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Sustainable Agrifood Supply Chain Management

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1.1 Introduction – Agrifood Supply Chain Management

The agrifood sector is one of the most regulated and protected sectors worldwide, with major implications for sustainability such as the fulfillment of human needs, the support of employment and economic prosperity, the environmental impact, the tackling of poverty, and the creation of new markets (Humphrey and Memedovic, 2006). Indicatively, the European Commission (EC) is promoting significant reforms to its Common Agricultural Policy (CAP) in order to respond to the plethora of internationally emerging agrifood supply challenges (EC, 2010; Scheherazade, 2014). Growing environmental, social as well as ethical concerns, and increased awareness

Supply Chain Management for Sustainable Food Networks, First Edition. Edited by Eleftherios Iakovou, Dionysis Bochtis, Dimitrios Vlachos and Dimitrios Aidonis.

of the impact of food production and consumption on the natural environment have led to increased pressures by consumer organizations, policy-makers, and environmental advocacy groups on agrifood companies to manage social and environmental issues across their supply chains (SCs) from “farm-to-the-fork” and along products’ life cycles (Courville, 2003; Weatherell and Allinson, 2003; Ilbery and Maye, 2005; Maloni and Brown, 2006; Vachon and Klassen, 2006; Welford and Frost, 2006; Matos and Hall, 2007; Grimm, Hofstetter, and Sarkis, 2014).

In this context, designing appropriate effective global strategies for handling agrifood products to fulfill consumers’ demand, while responding to ever-increasing changes of lifestyle and dietary preferences, has become quite a complex and challenging task. Specifically, adverse weather conditions, volatile global food demand, alternative uses of agricultural production and fluctuating commodities’ prices have led to a volatile supply of agricultural products that is expected to exceed its capacity limit in the forthcoming years. To that effect, developed countries have been increasing their agricultural production in agrifood supply chain (AFSC) operations in order to respond to the projected rise of 70% on global food demand by 2050 (FAO, 2006, 2009; Nelson *et al.*, 2010). At the same time, the value of family farms and the development of local food SCs is clearly recognized for both the developing and developed countries (FAO, 2014).

One of the most critical bottlenecks in agrifood production and distribution is the complexity and cost-efficiency of the relevant SC operations. Modern, global agrifood networks require multi-tier supply chain management (SCM) approaches due to the increased flows of goods, processes, and information both upstream and downstream the value chain. These increased requirements are related to the modern, emerging model of agrifood retailers (i.e., grocery retailers, fast-food and catering services’ providers, etc.), the need for vertical and horizontal integration along the AFSCs, the plethora of differentiated product offerings, the market segmentation, the dominance of multinational enterprises in the food processing and retailing sectors, the need for limiting food waste and overexploitation of natural resources, as well as the branding of firms (van Roekel *et al.*, 2002; Chen, Chen, and Shi, 2003; Mena *et al.*, 2014).

Furthermore, SCM has been recognized as a key concept for the agrifood industry competitiveness. The rapid industrialization of agricultural production, the oligopoly in the food distribution sector, the advancement of Information and Communication Technologies (ICT) in logistics, customer concerns, and a divergence of governmental food safety regulations, the establishment of specialized food quality requirements, the emergence of modern food retailer forms, the increasing importance of vertical integration and horizontal alliances, as well as the emergence of a large number of multinational corporations, are just a few of the real-world challenges that have led to the adoption of SCM in the agrifood sector (Chen, 2006). To this end, SCM embraces the challenge to develop and deploy efficient value chains tailored to the specifications of the modern, uncertain environment, subject to the constraints of local and cross-regional conditions, with respect to logistics means and infrastructure, access to land and water resources, allocation of harvesting areas and the various processing and storing facilities, innovative and sustainable good-practice methods, regulatory and techno-economic environments, and rapid changes of food market characteristics.

In order to develop competitive and sustainable AFSCs, there are a few critical issues that have to be first recognized:

1. the unique attributes of AFSCs that differentiate them from other SC networks;
2. the decisions that should be made on the strategic, operational, and tactical levels;
3. the necessary policies to ensure sustainability of the agrifood chains; and
4. the appropriate innovative interventions, which are required to foster major advances and competitiveness within the evolving AFSC context.

Therefore, more frequent changes in AFSC designs are necessary and strategic actions should be taken to foster sustainability (Halldorsson, Kotzab, and Skjøtt-Larsen, 2009), and thus to achieve higher efficiency in logistics' operations performance and resource usage (e.g., Gold, Seuring, and Beske, 2010; Carter and Easton, 2011).

In general, an AFSC is encompassing a set of operations in a "farm-to-the-fork" sequence including farming, processing/production, testing, packaging, warehousing, transportation, distribution, and marketing (Iakovou *et al.*, 2012). These operational echelons have to be harmonized in order to support five flow types, namely:

1. physical material and product flows;
2. financial flows;
3. information flows;
4. process flows; and
5. energy and natural resources' flows.

The aforementioned operations, services, and flows are integrated into a dynamic production–supply–consumption ecosystem of research institutions, industries, producers/farmers, agricultural cooperatives, intermediaries, manufacturers/processors, transporters, traders (exporters/importers), wholesalers, retailers, and consumers (van der Vorst, 2006; Matopoulos *et al.*, 2007; Jaffee, Siegel, and Andrews, 2010). Moreover, the continuous evolution of AFSCs, and the overall complexity of the agrifood environment along with global market trends further highlight the need for integration of individual SCs into a unified AFSC concept. In such a structure, strategic relationships and collaborations among enterprises are dominant, while these organizations are further required to secure their brand identity and autonomy (Van der Vorst, da Silva, and Trienekens, 2007). A conceptual configuration of AFSCs is depicted in Figure 1.1.

The actors involved in the AFSC system can be generally partitioned into public authorities and private stakeholders. The former category includes mainly national governments and the associated ministries, administrative authorities (regional,

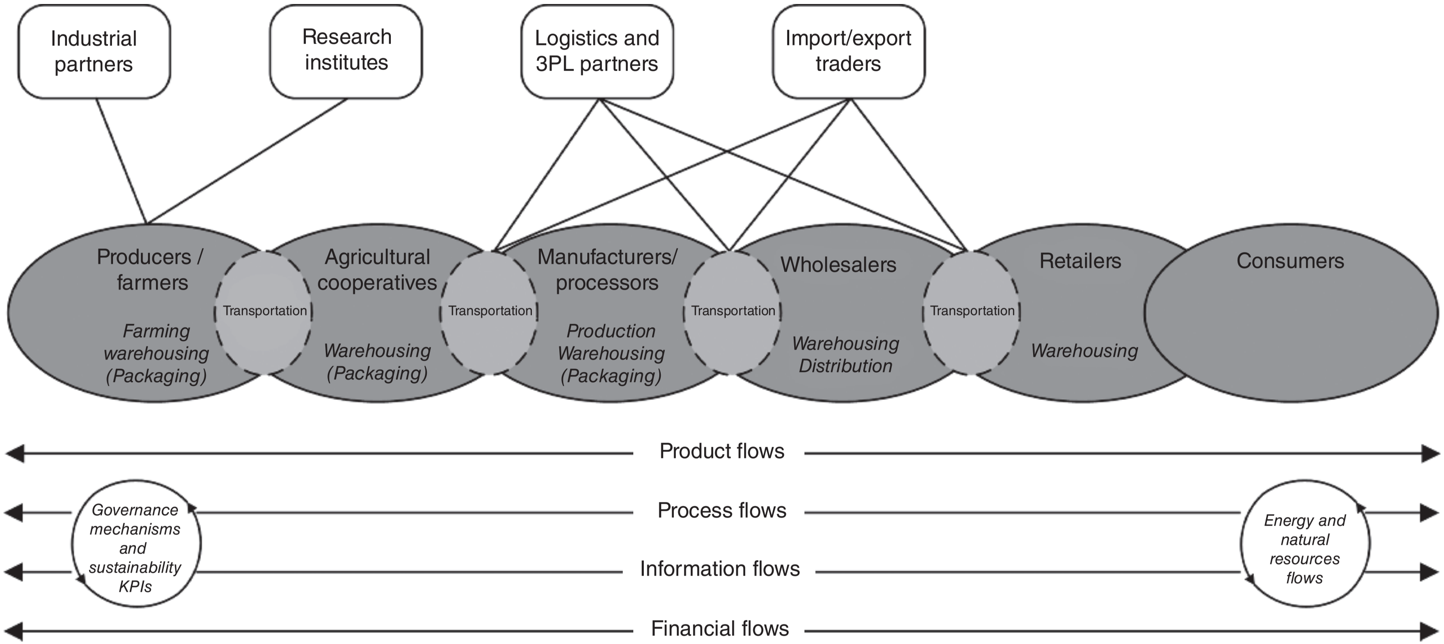

Figure 1.1 A typical agrifood supply chain. Adapted from Tsolakis et al., 2014a.

