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# An overview of approaches and methodologies for supporting smallholders: ICT tools, blockchain, business models, sustainability indicators, simulation models

Francesco Longo[a,*], Giovanni Mirabelli[a], Vittorio Solina[a], Laura Belli[b], Chaima Ben Abdallah[c], Oussama Ben-Ammar[d], Eleonora Bottani[b], José Manuel García-Gallego[e], Manuella Germanos[f], Francisco Javier Miranda González[e], Sergio Rubio Lacoba[e], Lilia Sidhom[c,g], Giuseppe Vignali[b], Gregory Zacharewicz[f]

[a]*University of Calabria, Ponte Pietro Bucci 45C, 87036 Arcavacata di Rende (CS), Italy*
[b]*University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy*
[c]*Laboratory of Energy Applications and Renewable Energy Efficiency (LAPER), Faculty of Sciences of Tunis, El Manar University, Tunis 1068, Tunisia*
[d]*EuroMov Digital Health in Motion, Univ Montpellier, IMT Mines Alès, Alès, France*
[e]*University of Extremadura, Avenida de Elvas s/n, 06006 Badajoz, Spain*
[f]*Laboratoire des Sciences des Risques (LSR), IMT Mines Alès, 30100 Alès, France*
[g]*National Engineering School of Bizerta, Carthage University, Tunis 7035, Tunisia*

**Abstract**

The recent COVID-19 pandemic has highlighted all the weaknesses of manufacturing systems and supply chains. In this challenging context, smallholders have faced several crises mainly related to the difficulty of finding manpower for harvesting activities and the impossibility of distributing food, due to the forced closure of many distribution channels. The main consequences were lost sales and wasted food. With the aim of increasing the responsiveness of smallholders in the face of COVID-like crises, this paper provides an overview of methodologies and approaches currently available in the literature in terms of: ICT tools, blockchain-based solutions, business models, sustainability-oriented frameworks, simulation models. The analysis of the literature provides two main outputs: (1) a list of challenges to be faced in the coming years to improve the working conditions of smallholders, (2) the definition of future research developments, which mainly concern the design of an ICT platform, which integrates multiple technological aspects.



*Keywords:* Smallholder, ICT, Blockchain, Business Model, Sustainability, Simulation

* Corresponding author.
*E-mail address:* francesco.longo@unical.it

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## 1. Introduction

The recent COVID-19 pandemic has highlighted the fragilities that characterize various supply chain actors [1]. Smallholders (i.e., small-scale farmers) are among those who have suffered most from the occurrence of unexpected and disruptive events [2]. On the one hand, the temporary closure of multiple distribution channels (e.g., open-air markets, shopping malls, bars, restaurants, school canteens, etc.) caused the waste of many agri-food products, which perished in the warehouses. On the other hand, the great spread of the infection limited the available manpower, then fruit and vegetables were wasted as the related harvesting activities were not carried out at the right time [3]. Basically, the main impacts concerned aspects of economic and environmental sustainability. Considering that it is of great importance to formulate strategies to support smallholders in the event of COVID-like crises, this paper aims to provide a preliminary analysis of the state of the art on methodologies and approaches currently available in the literature for smallholders. Five critical areas are analyzed: ICT tools (Section 2), blockchain technology (Section 3), business models (Section 4), approaches for ensuring sustainability according to the triple bottom paradigm (Section 5), simulation models (Section 6). The conclusions (Section 7) briefly discuss the main challenges to be faced in the coming years to improve the conditions of smallholders and provide them with support in the case of COVID-like crises.

This work is the first outcome of the research project entitled "Smart Models for Agrifood Local vaLue chain based on Digital technologies for Enabling covid-19 Resilience and Sustainability" (SMALLDERS).

## 2. State of the art regarding the use of ICT tools to support smallholders

This section is a review of the current state of the art on the use of Information and Communication Technology (ICT) systems (e.g., platforms, ecosystems, architectures, etc.) to support smallholders (or small-scale farmers). The main purpose is to provide an overview of the level of maturity related to the use of new technologies by small-scale farmers. Through some searches on Scopus, which is one of the most recognized scientific databases, it is possible to understand how much this topic has room for improvement and deserves to be explored in the coming years. The two generic queries ("ict") AND ("smallholder") and ("ict") AND ("small farmer") both provide only about 150 documents. Basically, the literature is still extremely limited when we talk about ICT solutions, designed specifically for small-scale farmers. However, it can be easily seen that in the years after the birth of Industry 4.0 (from 2011 onwards) the trend on the number of publications is growing, confirming the interest that the scientific community is reserving in this topic. The main scientific contributions regarding the proposal and application of ICT solutions, aimed at solving smallholder problems, are reported and briefly discussed below.

