. Since the start of the COVID-19 pandemic around the turn of the year 2019-2020 e.g., the media have almost continually reported problems with supply chains and resulting disruptions in food supplies. Examples include the closure of meat processing facilities due to COVID-19 outbreaks among staff (e.g., Guardian, 2020) or the occurrence of agricultural surpluses (with resulting losses and waste) due to mismatches in supply and demand and interruptions in supply chain operations (e.g., Los Angeles Times, 2020; Washington Post, 2020). The war in Ukraine has made us realize

[1] https://ourworldindata.org/yields-vs-land-use-how-has-the-world-produced-enough-food-for-a-growing-population
https://hbr.org/2016/04/global-demand-for-food-is-rising-can-we-meet-it

that the development of globalized agri-food chains has made many countries heavily dependent on agriculture in particular regions. The war has both disrupted production in Ukraine itself and closed the Black Sea, resulting in shortages in grain and consequently considerable price increases for both grain and commodities using use grain such as bread[2]. Ukraine is also a major exporter of sunflower oil, which became a scarce commodity in many places soon after the start of the war[3]. The resulting price increases in sunflower oil have since then had an effect on pricing and availability of products that use sunflower oil as an ingredient such as snacks.

Partly due to these events, the design and development of effective global strategies for managing the supply chain of agri-food products has become an even more complex and challenging issue. An added dimension is ever-increasing consumer requirement (which now encompass not just price and quality but other issues such as environmental and social stability or animal welfare) which require responding to almost continuous changes in lifestyle and dietary preferences (Tsolakis et al. 2021).

Agri-food supply chains have unique characteristics and challenges for which we need an appropriate analytical framework. In addressing these issues, we first discuss agri-food supply chain characteristics, after which we provide a framework for designing agri-food supply chains.

2 Agri-food supply chains (AFSCs): a brief review

An agri-food supply chains (henceforth abbreviated as AFSCs) comprises various stakeholders representing the different stages related to agricultural production, post-harvest, storage, processing, distribution and retail operations, and linkages between these components (Behzadi et al., 2018). The management and design of AFSCs has received considerable attention from both researchers and practitioners over recent decades. Although AFSCs have similarities with other manufacturing supply chains, they have specific characteristics that make the management of these chains more challenging than other manufacturing supply chains (Onggo et al., 2019). Some examples are fluctuations in raw material supply (e.g. due to weather conditions which are becoming more unpredictable and extreme with climate change). food price volatility, food waste, food and nutrition security, and specific power and governance issues due to regulation frameworks governing food production (Ali et al., 2019). In addition, each of the AFSC stakeholders faces specific and unique challenges compared to other types of supply chains when it comes to running their operations in the supply chain (Mccullough et al 2010). Farmers face issues with resource availability and fertilizer and pesticide use, amongst others (Yadav et al. 2022). Wholesalers and retailers face challenges such as variability in quality and quantity of farm-based inputs, seasonality in supply, and requirements for managing perishable food products in transport and storage, while shelf-life constraints and related raw material/finished product quality deterioration over time are an issue in all parts of the AFSC (van der Vorst, 2000).

[2] https://www.nbcnews.com/news/world/russia-ukraine-war-grain-blockade-global-food-crisis-rcna25910
[3] https://time.com/6155095/sunflower-oil-russia-ukraine/

The foremost issue that emerges both in practice and in the academic literature relates to food losses and waste (FLW). It is often argued that FLW accounts for one third of total food produced, with the UN arguing that food waste is a particular problem at consumer level in developed countries in particular (UNEP, 2021). FLW is not only a problem because of loss of valuable food product but also because many people still do not have access to sufficient food or a balanced diet. Food insecurity has been on the rise in recent years, even in developed countries (FAO, 2021). A number of initiatives aim to tackle this, including food banks in countries such as the Netherlands which redirect surplus food to low income families, simultaneously contributing to ameliorating food insecurity and FLW. They typically rely on donated food (e.g. provided free by retail outlets and consumers) and only rarely use financial donations to buy food.