district, urban), as well as international organizations (e.g., Food and Agriculture Organization), while the latter encompasses individual farmers/growers, cooperatives, research institutes and innovation centers, chemical industries, agro-industries and processors, food traders, logistics providers, transporters, supermarket chains and food stores, as well as financial institutions (Jaffee, Siegel, and Andrews, 2010). In this context, highly concentrated agro-industrial enterprises and retailers have recently morphed into dominant players in the agrifood field, while the public sector has emerged as a key-governance actor (Bachev, 2012).

Furthermore, AFSCs exhibit a set of unique characteristics that differentiate them from classical supply networks and raise an imperative need for customized managerial capabilities. According to Van der Vorst (2000, 2006), AFSCs are characterized by:

1. the unique nature of their products as in most cases they deal with short life-cycle and perishable goods;
2. high product differentiation;
3. seasonality in harvesting and production operations;
4. variability of quality and quantity on farm inputs and processing yields;
5. specific requirements regarding transportation, storage conditions, quality and safety, and material recycling;
6. a need for complying with national/international legislation, regulations, and directives regarding food safety and public health, as well as environmental issues (e.g., carbon and water footprints);
7. a need for specialized attributes, such as traceability and visibility;
8. a need for high efficiency and productivity of expensive technical equipment, despite often lengthy production times;
9. increased complexity of operations; and
10. the presence of significant capacity constraints.

The remaining of this chapter provides an in-depth examination of AFSCs and the related decision-making across the involved operations. Specific focus is provided on the three dimensions of sustainability, that is, economic, social, and environmental (Beske, Land, and Seuring, 2014) that modern, competitive AFSCs need to accommodate.

1.2 Why Sustainable Agrifood Supply Chain Management

The world has encountered and is expected to face even greater volatility and related challenges in the future, including economic crises, social exclusion, and climate change, with direct impact upon business activities (Validi, Bhattacharya, and

Byrne, 2014; Brorström, 2015). The design and adoption of sustainability strategies throughout business operations has emerged as a meaningful intervention to accommodate such challenges (Shaw, 2013). Interestingly enough, the concept of sustainability cannot be easily defined and is, in fact, determined by academicians and decision-makers alike (Parr, 2009). Initially, researchers and practitioners were solely focused on environmental aspects to accommodate corporate needs and drive shareholder value (Caniato *et al.*, 2011). Nonetheless, in the contemporary global contextual framework, sustainability transcends the environmental dimensions and further relates to market competition, availability of raw and virgin materials, access to energy sources and increasing global population (Bajaj, Jha, and Aggarwal, 2013). Hence, the concept of the “Triple Bottom Line” (Kleindorfer, Singhal, and van Wassenhove, 2005) or the “Three Pillars” (White and Lee, 2009) of sustainability has been introduced to highlight the need for a balanced approach to the three P’s, namely people, profit, and planet. The aforementioned dimensions provide corporate growth opportunities emanating from the adoption of sustainable good practices (Byrne, Ryan, and Heavey, 2013; Sezen and Turkkantos, 2013).

The value proposition of linking research to sustainable development is strongly acknowledged. This is further affirmed in the most recent research and development policy documents of the European Union (EU). Specifically, the European Research Area (ERA) vision 2020 calls for a focus on societal needs and ambitions toward sustainable development. The three “Key Thrusts” identified by the European Technology Platform on the “Food for Life” Strategic Research Agenda 2007–2020 meet all of the criteria required to stimulate innovation, to create new markets, and to meet important social and environmental goals. These “Key Thrusts” are:

- Improving health, well-being, and longevity.
- Building consumer trust in the food chain.
- Supporting sustainable and ethical production.

While, the topic of “sustainability” is inherent to SCM (Ahi and Searcy, 2013; Pagell and Shevchenko, 2014), it is only during the last two decades that sustainability in SCM has attracted increased academic and business interest, further reflecting the fact that SC operations are a field where most organizations can and actually implement green strategies (Kewill, 2008; Seuring, 2013). Indicatively, Seuring and Muller (2008) present a comprehensive literature review of almost 200 relevant papers while further outlining the major research directions in the field. Moreover, in the work of Gupta and Palsule-Desai (2011), the existing sustainable SCM literature is classified under four broad categories related to decision-making, namely strategic considerations, decisions at functional interfaces, regulation/government policies, and decision support tools. Similarly, Seuring (2013) reviews papers that tackle the issue of sustainable SCs with a focus on the application of quantitative models. More recently, Ahi and Searcy (2014) conducted a structured review of 445 articles and provide an analysis of 2.555 unique metrics employed in assessing green and sustainable SCM.

The issue of sustainability is even more vital for the food industry which is dominated by a growing demand for sustainably produced food as consumers today are highly cognizant of the manner in which the food is produced, processed, and distributed (Beske, Land, and Seuring, 2014). In general, AFSCs are dynamically evolving over time in order to follow the persistent changes within the broader agrifood environment and to further accommodate the continued introduction of new environmental and food safety legislation from both European and international directives (Glover *et al.*, 2014). In the forthcoming years, modern AFSCs will have to cope with a plethora of major challenges that are underway, encompassing amongst others: rapid urbanization, growth and liberalization of domestic/global factors and markets, decrease of public sector funding, dominance of global SCs, concerns for food quality and safety, changes in technology, weakness of regional rural populations to comply with the requirements posed by dominant enterprises, climate change effects on farming, and the adoption of corporate social responsibility (CSR) practices. Therefore, the recognition of the most critical issues that need to be addressed by all AFSCs' stakeholders toward an integrated decision-making process emerges as a prerequisite for designing and managing such complex, multi-tier SCs and ensuring their overall efficiency and sustainability.

Furthermore, societal stakeholders demand corporate responsibility to transcend product quality and rather extend to areas of labor standards, health and safety, environmental sustainability, non-financial accounting and reporting, procurement, supplier relations, product life cycles, and environmental practices (Bakker and Nijhof, 2002; Waddock and Bodwell, 2004; Teuscher, Grüninger, and Ferdinand, 2006). Therefore, sustainable SCM expands the concept of sustainability from a company to the SC level (Carter and Rogers, 2008) by providing companies with tools for improving their own and the sector's competitiveness, sustainability, and responsibility toward stakeholder expectations (Fritz and Schiefer, 2008). In addition, the principles of accountability, transparency, and stakeholder engagement are highly relevant to sustainable SCM (Waddock and Bodwell, 2004; Teuscher, Grüninger, and Ferdinand, 2006; Carter and Rogers, 2008). More specifically, in response to pressures for transparency and accountability, agrifood companies need to measure, benchmark, and report environmental sustainability performance of their SCs; whilst on the other hand, policy-makers need to measure the sectorial performance within the SC context for effective target setting and decision-making interventions.