Bouali et al. [4] have recently proposed a smart agriculture solution, based on the use of an IoT (Internet of Things) system, with the aim of supporting small and medium-sized farmers in the following aspects: intelligent irrigation through real-time data monitoring to improve the quality and quantity of crops and preserving the soil; promotion of efficient agriculture through the minimization of dependence on fossil fuels in the pumping of aquifers. Problems related to water management are also considered by Amarnath et al. [5], who highlight the need for Sudanese farmers to access water-related information in real-time using ICT tools. It is shown that the integration of remote sensing, Geographic Information Systems (GIS) and forecasting models can help predict floods. In this context, the main benefit is that farmers can irrigate with the right amount of water at the right time, maximizing profits.

An interesting result is related to the research carried out by Van Campenhout et al. [6] who evaluate the consequences of using some ICTs in facing the problems of small-scale maize farmers in Uganda. Three technologies are tested: audiovisual messages for providing information on agricultural practices, interactive voice responses, time-sensitive short messages as a reminder for some critical activities. The results show that ICTs can significantly improve yield and decrease waste.

Chaudhuri and Kendall [7] show how the use of ICT technologies can help to improve the collaboration of multiple small-scale farmers, positively change daily practices and be more resilient to recent climate change. The concept of collaboration is also addressed by Omulo and Kumeh [8], who report the experience related to the adoption in Kenya of "Wefarm", an ICT-based platform, which promotes knowledge-sharing between small-scale farmers. The aim is to improve access to information relating to agricultural production, marketing and financial services.

Rubanga et al. [9] argue that small-scale farmers poorly adopt innovative sensing technologies because they are unwilling to invest significant capital. Therefore, they show how to develop a simplified smart agriculture system characterized by limited use of resources. It is characterized by Wireless Sensor Network (WSN) devices and a web database for the daily collection of data, aimed at the best crop management and monitoring. The application of the proposed solution to a real tomato greenhouse shows very promising results.

Moreover, we can state that the use of ICT tools can help smallholders to solve multiple issues such as credit access [10], dissemination of information on farm inputs [11], access to knowledge and development of business linkages [12], sustainability of farming systems [13].

It is important to underline that the vast majority of scientific contributions on this topic are geographically located in developing countries and in particular in Africa. On the one hand, the reasons are to be found in the vast presence of smallholders, on the other hand in the limited diffusion of Industry 4.0-related technologies there [14].

## 3. State of the art regarding the use of the blockchain technology to support smallholders

A blockchain can be defined as a digital transaction ledger maintained by multiple computing entities, in turn organized in a network and not relying on a trusted third party. Each single "atomic" operation in a blockchain is denoted as *transaction* and represented by data files (denoted as *blocks*) managed through specific software instances allowing data to be transferred, processed, stored, and represented in human-readable way. Moreover, the blockchain technology, originally presented in [15], was firstly related to cryptocurrency and financial transactions topics, in detail allowing ubiquitous monetary transactions among distributed untrusted parties, without the need of trusted intermediaries (e.g., banks). Nowadays, several contexts and applications are exploring the opportunities given by the blockchain in order to handle information and enable smart and trustable contracts (e.g., Ethereum [16] and Hyperledger Sawtooth [17]), such as, just to name a few: (i) administrative records management, (ii) digital authentication or signature systems, (iii) health records management, (iv) electronic voting, (v) distribution of locally produced goods, and, in general, (iv) supply chain products' tracking from the manufacturer to distributors and final buyers.

As a reference, Kamilaris et al. [18] provide an analysis of the impact of blockchain-oriented technologies in agriculture and food supply chain, presenting ongoing projects and initiatives, and highlighting how the blockchain is a promising technology towards transparent supply chains (e.g., in the aim of agri-food supply chain, thanks to its integrity, support of small farmers, and better supervision and management capability). Even if various initiatives are on-going, there still exist barriers and challenges which may hinder the wider popularity of the blockchain paradigm among farmers and systems, thus involving technical aspects, education, policies, and regulatory frameworks. In fact, small cooperatives of farmers are a way to raise competitiveness in developing countries, to be able to win bigger shares of the value of the crops they are cultivating.