FLW also represents a loss of resources, including water, inputs, energy and land (Scherhaufer et al. 2018). Water use for food production and processing is the biggest factor affecting global water scarcity (Weinzettel & Pfister 2019). The FAO has established that 70% of freshwater withdrawals are for food production. In addition to the energy required in food production (either directly in e.g. fuel for farm machinery or indirectly e.g. in the energy required to manufacture inputs such as fertilisers and pesticides), several types of food (particularly fresh produce) are also often transported over long distances and may require refrigeration to stay fresh, all of which requires fuel or electricity. These resources could have been used more productively had FLW been prevented.

Closely related to the FLW issue is sustainability. It is well known that agriculture is a major contributor to greenhouse gas (GHG) emissions (Poore & Nemeck, 2019). In AFSCs the dominant share of emissions (around 80%) comes from farming, representing up to 24% of global GHG emissions (Kucukvar & Samadi 2015). However, it has been estimated that transport accounts for about 20% of food systems-related emissions (Li et al., 2022). In fact, one could argue that that FLW should be viewed from the perspective of sustainability to get a correct view of its impact: wasting 1 kilogramme of meat has a much bigger impact on the environment than wasting 1 kilogramme of vegetables, simply because of the higher level of inputs needed to produce meat (Van Rooijen et al., 2024). Reviews of agrifood supply chain reviews such as Yadav et al (2021) mainly focus on the environmental and economic aspects of sustainability. The social implications of sustainability (such as effects on labour conditions or farmer behavior) are far less studied.

An often-quoted issue in AFSCs relates to food safety and food quality. In 2012 e.g. Europe witnessed a major horsemeat scandal with research showing that consumers were particularly concerned about the authenticity (as well as safety) of meat products (Agnoli et al 2016). Traceability of food has become a topic of concern that is often raised in research (cf. Yadav et al. 2021). However, food traceability systems are still relatively undeveloped compared to other supply chains (Feng et al 2020). Blockchain technology, which is a distributed and decentralized system of time-stamped and linked blocks of information, is considered a promising technology to help increase transparency (Fen et al. 2020).

All these factors mean that there are many important and distinctive characteristics to be taken into account when designing AFSCs which, in other types of supply chain, would not play such an important role. These particularly relate to quality decay and perishability of food that should be accounted for in areas of supply chain design such as network modeling, distribution handling strategies or inventory management. Several models have been developed to address different aspects of these challenges (see Yadav et al. (2021) for examples). The remainder of this chapter focuses on a design approach to address key challenges in AFSCs.

3 The development of the concept of 'supply chains'

An early reference to the notion of supply chains is by Professor Jay Forrester in his seminal book *Industrial Dynamics* (1961) which he referred to as supply pipelines. Many people point to the work of military theorists such as Sun Tzu (*The Art of War*) or Von Clausewitz (*On War*) on the challenges in supplying armies as the origin of thinking about supply chains. It is less well known that commercial organizations picked up the idea of building and managing relatively complex agri-food supply chains many years ago. Amongst others, the East Indies Company based in Amsterdam (in The Netherlands) created their own supply network in the seventeenth and eighteenth centuries, building and operating a global shipping fleet to transport spices and other valuable food products from sources of production in Asia to consumer markets in Europe[4]. Between 1700 and 1730 the Zaanstreek area north of Amsterdam was already a logistics hub before the term had been invented. It was the shipbuilding heart of Europe with, at its height, a production output of almost one seagoing ship built every two days. Many principles that we see in supply chains were already applied back then. As an example saw mills were situated close to the wharfs to avoid carrying heavy wooden components over long distances. More distant factories produced canvas for the sails or biscuits for food during the voyage since both were relatively light and could be transported easily over greater distances. In these more rural areas labour was also cheaper to keep costs down. Circular supply chain principles were also already applied: waste timber e.g. was used to build wharfs which also helped manage costs. In addition a range of wood suppliers were used to ensure critical supplies kept coming in (cf. Daly et al., 2021).