Particularly, as dictated by the third "Key Thrust" that ERA articulates, food chains need to operate in a manner that exploits and optimizes the synergies among environmental protection, social fairness, and economic growth. This would ensure that the consumers' needs for transparency and for affordable food of high quality and diversity are fully met. Progress in this area is expected to have important benefits for the industry in terms of reduced uses of resources, increased efficiency, and improved governance. An overview of emerging global trends, policy developments, challenges, and prospects for European agri-futures, points to the need for novel strategic frameworks for the planning and delivery of research. Such frameworks should address the following five challenges:

- *Sustainability*: facing climate change in the knowledge-based bio-society.
- *Security*: safeguarding European food, rural, energy, biodiversity, and agri-futures.
- *Knowledge*: user-oriented knowledge development and exchange strategies.
- *Competitiveness*: positioning Europe in agrifood and other agricultural lead markets.
- *Policy and institutional*: facing policy-makers in synchronizing multi-level policies.

Addressing these challenges could usher the European agrifood sector to the knowledge-based bio-economy, while ensuring that the sector (and food retailers) remains globally competitive further addressing climate change and sustainable development concerns, such as the maintenance of biodiversity and prevention of landscape damage. Meeting these multi-faceted sustainable development challenges facing the agrifood sector worldwide, will require a major overhaul in the current agriculture research system. Recent foresight work under the aegis of Europe's Standing Committee for Agricultural Research (SCAR), has highlighted that in the emerging global scenario for European agriculture, research content needs to extend to address a diverse and often inter-related set of issues relating to sustainable development, including food safety/security (Keramydas *et al*., 2014), environmental sustainability, biodiversity, bio-safety and bio-security, animal welfare, ethical foods, fair trade, and the future viability of rural regions. These issues cannot simply be added to the research agenda. Rather, addressing them comprehensively and holistically in agriculture research requires new methods of organizing research, in terms of priority-setting, research evaluation and selection criteria, and in bringing together new configurations of research teams, as well as managing closer interactions with the user communities and the general public in order to ensure that relevant information and knowledge is produced and the results are properly disseminated.

Furthermore, in order to unleash value, it is important to exploit the potential of utilizing agrifood waste and the associated by-product biomasses for energy recovery and nutrient recycling, to mitigate climate change and eutrophication (Kahiluoto *et al*., 2011). To that end, biomass has emerged as a promising option, mainly due to its potential worldwide availability, its conversion efficiency, and its ability to be produced and consumed on a CO_2-neutral basis. Biomass is a versatile energy source, generating not only electricity but also heat, while it can be further used to produce biofuels (Verigna, 2006; Watanabe *et al*., 2014; Toka *et al*., 2014). Iakovou *et al*. (2010) provide a critical synthesis of the state-of-the-art literature on waste biomass SCM. Agrifood biomass is usually free of toxic contaminants and is determined spatially and temporally by the respective local/regional profile of the pertinent activities.

It is well documented that 31% of the greenhouse gas (GHG) emissions and more than 50% of eutrophication are related to food chains, thus highlighting the need to intervene in the AFSC to ameliorate its impact on the environment (CEC, 2006). In order to promote "green" AFSCs and elaborate agrifood biomass operations on a large scale, the application of appropriately designed innovative policies and systems is necessary (Van der Vorst, Tromp, and van der Zee, 2009; Negro, Hekkert, and Smits, 2007). Green SCM is one of the top two strategic priorities for global corporations (McKinsey, 2011). The benefits of going green are substantial, as green SCM cannot only reduce an organization's carbon footprint but it can also lead to reduced costs, improved reputation with customers, investors, and other stakeholders, thus further leading to a competitive edge in the market and increased profitability. Indicatively, a case study for the new business model for agricultural material sourcing of Nestle, a leading food company (Goldberg and Fries, 2012), summarizes a set of trends that are valid for most food companies.

Indeed, the post-2009 recession period has further underlined the need to turn the business focus, across the world, not only to profitability, but to sustainability as well. Today, one of the key priorities in corporate strategic design for an organization is to emerge as socially responsible and sustainable. Companies are structuring their sustainability reports to disclose their strategy to address the growing concerns of environmental degradation and global warming. Today, 93% of the global Fortune 250 companies release their annual sustainability report (KPMG, 2013), up from 37% in 2005 (Singh, 2010). As a focal part of sustainability initiatives, green SCM has unequivocally emerged as a key discipline that can provide competitive advantage with substantial gains for the company's bottom line. In designing green SCs, the intent is to adopt, comprehensively and across business boundaries, best practices right from product conception to the end-of-life recycling stage. In this context, green initiatives relate to both tangible and intangible corporate benefits. Sustainability reports of many companies indicate that the greening of their SCs has helped them to reduce their operating costs with increased sustainability of their business.

Additionally, modern AFSCs are exposed to a wide variety of natural, technological, and man-made risks, such as weather related risks and extreme weather events (e.g., hail storms, floods, and droughts), natural disasters (e.g., earthquakes, volcano eruptions), biological and environmental risks (e.g., livestock diseases), production risks (e.g., yield uncertainties), human resource risks (e.g., seasonal personnel unavailability), management and operational risks (e.g., forecasting errors), logistical, infrastructural, and technological risks (e.g., uncertainty of new technologies adoption), price and market risks (e.g., price volatility of inputs and outputs), financial risks (e.g., disruptions of farm business financing), policy, institutional, and regulatory risks (e.g., uncertainties of tax and fiscal policies), and political risks (e.g., political and/or social instability) (Jaffee, Siegel, and Andrews, 2010). These risks may inhibit normal operations of AFSCs and could provoke deviations, disruptions, or shutdowns to the SC's fundamental flows. Furthermore, they may have a dramatic impact on cost, efficiency, and reliability of the included activities and operations.

The associated core risk-related decisions refer to: (i) the selection of appropriate risk governance modes; and (ii) the implementation of suitable risk mitigation strategies. The first set of decisions explores the options of the market, private and public risk governance along with the relevant intervention levels. The second set refers to the nature of the applied risk mitigation policy including technology development and adoption, enterprise management practices, financial instruments, investments in infrastructure, policy and public financial support schemes, and private collective actions (OECD, 2009).

The existing research has focused only on few critical aspects of the agrifood risk management concept including cross-border transaction risks (Ameseder *et al.*, 2009), chemical and biological risks (Bachev, 2011), agricultural contracts (Ligon, 2003), catastrophic/disaster risk management (Antón, Kimura, and Martini, 2011; RPDRM, 2012), income risk management (OECD, 2000), climate risk management (Wall, Smit, and Wandel, 2004), and insurance schemes (Bielza Diaz-Caneja *et al.*, 2009).

To sum up, the nature of the overall decision-making process in sustainable AFSCs is purely dynamic, as it unfolds in real-time within an uncertain environment that changes continuously bringing new challenges and opportunities. Consequently, the decisions along with the associated implemented strategies should be continuously evaluated and reconsidered in order to ensure the long-term efficiency and sustainability of an AFSC.

1.3 Hierarchy of Decision-Making for AFSCs

Designing, managing, and operating AFSCs involves a complex and integrated decision-making process. This is even more accentuated when AFSCs deal, for example, with fresh, perishable, and seasonable products in the context of high volatility of supply and demand. In general, the design and planning of sustainable AFSCs needs to address a wide range of issues including crops planning, harvesting practices, food processing operations, marketing channels, logistics activities, vertical integration and horizontal cooperation, risk and environmental management, food safety, and sustainability assurance.

1.3.1 Strategic Level

The strategic decisions involve all stakeholders that are interested in participating in a sustainably driven SC network of agricultural goods. Thus, decisions at the strategic level of the hierarchy span the following aspects: selecting the appropriate farming technologies, SC partnership relations, design of SC networks, establishment of a performance measurement system along the AFSC, and finally, quality assurance. Below, these decisions are further discussed, while a synthesis of the relevant and up-to-date research efforts is provided.

1.3.1.1 Selection of Farming Technologies

Today's trends toward diversified crops, quality standards, increased environmental concerns, biological and weather implications, and safety regulations dictate the need for a careful selection of the farming technologies to be employed (Søgaard and

Sørensen, 2004). To this end, farming technologies range from traditional farming machinery to sophisticated information technology (IT) and precision agriculture (PA) applications; the latter are recognized as a major contributor to increased farming efficiency and environmentally sustainable farming practices (Aubert, Schroeder, and Grimaudo, 2012; Bochtis, 2013).