Hence, integrating blockchain can move forward to a new agriculture model based on the *community concept distributed consensus*, token-based equity shares, and automated governance, in order to foster greater community engagement while removing some of the managerial burdens. Several blockchain-based agricultural solutions and platforms are emerging throughout the world, such as, as an example, FarmShare [19], AgriLedger [20], and AgriDigital [21]. Some examples also start being proposed for the specific case of smallholders (e.g., [22]) and often target developing countries (e.g., [23-24]), as the role of smallholders in the country's economy is particularly relevant. Therefore, applying blockchain in agriculture will support traceability and transparency in all the agriculture supply chains-related transactions, from the farm to the consumer, including the contracts that are typically established between the involved parties, namely:

- Farmer-to-Deliver (F2D) and Industry-to-Deliver (I2D): contract related to the farming or processed food environments, origin of drug variety and processed foods, fertilizing, and product distribution requirements (e.g., cold chain);
- Deliver-to-Farmers (D2F), Deliver-to-Industry (D2I) and Deliver-to-Farmers (D2F): contract terms regarding product distribution, warehousing, delivery, expected product recipient (retailer or industry);
- Retailer-to-Customer (R2C): contract terms regarding sales time, price, and quality.

Enabling these smart contracts allows consumers to exploit improved information about foods they are buying, and stakeholders in the food supply chain to build better relationships with their customers, and to reduce the risk and cost of food recalls, fraud, and product loss [25-27]. Some implications of the usage of these technologies for enhancing sustainability have been also discussed by Quayson et al. [28].

In [29] is highlighted how many farming-oriented blockchain-based frameworks focus on food tracking and traceability, but rarely focus on the design of digital marketplaces supporting the trading of agricultural goods between farmers and potentially interested third-party stakeholders, thus with performance evaluations for the proposed existing frameworks being rarely provided and performed. Due to this, they propose a blockchain-based farming marketplace platform denoted as FarMarketplace, and a methodology to help software solution integrators to better measure the influence of a given configuration setting on the overall Quality of Service (QoS).
Finally, another aspect to be considered is that IoT-oriented technologies have been recently widely applied together with blockchain frameworks [30-32]. This leads to a novel smart farming model, where IoT-based sensors and devices collect and provide data, related to farm goods production and consumption, to the interested subjects (e.g., farmers and agronomists), while blockchain-oriented infrastructures guarantee that production, processing, storage, and distribution records and information may be considered as reliable and genuine in the overall system.

## 4. State of the art on agri-food business models

In recent years there has been a growing interest in research on business model innovation [33] and its effect on business competitiveness. However, as some studies point out [33-34], academia has paid little attention to the case of business models in the agri-food sector.

Based on a review of the literature on business models in the agri-food sector, different typologies of business models have been identified. Specifically, they can be grouped into three categories: Sustainable Business Models (SBM), Business Models 4.0, and Cooperative Business Models (CBM).

The first category includes SBMs (also known as Green Business Models - GBMs) that are not only limited to maximizing economic value but are oriented towards creating benefits for a wide range of stakeholders, always considering environmental and social values. In their literature review, Barth et al. [35] demonstrate the growing interest in this type of business models in the literature. Following Bocken et al. [36], we can identify eight SBM archetypes, depending on the main objective they pursue, i.e.: a) Maximizing efficiency in the use of materials and energy; b) Creating value from waste; c) Using renewable and natural processes; d) Providing functionality and not ownership; e) Adopting a stewardship role; f) Focusing on sufficiency; g) Reusing for society/environment; h) Developing scalable solutions.

Based on this classification, the following list of innovative SBMs has been compiled:

- Community Supported Agriculture (CSA);
- Alternative Agri-Food Networks (AAFNs);
- Solidarity Purchasing Group (SPG);
- Short Food Supply Chain (SFSC);
- Participatory Harvesting Schemes;
- Crowdfarming:
- Business models based on “Participatory guarantee systems” (PGS);
- Bio-districts;
- Sustainable Collective Innovation model.