Typically, most food supply chains in this period were still local or regional, with networks of local farms supplying neighbouring towns and cities. The development of railroads, advances in shipping (e.g. the development of steam power) and early refrigeration technologies in the nineteenth and early twentieth centuries stimulated the movement of food over longer distances (e.g. import of grain from North America and meat and dairy products from South America into Europe). However, it took until well into the twentieth century for supply chains to really explode globally. In particular, the development of the container made shipping over long distances more economical, making way for the development of regional and global third-party logistic networks (Notteboom and Rodrigue, 2006). It is now hard to imagine global food

[4] This is further described in the canon of the Netherlands (https://www.canonvannederland.nl/en/noord-holland/zaanstreek/scheepsbouw)

transport without use of (in particular refrigerated) containers. Continual innovations in food packaging have also further expanded options for transporting food globally (see Risch, 2009, for an historical overview of developments in food packaging).

4 Food systems versus food supply chains

The notion of managing supply chains has long been acknowledged in food and agriculture research, albeit with more policy-oriented approach often focused on the concept of a 'food system'. The International Food Policy Research Institute (IFPRI) defines a food system as "…the sum of actors and interactions along the food value chain—from input supply and production of crops, livestock, fish, and other agricultural commodities to transportation, processing, retailing, wholesaling, and preparation of foods to consumption and disposal"[5]. Even though this definition seems to have food supply chains at its core, food systems research does not usually focus on the practical issues in management of flows of goods from farm to consumer, which is where agri-food supply chain (AFSC) research can make a contribution.

There are two main ways in which a food systems perspective and a food supply chain perspective differ: scope and scale. Scope refers to the actors involved. Early supply chain research mostly considered the decision-making processes of commercial firms. The growing focus on sustainability has required a broader approach. In their seminal paper, Kleindorfer et al. (2005) call this the extended supply chain. The inclusion of environmental and social impacts in addition to classic economic considerations requires including the domains of government policy/regulation and societal expectations, meaning that actors such as governments, consumers, employees and non-governmental organisations (NGOs) also play a role.

This brings us to the second way the food systems perspective and the food supply chain perspective differs: scale. Typically, the food system perspective takes a more macro view as opposed to a micro view on businesses. This means that studies of food systems typically look at developments at a sector or product level, often including the biological systems that food production interacts with (e.g. by looking at areas such as how agriculture affects, or is affected by, the physical, chemical and biological health of the soils in which crops are grown). As an example, an important recent discussion is on the role of circular economy principles in the sustainability of food systems, in which different land use scenarios can be analyzed on a national or even global level (see Van Zanten et al., 2023 for an analysis on the EU level). How this then translates to individual businesses and supply chains operating in the food system is typically not the focus of such studies. Clearly, both the food systems perspective and the food supply chain perspective are important contributors to the body of knowledge on the food sector.

Figure 1 provides a picture of a generalized agri-food supply chain, which consists of farming activities, processing activities (which relate to preparing the farm products for consumption where needed), distribution from farm and/or processing facilities to food service and retail

[5] See https://www.ifpri.org/topic/food-systems for more on food systems

outlets where consumers obtain food for consumption. Different companies in AFSCs cooperate strategically in one or more areas as legally-independent and autonomous organizations. As a result, companies may be active in different AFSCs and play a different role in each. It is also important to note that AFSCs are not just focused on ensuring a safe, efficient and cost-effective flow of food products to the end consumer. They must also consider problems such as FLW which highlight broader resource management issues that must be addressed in AFSCs (Akkerman and Cruijssen, 2023).