The main decisions involved in the selection process of the farming technologies relate to:

1. the determination of the capital requirements and expenditure on farming equipment;
2. the development of cooperative schemes in the utilization of farming machinery; and
3. the adoption of innovative farming applications.

In terms of capital expenditure and cooperative actions, the optimum solution must be investigated with relevance to the type of planting, tillage practices, harvesting methods, ownership costs, operating costs, labor costs, and timeliness costs. In terms of innovation and performance, the factors that affect the selection of farming technologies can include, indicatively, the size of the yielded production, the required quality of the agricultural products, and the volatility of weather and soil conditions.

Farming technologies ensure the uninterrupted supply of adequate goods so that a particular AFSC can respond to market demand over the strategic horizon. In the literature, there are well documented quantitative models that deal with the optimal mechanization level of farms with regard to the capital expenditure, economic efficiency, and capacity utilization (e.g., Glen, 1987; Godwin *et al*., 2003; Søgaard and Sørensen, 2004; Sørensen, Madsen, and Jacobsen, 2005; Pandey, Panda, and Panigrahi, 2006; Katalin *et al*., 2014). Moreover, many researchers stress the importance of cooperative schema in machinery utilization, especially in the case of small- and medium-scale farms, which are characterized by common agricultural factors such as the cultivated crop varieties, farm size, soil type, environmental impact, and labor employability (e.g., de Torro and Hansson, 2004; Aurbacher, Lippert, and Dabbert, 2011; Abebaw and Haile, 2012; Dai and Dong, 2014). Today, modern research deals with the incorporation of innovative approaches into applied farming technologies. Robotics and IT applications toward production automation, image analysis, and quality sensing are only a few of the radical advances that have been developed for vegetable propagation, picking, trimming and packaging, robotic milking, and livestock monitoring (Wrest Park History Contributors, 2009). Finally, the utilization of PA technologies (i.e., satellite imagery and geospatial tools that allow the selective treatment of a field as a heterogeneous entity) has emerged as a viable intervention to promote farming efficiency and foster environmental sustainability though drastic reductions in the use of contaminants (by even 90%) (e.g., Du *et al*., 2008; Isgin *et al*., 2008; Aubert, Schroeder, and Grimaudo, 2012; Busato *et al*., 2013; Hameed *et al*., 2010).

1.3.1.2 Supply Chain Partnership Relations

In terms of business relationships, AFSCs present common features and characteristics with the traditional supply networks of commercial products and services. An interesting characteristic of AFSCs is the high level of relationship complexity throughout the entire chains, as there are many stakeholders with shared, but also in some cases conflicting, goals and targets. In any case, effective business relationships contribute to the sustainability of the AFSCs by reducing environmental uncertainty, fostering the development of dynamic capabilities and resulting in higher levels of business productivity (Dyer and Singh, 1998; Fischer *et al.*, 2008; Beske, Land, and Seuring, 2014). Moreover, effective business relationships have been characterized as one of the pillars for SCs' integration (Akkermans, Bogerd, and Vos, 1999; Thakkar, Kanda, and Deshmukh, 2008) which further leads to improved inventory control management and renders SCs with increased levels of resilience (Fernández Lambert *et al.*, 2014).

The issue of business relationships has been analytically examined in the literature. Tsolakis *et al.* (2014a) identify efficient business relationships among the partners of the AFSCs as the key factor for sustaining high performance. Such relationships should be built upon certain principles such as integration, collaboration, coordination, and cooperation. Many authors highlight that it is unlikely for all partners to share equally the benefits stemming from collaboration; however, in cases where the partners share similar paradigms, there is a great possibility for success (Mungandi, Conforte, and Shadbolt, 2012). On the other hand, there are many cases where collaborating parties in AFSCs do not share balanced relations. Matopoulos *et al.* (2007) argue that the most powerful stakeholder dominates the SC by imposing its rules convincingly on the other parties. Therefore, a critical issue is the rivalry between collaborating partners in AFSCs mainly due to this asymmetry in their relationships. Conflicting objectives always affect negatively the relationship schema. Burch and Goss (1999) discuss the competitiveness among manufacturing and retail channels in specific SCs. Moreover, Bijman *et al.* (2006) present the high levels of competition and rivalry between wholesalers and retailers in the Dutch fresh vegetable SCs.

Alliance members in different chain stages (e.g., farmer–processor, processor–retailer, etc.) should invest in building successful partnerships and promoting the sustainability of their AFSCs. To that end, Fischer *et al.* (2008) analyze the factors that affect sustainability in partners' relationships in the agrifood sector in different European countries.

Collaboration and coordination among partners can further help in establishing long term and robust relationships through synergies and common activities. Effective collaboration can only be attained when all members of the SC operate under a "win-win" paradigm, working jointly under the same framework trying to achieve common goals and targets (Barratt, 2004). Through collaborative relationships, all partners can share the added value stemming from the integration of SCs while they can further improve risk management. To that effect, collaboration between farmers, processors, and retailers is pivotal for facing contemporary challenges, such as high consumers' expectations, strict legislative framework for environmental and social issues, and so on (Schiemann, 2007; Lamprinopoulou *et al*., 2014). Mussell and Gooch (2008) present four case studies of collaboration in agrifood value chains (The Ontario Processing Tomato Industry, The Warburtons Value Chain, Perfection Fresh Australia Pty Ltd, Milk Marketing in the Upper Midwest US). In all cases, the collaborative relationships of the partners increased the level of efficiency of the chains. Additionally, Hobbs and Young (2000) present a conceptual framework for analyzing vertical SC coordination in the agrifood sector.

In the literature, key factors have been recognized that affect the quality of coordination among the partners in a specific SC. Communication, through the sharing of information between stakeholders has been recognized as a vital element for the sustainability of the business relationships in AFSCs (Reynolds, Fischer, and Hartmann, 2009; Del Borghi *et al*., 2014). Fischer (2009) presents the results of an empirical analysis of survey data dealing with the main determinants of a relationship's sustainability in all stages of AFSCs. In the survey, 1442 partners (farmers, processors, and retailers) acting in two AFSCs (one for meat and another for cereals) from six different European countries (UK, Germany, Spain, Poland, Ireland, Finland) participated. According to the results, effective communication is the most important factor for the sustainability of the SC.

Moreover, trust has been documented as another essential factor influencing the quality and stability of business relationships in the AFSCs. According to Lindgreen (2003), trust can be considered as a complex multidimensional and dynamic concept of strategic importance in the food sector. More specifically, it is a vital indicator for sustainability in young relationships (Reynolds, Fischer, and Hartmann, 2009), where collaboration history data are missing. To that end, mistrust, for many authors is the main obstacle for implementing successful business relationships in the food industry (Kumar, Scheer, and Steenkamp, 1995; Fearne, Hughes, and Duffy, 2001). Kottila and Rönni (2008) present interesting findings of a case study with two cases in organic food chains, where development of trust among the partners is a more significant factor for success than the frequency and quality of communication.

Finally, contracting among actors can be considered as another fundamental issue for collaboration and integration of AFSCs. Ligon (2003) investigates the risk mitigation related with optimal contracts in the agricultural sector. Fischer and Hartman (2010) analyze the main characteristics of the agrifood SC that influence the selection of the optimal contract type. Da Silva (2005) proposes contract farming as a key component for the development of the agrifood systems. The appropriate regulatory environment, the minimization of contractual hold-ups, the minimization of transaction costs, and the contract design are recognized as key success factors. However, contract farming has been responsible for the emergence of certain problems throughout the AFSCs, such as concerns about unequal power relations, shifting of management decisions, and quality control. Such issues of concern are even more evident in small farmers, as agro-industrial firms tend to work with large farmers and cooperatives in order to minimize transaction costs (Sartorius and Kirsten, 2007; Mungandi, Conforte, and Shadbolt, 2012).

1.3.1.3 Design of Supply Chain Networks

The configuration of an AFSC is a vital issue for the operation and sustainable efficiency of the network in the long-term, in order to respond to increased manufacturing costs, shortened product life cycles, and the global market economies (Beamon, 1998; Farahani *et al.*, 2014; Govindan *et al.*, 2014). In this context, the core set of decisions regarding the configuration of the AFSC network includes:

1. the identification of agricultural capacity over a region, and the selection of the optimal sourcing policies;
2. the development of efficient procurement channels;
3. the allocation of processing/production facilities;
4. the allocation of intermediate warehouses;
5. the design of the transportation networks;
6. the design of the retailers' networks; and
7. the selection of markets.

Despite the significance of the aforementioned decisions and the plethora of relevant papers within the general SCM context, the agrifood literature that focuses on these issues is rather poor, probably due to difficulties generated by the structure and complexity of the relationships across an entire agrifood chain, as well as the uncertainties that characterize this type of network (Mena *et al.*, 2014; Tsolakis *et al.*, 2014a).

Taking into account that very few aspects of agrifood supply network configuration have been addressed in the literature, only a small number of papers have focused on transportation network design. More specifically, Govindan *et al.* (2014) propose a sustainable perishable food SC network design model that minimizes logistic costs and environmental impacts in terms of CO_2 emissions. Furthermore, Boudahri, Bennekrouf, and Sari (2011) propose a model for the design and optimization of the transportation network of an AFSC, tailored to the specific case of chicken meat. Additionally, Higgins *et al.* (2004) propose a framework for the integration of harvesting and transport systems for sugar production. Furthermore, Burch and Goss (1999) discuss the global sourcing issue for retail chains and its impact on the agrifood system. Finally, there is a considerable volume of research addressing SC configuration issues including methodologies and practises that could be appropriately employed in AFSC design, concerning market selection (e.g., Ulaga, Sharma, and Krishnan, 2002), plant location (e.g., Bhatnagar and Sohal, 2005), warehouse location (e.g., Demirel, Demirel, and Kahraman, 2010), and transportation network design (e.g., Akkerman, Farahani, and Grunow, 2010).

1.3.1.4 Key Performance Indicators

Real-world practice has highlighted the measurement of performance as a critical process for companies and organizations in order to improve their SC efficiency and effectiveness, and to further ensure their long-term success and profitability

(Chan, 2003; Neely, Gregory, and Platts, 2005; Aramyan *et al*., 2007). In this context, sophisticated measurement systems have been developed for the continuous monitoring and evaluation of the SCs' performance. These performance measurement systems are even more complicated in the case of the AFSCs, due to explicit technical and managerial uniqueness (Aramyan *et al*., 2006; Tsolakis *et al*., 2014a). The development of measurement systems is mainly based on the selection of the Key Performance Indicators (KPIs). According to van der Vorst (2006), performance indicators in the AFSC networks can be grouped into three main levels, namely: (i) SC network level; (ii) organizational level; and (iii) process level. Aramyan *et al*. (2007) propose a conceptual performance measurement framework for AFSCs based on KPIs in four main categories: efficiency; flexibility; responsiveness; and food quality.

The latest agenda in the field of KPIs deals with the sustainability measurement and the reporting of the SCs' performance. Taticchi, Tonelli, and Pasqualino (2013) recognize transparency and communication to stakeholders, improvement of operations, and strategy alignment as the main drivers for organizations to measure the levels of sustainability in their SCs. Tsolakis *et al*. (2014b) propose a conceptual framework of financial KPIs to measure sustainability interventions in the AFSCs, while they provide a map of existing sustainability KPIs for all echelons in the AFSCs (e.g., chemical industries, farmers, wholesalers, etc.). Further, Bourlakis *et al*. (2014) propose a performance measurement framework for sustainable food SCs. Within this framework, 18 sustainable measures were identified and categorized into 5 main groups of performance elements: consumption; flexibility; responsiveness; product quality; and total SC. In addition, Yakovleva, Sarkis, and Sloan (2012) propose a four-stage methodological framework for the evaluation of the food SCs' sustainability performance. The first stage deals with the selection of the appropriate economic, environmental, and social indicators, while in the second and third stage data gathering, transformation and adjustment using Analytical Hierarchy Process are conducted. In the final stage, a sensitivity analysis is proposed, in order to obtain meaningful managerial insights. Finally, Tajbakhsh and Hassini (2014) present an envelopment analysis model for the evaluation of SC sustainability focusing on the evaluation of all operations relevant to economic, environmental, and social issues.

1.3.1.5 Quality Assurance

Over the last few years, numerous crises and incidents in the food sector [e.g., the major outbreak of Bovine Spongiform Encephalopathy (BSE), commonly known as mad cow disease, the Variant Creutzfeldt–Jakob disease (vCJD), the avian influenza, etc.] have been recorded. According to Resende-Filho and Hurley (2012), 47.8 million people in the USA (approximately 16.7% of the total population) were affected by an illness related to food in 2011. The outcome of these food crises has been the dramatically increased consumers' awareness of food safety. To that end, the implementation of food safety control systems has become an emerging issue for all stakeholders in the sector.

In terms of food management systems, there is a number of outstanding tools available, such as Hazard Analysis Critical Control Points (HACCP), Good Manufacturing

Practice (GMP), and Good Hygiene Practice (GHP) (van Schothorst, 2004; Gorris, 2005). Moreover, a plethora of well-established Quality Management Systems (QMSs) is also available, ensuring the delivery of high quality food products to end-users. Through the implementation of QMSs, companies can adopt common standards for food safety issues, product characteristics, production and business processes, hygiene levels, and so on. The implementation of QMSs schema can be either applied individually by companies or in some cases QMSs can be implemented horizontally throughout the entire SC. The horizontal implementation can guarantee the continuity of increased food safety levels, as all stakeholders employ quality assurance mechanisms and tools with common characteristics and qualifications.

ISO 22000:2005 is one of the most popular and well-established QMSs in the food sector. It is a food safety management system specifying the minimum requirements for any stakeholder in the food chain. These requirements, among others, include the ability of companies to control food safety hazards, to fulfill all applicable statutory and regulatory requirements and to communicate food safety issues to all interested parties (ISO 22000:2005, 2005).

In the same framework, the British Retail Consortium (BRC) has developed a number of BRC Standards for Food Safety, providing quality and operational criteria for suppliers, manufacturers, and global retailers in order to ensure compliance to legal and statutory requirements (BRC Global Standards, 2012). BRC standards are widely used, as there are over 21 000 certified companies in 123 countries. Indicative examples of BRC standards include issues for food safety, consumer products, packaging and materials, storage and distribution, and best practice guidelines.

Another certification scheme with characteristics similar to those of the BRC is the International Features Standards (IFS) for food. The basic objectives of IFS for food include the establishment of evaluation systems, the enhancement of transparency throughout the entire food SC and the reduction of costs and waste time for all players in the chain.

An interesting quality certification scheme, mainly focused on the primary food sector, is the Global Good Agricultural Practices (GlobalGAP). GlobalGAP has published a number of voluntary norms and standards for the certification of primary production in the food sector. Its main objective is to link farmers from developing countries to key international retailers (Asfaw, Mithöfer, and Waibel, 2009; Tipples and Whatman, 2010).

Despite the many initiatives which have been developed in the field of QMSs for the food sector, there are still specific barriers that prevent the development of these systems and tools. According to Bas, Yüksel, and Çavuooflu (2007), such barriers include the lack of knowledge and of qualification programs for food safety systems along with insufficient facilities. To that end, the contribution of several researchers (e.g., Akkerman, Farahani, and Grunow, 2010; Wever *et al.*, 2010) who analyze the integration of QMSs in food SCs focusing mainly on the optimization of processes, economy, and governance is deemed quite valuable.

1.3.2 Tactical and Operational Levels

In this subsection, we discuss the decision-making process at the tactical and operational levels for managing AFSCs. We first address the common characteristics that the AFSCs display when compared with the traditional SCs and then proceed by pointing out unique and challenging issues, including the planning of harvesting and logistics operations along with transparency and traceability issues.