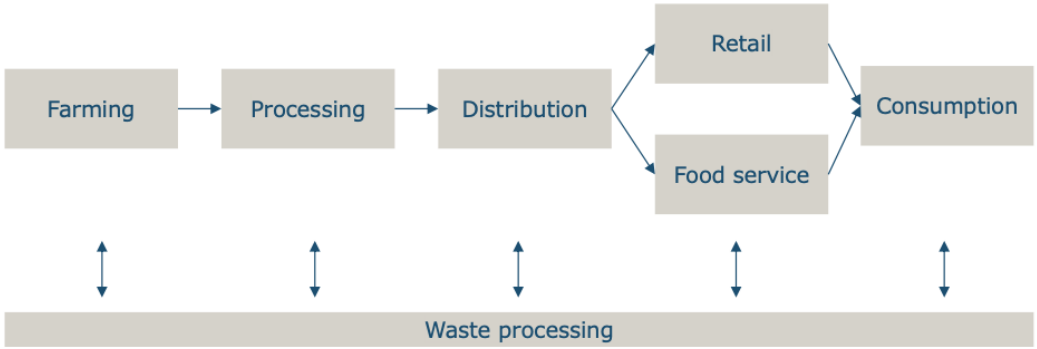

Figure 1. Agri-food Supply Chain model

5 Designing AFSCs: a framework

Frameworks for the design and management of supply chains have been a topic of research for a few decades. Bemelmans (1982) was one of the first to develop a framework for information systems management in supply chains. Fundamental to his work was that the need to develop processes and control in supply chains first, before starting to design information systems to manage them. Van der Vorst (2000) based his supply chain analysis framework on this concept and combined it with the systems approach of de Leeuw (1988). De Leeuw (1988) uses a systems approach and differentiates between the managed system, the managing system, and the information system. Transformations take place in the managed system, which is where services or products are made. The information system is used to take stock of the relevant data that are generated during transformation. This results in key performance information or other types of information that is necessary to measure whether the output of the system meets the targets set. The managing system focuses on realizing this output by means of control variables (decision variables such as production volume), taking into account environmental factors (e.g. disruptions or illness). Each aspect influences key performance outcomes.

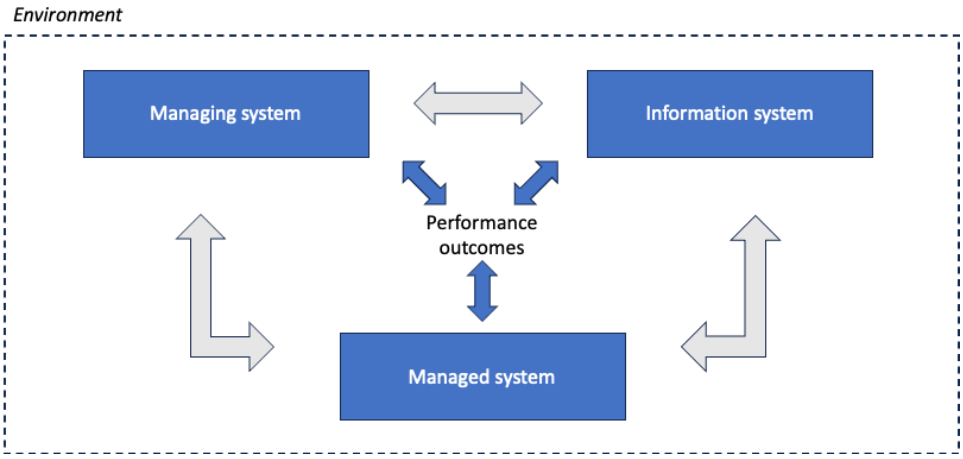

Figure 1. Systems approach to managing supply chains (adapted from van der Vorst (2000) and de Leeuw (1988)).

6 The structure of the book

This book is split into three parts. In Part 1, we first outline the state of development of agri-food supply chains across the globe. In Chapter 2 Schoenherr et al discuss the development of agri-food supply chains in the Americas, after which Bourlakis et al. provide an overview of developments in northern and western Europe in Chapter 3. Ruiz et al discuss the state of development and challenges in Southern and Eastern Europe in Chapter 4. Teng et al close this section in Chapter 6 with an overview of developments in Asia.

In Part 2, following the structure of Figure 1, we outline the challenges and opportunities in each of the parts. In chapter 6 Aramyan et al discuss the measurement and management performance in agri-food supply chains, after which Soysal et al review the literature on agri-food supply chain infrastructure in Chapter 7. In Chapter 8 Transchel et al discuss developments in planning and control of agri-food supply chains, after which information system developments are discussed in Chapter 9 by Schiefer et al.

Part 3 is devoted to case studies on how to improve agrifood supply chains across the globe. In Chapter 10 Soleiro et al discuss the Americas, after which Akkerman et al discuss developments in Europe based on a case study of the COVID pandemic in Chapter 11. Jordaan et al discuss opportunities in Africa in Chapter 12 and Cong et al do this for Asia in Chapter 13. Concluding remarks and future research opportunities in AFSCs are provided in chapter 14.

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