1.3.2.1 Harvesting Planning

The role of harvesting planning on the performance of the entire AFSC is of pivotal importance. One of the most critical issues that needs to be tackled is the extreme vulnerability of harvesting planning to disruptions, such as weather conditions and poor sunlight, plant diseases, poor soil performance, and so on (Epperson and Estes, 1999). At the same time, during the planning of agricultural operations several environmentally sustainable practices must be adopted in order to reduce GHG emissions, maintain biodiversity and foster ecological resilience (Dile *et al.*, 2013). These challenges are even more accentuated in the case of perishable goods, where time is a critical parameter that affects planning throughout all echelons of an AFSC. In this case, the trade-off between the quality of the products (time to reach the market) and the incurred costs (due to agrifood spoilage and wastage) needs further scrutiny and due diligence.

The decisions related to the harvesting operations involved in an AFSC include: (i) the scheduling of planting and harvesting; and (ii) the effective resource management among competing crops. Throughout the literature, factors such as timing of planting and harvesting, planting varieties, fertilizer utilization, water consumption, labor scheduling, and post-harvesting operations have been recognized as very important for cost minimization and maximization of yielded quality (e.g., Higgins *et al.*, 2004; Ahumada and Villalobos, 2009). In addition, several researchers have adopted the concept of Life Cycle Analysis (LCA) in order to assess the sustainable efficiency of on-farm operations (Biswas, Barton, and Carter, 2008; Meisterling, Samaras, and Schweizer, 2009).

More recently, Ahumada and Villalobos (2011) developed a comprehensive quantitative modeling approach for the complex decision-making of the harvesting and the distribution of perishable goods. Furthermore, the location of farms according to the overall AFSC planning, the matching of soil types with the desired crops, the design of crop rotations, the irrigation development and fallow systems and resource utilization balance among multiple farms are key capital-dependent decisions in order to deploy effective and sustainable AFSCs (Tan and Fong, 1988; Glen and Tipper, 2001; Rodrigues *et al.*, 2010; Schönhart, Schmid, and Schneider, 2011).

1.3.2.2 Logistics

The logistics operations in an AFSC deal with the management of the flow of goods along the entire SC in order to provide superior value to the customer at the least cost and in compliance with predetermined performance criteria and regulations.

The significance of the logistics operations upon the sustainability domain is clearly documented in the case of perishable and ready-to-eat products as agrifood products have to comply with quality specifications (Brunner, van der Horst, and Siegrist, 2010), while the sourcing and distribution of the commodities at a global scale and the increased distances between SC partners further highlight the growing awareness toward environment conservation (Soysal, Bloemhof-Ruwaard, and van der Vorst, 2014). It is no surprise that transportation is reported to be one of the main sources of CO_2 emissions (Delgado *et al.*, 1999).

The relative logistics decisions are listed below:

1. fleet management, vehicle planning, and scheduling;
2. the identification of the optimal inventory management and control systems; and
3. the selection of the appropriate packaging techniques.

Ting *et al.* (2014) propose a decision support system to assist managers in food brands to draft logistics plans in order to secure food quality and safety, while ensuring SC sustainability. In addition, Akkerman, Farahani, and Grunow (2010) provide a thorough review of agrifood distribution and logistics operations, such as unitization of goods, packaging, stacking, bundling, wrapping, unstacking, and inventory control (e.g., van Beek *et al.*, 2003).

The optimization of the transport system of AFSCs has been addressed by many researchers. For example, Higgins *et al.* (2004) propose a modeling framework to improve the efficiency of both the harvesting and transport operations while further presenting two real-world case studies encountered in the Australian sugar industry. Additionally, Higgins (2006) proposes a mixed integer programming model for scheduling road transport vehicles in sugarcane transport. A number of researchers have developed optimization models in order to solve truck scheduling problems for transporting biomass and to determine the operating parameters under various management practices in biomass logistics systems (e.g., Ravula, Grisso, and Cundiff, 2008a,b; Han and Murphy, 2012). More specifically, agricultural fleet management deals with resource allocation, scheduling, routing, and the real-time monitoring of vehicles and materials that is mostly undertaken by farmers or machine contractors. Intensive agricultural production systems involve complex planning and coordination of field operations, mainly due to uncertainties associated with yield, weather, and machine performance. The planning of such operations in general, involves four highly interconnected stages, namely harvesting, out-of-field removal of biomass, rural road and public road transportation, supported by the appropriate machinery system (harvesters, transport units, medium and high capacity transport trucks, unloading equipment) (Sørensen and Bochtis, 2010). Current scientific research has contributed to the development of models for the scheduling of field operations involving fleets of agricultural machines with off-line management systems (e.g., Higgins and Davies, 2005; Busato, Berruto, and Saunders, 2007; Berruto and Busato, 2008), with on-line planning (e.g., Bochtis and Vougioukas, 2007) or based on methods form other scientific areas (e.g., Guan *et al.*, 2008). Indicatively, Sørensen and Bochtis (2010) propose a conceptual model of fleet management in agriculture that embeds the on-line positioning of vehicles, machine monitoring/tracking with an improved general knowledge of the production process and management, coordination of multiple machines, route, and path guidance, and so on. Jensen *et al*. (2012) present a path planning method for transporting units in agricultural operations involving in-field and inter-field transports. Vehicle routing in the agricultural sector also constitutes an interesting research field (e.g., Sigurd, Pisinger, and Sig, 2004; Zanoni and Zavanella, 2007; Ahumada and Villalobos, 2011), in food logistics applications (Tarantilis and Kiranoudis, 2004) analogous to other general commodities, or for in-field operations (Bochtis and Sørensen, 2009, 2010).

Regarding the literature of inventory management and control for AFSCs, great importance is attributed to the deterioration of products and their implications on the planning of production and distribution operations (e.g., Akkerman, Farahani, and Grunow, 2010; Bakker, Riezebos, and Teunter, 2012; Zanoni and Zavanella, 2012). Notably, Karaesmen, Scheller-Wolf, and Deniz (2011) provide a comprehensive review and classification of research efforts concerning inventory management of perishable goods, while they further highlight the need for future research in areas such as multiple-products' inventory management, inventory capacity planning, freshness, disposal and outdating, inventory issuance and demand competition, contracting and pricing. Finally, Yu, Wang, and Liang (2012) developed an integrated modeling approach for a Vendor Managed Inventory (VMI) chain and concluded that the deterioration rate of the final products can increase total inventory costs by more than 40%.

Additionally, the packaging techniques along food SCs, from raw materials to final products, are strongly connected with the delivered quality to consumers, and thus they have been thoroughly scrutinized in the literature (e.g., Appendini and Hotchkiss, 2002; Vitner, Giller, and Pat, 2006; Restuccia *et al*., 2010). In their pioneering work, Wikström *et al*. (2014) highlight packaging design attributes that can influence the volume of food waste and which need to be considered by relevant AFSC stakeholders. Most of the existing sectorial studies focus on specific agri-product cases. For example, Sothornvit and Kiatchanapaibul (2009) determine the optimum atmospheric packaging conditions for fresh-cut asparagus so as to increase the food safety and extend the shelf-life of the product. Other indicative works are those of Hertog *et al*. (1999) and Zhang, Xiao, and Salokhe (2006). The latter, examined weight loss, respiration rate, and susceptibility to fungal contamination of fresh strawberries and managed to extend their shelf-life through testing different atmospheric treatment and packaging conditions.

Finally, the decision-making process concerning the logistics operations is closely interrelated to other key attributes such as transparency, food safety, and traceability. In this context, Van der Vorst, van Kooten, and Luning (2011) provide a holistic framework for optimizing the performance of an AFSC with regard to product quality and availability.

1.3.2.3 Food Safety Transparency

Following a number of serious food safety incidents, investors, advocates, and consumers alike, demand that companies ensure food quality in all stages of their SCs and to further disclose quality information about their products (Dai, Kong, and

Wang, 2013). Indeed, food safety is one of the most critical aspects of the AFSCs, enforcing all stakeholders to increase the level of transparency in all stages of their own SCs. Transparency refers to the shared understanding and product-related information exchange among a SC's stakeholders and can guarantee food quality and provenance to all users of food products (Hofstede *et al.*, 2004; Wognum *et al.*, 2011; Trienekens *et al.*, 2012; Tsolakis *et al.*, 2014a).

The adoption of tracking and tracing technologies is a key element for a "smart" AFSC. Innovative traceability systems at all tiers of the supply network can also improve transparency (Kassahun *et al.*, 2014). According to the European Parliament (2002) "traceability means the ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing, and distribution"; while according to the International Standard Organization (2007) "traceability is the ability to follow the movement of a feed or food through specified stage(s) of production, processing, and distribution". Wilson and Clarke (1998) define traceability as the available information regarding the history of food production from farm to final consumer.

Leat, Marr, and Ritchie (1998) outline the increased need for traceability in food safety by providing a number of drivers, for example, identification of the source of the infected product, disease control, labeling regulations, and so on. Bosona and Gebresenbet (2013) outline the driving forces for food traceability. More specifically, they partition the driving forces into: regulatory (e.g., new food safety legislations, ownership disputes, etc.); safety and quality (e.g., tracking food safety crises, value preservation in food SCs, etc.); social (e.g., increase in consumers' awareness, changing lifestyles, etc.); economic (e.g., market share, products' prizing, etc.); and technological (advancement in technology).

Contemporary traceability systems are rather sophisticated as they are developed capitalizing on the usage of ICT instruments. The adoption of radio frequency identification (RFID) tags, barcodes, and alphanumerical codes can assist in securing visibility among the partners of the SCs by facilitating data acquisition and processing and reduce significantly management costs in the entire SC network (Gandino *et al.*, 2009; Dabbene and Gay, 2011; Zhang and Li, 2012; Grunow and Piramuthu, 2013). According to Wang and Li (2012), tracking and tracing technologies can help in the development of a product's quality assessment model and in the decision regarding appropriate pricing strategies. On the other hand, Beulens *et al.* (2005) outline that even if innovative tracking and tracing systems can be easily installed and implemented by each player in the SC, the most important element still remains the coordination at a physical unit's level.

To this end, the establishment of appropriate channels for exchanging information and data and the promotion of the required mechanisms for collaboration and coordination are essential in order to overcome certain difficulties due to the dynamic nature and the high levels of complexity in the structure of modern AFSCs. Finally, Trienekens *et al.* (2012) present a comprehensive framework for transparency analysis in food SCs by identifying the necessary governance mechanisms adapted to different stakeholders' demands for transparency in all echelons of the SCs.

1.4 Emerging Trends and Technologies in Primary Production

On a global scale, GHG emissions from agriculture account for almost 14% of total emissions. Agriculture production is the most important source of nitrous oxide (N_2O) from organic and mineral nitrogen fertilizers, and methane (CH_4) from livestock digestion processes and stored animal manure. At the EU-27 level, emissions from agriculture account for 9.2% of total emissions (corresponding to 462 Mt of CO_2 equivalent in absolute numbers). However, this figure does not include agriculture-related emissions such as the emissions from agricultural land use (57 Mt CO_2 in EU-27 accounting for approximately 1% of the total emissions of all sectors), from fossil fuel use in agricultural buildings and agricultural machinery for field operations, which account for around 1% of CO_2 emissions of all sectors [following the reporting scheme of the United Nations Framework Convention on Climate Change (UNFCCC) these emissions are accounted in the "energy" inventory], and emissions from the manufacturing of fertilizers and animal feed.

Finally, it is worth noting that although agricultural emissions of N_2O and CH_4 rose globally by approximately 17% in the period 1990–2007, mainly due to the increased production in developing countries, during the same period in the EU-27, agricultural emissions declined by approximately 20% mainly due to reductions in livestock numbers and the improved fertilizer applications. Additional reductions in N_2O and CH_4 emissions could be achieved by various farm management practices including, among others, the overall reduction of external inputs (e.g., by employing precision agriculture principles and ICT tools), and the implementation of alternative tillage systems. These issues are further discussed in the following sections.

1.4.1 Alternative Production Systems

Current intensive tillage production systems highly influence soil structure decreasing the soil organic matter leading to significant GHG emissions due to the loss of CO_2 from arable soil. The introduction of less intensive methods in terms of soil preparation (indicated as conservation agriculture systems) and agricultural vehicle traffic (indicated as controlled traffic systems), is expected to keep reducing the agricultural impact on the global CO_2 balance (Chatskikh *et al.*, 2008). Conservation agriculture systems include reduced and zero tillage systems, and direct seeding combined with a varied crop rotation which eliminates disease and pest complications. According to FAO (2001) conservation agriculture conserves and improves arable soil conditions, while conserving water and biological resources thus enhancing and sustaining farm production. It maintains either a permanent or a semi-permanent organic soil cover (e.g., dead mulch) which protects the arable soil from the negative effects of sun, rain and wind, allowing micro-organisms living in the soil and fauna to further preserve nutrient balancing since all inherent natural processes are not disturbed by the mechanical tillage intervention.

Conventional in-field traffic systems can cause a trafficked area of 80–100% of the total field area, while in conservation tillage systems the trafficked area is reduced to 30–60% (Tullberg, Yule, and McGarry, 2007). Sørensen *et al.* (2014) studied the environmental effects of the implementation of reduced soil tillage and no soil tillage systems. They documented that the average of the total GHG emissions per kilogram of product for the conventional soil tillage, the reduced soil tillage, and the no soil tillage scenarios amounted to 915, 817, and 855 g CO_2/kg, respectively. The reductions in CO_2 emissions occurred in conservation systems when compared with the conventional system mainly stem from the reduced CO_2 emissions from carbon mineralization. Furthermore, when considering the operational cost benefits in conservation production systems in conjunction with the above mentioned environmental benefits, it becomes clear that conservation systems provide an overall advantage compared with conventional methods. However, for a comprehensive evaluation, the increased demands for management aimed at sustaining yields should also be an integral part under a systems approach; otherwise, the environmental benefits will be compromised.

In-field traffic, on the other hand, is a main concern in terms of soil sustainability and energy consumption. Controlled-traffic farming (CTF) is a traffic system for agricultural vehicle for their in-field activities which diversifies the cropped area and the trafficked area by creating permanent parallel field-work tracks (Chamen *et al.*, 2003). CTF reduces the trafficked area of a field area (in the range of 20% of the total field) even more compared with various conservation tillage systems. Various studies demonstrate that the implementation of CTF is able to reduce the effects of arable crop production systems on environmental impacts, such as climate change, acidification, eutrophication, non-renewable resources depletion, human-toxicity, eco-toxicity, and furthermore, on soil erosion and land use. Based on a comprehensive review conducted by Gasso *et al.* (2013), a state-of-the-art analysis on the environmental impacts of CTF compared with the conventional traffic systems demonstrated that CTF is able to reduce:

- soil fluxes of N_2O in the range of 21–45%;
- water runoff in the range of 27–42%;
- in-field operations direct emissions up to 23%;
- indirect impacts associated with fertilizers up to 26%;
- indirect impacts associated with pesticides up to 26%;
- indirect impacts associated with seeds up to 36%; and
- indirect impacts associated with fuels up to 23%.

From an operations execution point of view, advanced navigation aiding and auto-steering systems for agricultural machinery ensure accurate driving on predetermined tracks making the implantation of CTF feasible. However, modifications are needed so that the wheel distance widths of the implemented machinery are able to match the permanent tracks offset, allowing the tires to run exclusively on the permanent tracks. This compatibility between the machinery and the spatial configuration of the permanent tracks remains a major impediment to a wide adoption of the CTF; this hindrance can be addressed only with the active engagement of the agricultural machinery industry (Tullberg, 2010).

1.4.2 Innovative Technologies

Advanced engineering and systems engineering approaches in bio-production systems provide great potential for supporting producers to amend environmental impacts in various ways. Selected examples of the implementation of these technologies are listed in the following paragraphs.

1.4.2.1 Satellite-Based Navigation

Global Positioning System (GPS) based navigation-aiding systems and auto-steering systems for agricultural vehicles can reduce the overlapping application of fertilizers and pesticides. Specifically, continuous recording of the field areas where material is applied drives the automatic turning on or off sections of the sprayer preventing double coverage of previously sprayed field areas. The potential savings using automatic section control have been reported to be up to 25% (Stombaugh, Zandonadi, and Dillon, 2009). In general, these systems have provided a number of tangible benefits including the elimination of overlaps and underlaps (untreated areas) leading to savings in input materials, fuels, operational time, and operational cost, reduced operator fatigue, reduced soil compaction, and improved crop establishment. Especially, the latter is a crucial KPI for an effective implementation of the precision agriculture principles as it reduces the spatial uncertainty inherent in crop production systems. Finally, the usage of GPS-based navigation technologies for agricultural machinery is a prerequisite for the utilization of CTF.

1.4.2.2 Satellite-Based Monitoring

Satellite imagery is a powerful tool for crop production which can provide micro-variations in a dynamic and comprehensive manner on crop productivity parameters, such as spatial and structural distribution of soil properties, growing status, moisture, and water content. In contrast to proximal sensing, remote sensing applications in agriculture are based typically, on the reflecting electromagnetic radiation of soil and plant material. These satellite monitoring technologies are replacing the intensive and costly process of laboratory analyzed soil and crop samples. A typical cost in the USA of satellite imagery services is less than US$15 per hectare for multiple readings per year providing a potential increase to the yield of as much as 10% (The Economist, 2009).

The spatial resolution of satellite imagery has improved from 80 m, at the time of the first application in agriculture (Bhatti, Mulla, and Frazier, 1991) (with Landsat), to sub-meter resolution in modern applications (with GeoEye and WorldView).

Furthermore, the visit frequency has improved from 18 (with Landsat) to 1.1 days (with WorldView-2) (Mulla, 2013). The added value of satellite-based monitoring has been proven for the level of large-scale applications, for example, for monitoring areas in relation to EU directives and policies (Alexandridis, Zalidis, and Silleos, 2008). However, modern agricultural production management systems, such as precision agriculture, require spatial information of a higher accuracy in order to support reliable decision-making. To this end, integrated frameworks have been proposed which combine satellite, aerial [i.e., based on unmanned aerial vehicles (UAVs)], and ground (i.e., mobile vehicles and static stations) sensing providing multi-sources and multi-scales monitoring approaches (Shi *et al.*, 2014). These approaches appear to be extremely valuable in the case of small-holder agricultural production systems and, in general, to geographical areas with fragmented agricultural land.

1.4.2.3 Robotics

For over six decades, robots have been playing a leading and often innovative role in increasing the efficiency and reducing the cost within industrial production. In the case of agricultural production, their usage is expected to highly improve sustainability. This conjecture stems from the hypothesis that the current large (in terms of power and size) machinery systems, developed under the economies of scale paradigm, can be replaced by multiple-unit robotic systems consisting of lighter and more autonomous units. However, the challenge is that in contrast to the floor production, where tasks and the environment are predefined, intelligent robotic systems have to be developed to be able to cope flexibly with outdoor, non-structured (i.e., arable farming), or in the best case semi-structured (e.g., orchard farming), environments where agricultural production takes place.

A targeted area for the use of field robots is in pesticide application. Pesticide usage represents a substantial chemical load for the environment with a high risk of undesirable side effects on human health. There is a significant potential for reducing pesticide by implementing patch spraying based on the combination of machine vision and subsequent image analysis techniques combined with precision spraying systems carried out by conventional machinery of small field robots (Bochtis *et al.*, 2011). A state-of-the-art case of robotic variable rate application has been recently presented (Pérez-Ruiz *et al.*, 2015), where based on field trials it was documented that the estimated cost reduction for site-specific flame weeding was approximately 28 €/ha when compared with a conventional system (from 52 to 24 €/ha).

In addition to the ground unmanned vehicles, UAVs appear to have great potential. The use of UAVs is the new trend for small-scale monitoring operations with a current global unmanned aerial systems market revenue of 5400 M€ and this is expected to grow up to 6350 M€ by 2018 (MarketsandMarkets, 2013). Agricultural production belongs to an area that is likely to be able to considerably expand the use of UAVs to high rates, as it involves flying solely on unpopulated areas where restrictions dealing with built-up locations are non-existent (Kuchler, 2014). For agricultural production applications, UAVs offer a complementary solution for crop management and monitoring combined with satellite and ground monitoring layers. Furthermore, the use of

UAVs in agricultural production provides a fast deployment monitoring system at low cost, with the ability to deliver high image resolution suitable for small-scale investigations, and able to overcome the difficulty of repeated measurements during the crop (a barrier inherent in full implementation of satellite-based monitoring; Colomina and Molina, 2014). Finally, regarding small-farm-based production systems, the benefits obtained by the employment of UAVs for monitoring small productive areas have still to be proven (Lelong *et al*., 2008).

1.5 Conclusions

SCM is widely accepted as an area of critical importance for the agrifood sector. SC stakeholders involved in both the design and the execution of AFSCs are called to address systemically an array of complex and often interwoven decisions spanning all levels of the natural hierarchical decision-making process. To that effect, this chapter captures comprehensively and in a novel interdisciplinary framework, both the associated challenges and the complexity of the decision-making process for the design and planning of AFSCs.

We began by presenting the generic system components along with the unique characteristics of AFSC networks that differentiate them from traditional SCs. We proceeded by identifying and discussing the most critical issues for the design and planning of AFSCs, along with the most relevant emerging technologies, as well as by presenting a critical synthesis of the related existing state-of-the-art literature efforts in order to identify major gaps, overlaps, and opportunities. These issues were further mapped accordingly on the recognized natural hierarchy of the relevant decision-making process.

Our critical analysis reveals the following key findings:

- Even though SCs of the agrifood sector have been addressed by the research community, there is a lack of integrated systemic approaches that could support effectively the design and planning of such networks.
- There is a need for the development of appropriate channels for exchanging information and data alongside the promotion of the required mechanisms for collaboration and coordination within modern AFSCs in order to address various challenges stemming from the dynamic nature and the inherent high levels of complexity of these SCs.
- The decision-making process concerning the logistics operations should be closely interrelated to other key attributes such as transparency, food safety, and traceability.
- The integration of QMSs in the AFSCs focusing on the optimization of processes, the economy, and governance is a critical aspect for ensuring a sustainability-driven flow of information, processes, and materials.
- More integrated and sophisticated measurement systems have to be developed and standardized for the continuous monitoring and evaluation of the AFSCs' performance in terms of sustainability aspects.

- Even though in the general SCM literature there is a significant volume of relevant research, a number of core customized decisions regarding the configuration of AFSC networks are still lacking. Targeted research actions have to overcome the difficulties imposed by the structure and complexity of the relationships across an entire agrifood chain toward the development of dedicated decision-making approaches for this type of network.

- The implementation of advanced engineering and systems engineering approaches (such as satellite-based navigation, remote sensing and monitoring, and robotic systems) in primary production provides great potential to amend environmental impacts in both large-scale and small-holder agricultural production systems. In parallel, a widespread adoption of less intensive methods in terms of soil preparation and in-field traffic, are expected to reduce the agricultural impact on global CO_2 balance and prevent soil degradation as a "growth medium."

We envision that the presented decision-making framework, along with the respective critical synthesis, which merge the worlds of operations management, SCM, and agriculture could provide a platform of great value for researchers and practitioners alike to build upon, in their evolving efforts toward the scientific development and management of highly competitive and sustainable AFSCs.

Acknowledgments

This study has been conducted in the context of the GREEN-AgriChains project that is funded from the European Community's Seventh Framework Programme (FP7-REGPOT-2012-2013-1) under Grant Agreement No. 316167. This chapter reflects only the authors' views; the EU is not liable for any use that may be made of the information contained herein.

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