In the second category, Vlachopoulou et al. [37] propose a classification of the main Business Models 4. 0 that can be applied in the agri-food sector: a) The "e-Marketplace" model: which connects farmers, partners and consumers based on a technological platform that allows the exchange of information, factors and products between the parties involved; b) The "Subscription" model, which uses a fee that is charged periodically. In this case, it is common to offer a free membership with time or access restrictions and a paid membership option which allows to combine a trial or a free and a premium level of services; c) The Data-Driven (DD) model, which refers to organizations that use data as a key resource for their business execution; d) The "Everything-as-a-service" business model (called Xaas), that uses X as a placeholder for any kind of product, meaning that you don't sell the product itself but charge for the usage or the output of the product [38], such as pay-per-use or a monthly flat fee, like Uber or Netflix, respectively.

Although many of the business models included in the two previous categories could be included in the third category of Cooperative Business Models (CBM), this third category has been limited to include some CBMs that cannot be considered as sustainable or as 4.0.
Following De Man and Luvison [39], we can distinguish three variants of CBM: a) Sharing model: in which companies

have similar capabilities to achieve greater scale or network effects; b) Specialization model: in which companies combine their complementary capabilities to offer products that they could not offer individually; c) Allocation model: model in which companies have overlapping capabilities, so that the company that is most efficient in performing each of the activities is selected, thus improving the efficiency of the alliance.

## 5. State of the art about approaches to ensure the social, economic and environmental sustainability of smallholders

Nowadays, the notion of sustainability is becoming increasingly relevant especially in the activity of small farmers as a result of rising concerns about food safety and quality [40]. In the literature, there are different approaches that ensure the economic, social and environmental sustainability of smallholders [41]. One of them is defined by a general Context-Based Sustainability (CBS) which is provided by the study of the smallholders expectations. It is focused on the definition of regulations, standards or of a cycle of actions, adjustment to the environment and accommodation to change. For example, ISO 14040 standard for environmental management can be cited [42]. In other words, this approach defines sustainable agricultural practices in order to provide some guidelines, conceptual framework and checklists. For the smallholders' case, Business Fights Poverty in collaboration with the American group Mars and the Anheuser-Busch InBev group (ABInBev) have recently defined a guide in order to assist enterprise or organism that support the Sustainable Development Goals (SDGs) by associating their activities with those of smallholders to increase sustainable development impact and also business benefits [43]. In fact, this guide provides suggestions for companies to optimally harness the SDGs in their smallholder supply chains for greater business and societal impact [44]. Such study of the sustainability context makes it possible to select indicators in order to measure a given capital such as natural, social or economic capital. For example, Yan et al. [45] prioritized small farmers' perceptions to achieve sustainable development goals. The main proposed indicators were categorized into environmental capital such as sustain resource availability, enhance water security, increase energy security and climate action. According to social capital, the proposed indicators were good health, clean water, gender equity and reduced inequality. Based on the conceptual framework, Azadi et al. [46] proposed an innovative one including four main indicators based on the small-scale farmers' sustainable capitals. First, there is a need to recognize the important role of small-scale farmers in order to provide technical knowledge and training on best management practice. Second one is the consideration of small-scale infrastructure investments. The two other indicators are regarding the access farmer's to financial resources based on new services and the alignment between the objectives and the ability of smallholders to achieve them. Despite the great importance of this 1st-sustainable approach, it relies on the responsibility of smallholders and their implications for correctly applying the guidelines in order to ensure sustainability. That's why, many research works have been oriented towards the quantitative integrated sustainability approach. This last one defines the required tools, methods or frameworks to integrate, to measure and also to evaluate sustainability development. This requires a set of methods implemented to collect and analyze data related to some case study. The aim is to select a number of relevant indicators allowing the quantitative monitoring of sustainability capital [47]. The data collection and analysis tools depend on the research methodology used to ensure and measure sustainability [48]. Different data collection tools that can be cited such as: survey [49], interviews with experts [50], online data, firm data. The methodology defined on the survey tool is based on hypothesis approach and the statistical analysis is usually used for data analysis techniques. In contrast, the methodology-based scenario approach is mostly applied with simulation methods as a data analysis technique [51]. In this context, an integrated farming system was proposed by Das et al. [52] as an innovative strategy of sustainability for very small farmers with high level of risk due to lack of resources, climatic uncertainty and unavailability of improved technologies. Adolph et al. [53] used case studies and questionnaire survey approaches to analyze the long-term sustainability of smallholders in the institutional, socioeconomic and environmental context. They concluded that achieving sustainability by smallholders and poor farmers acquires practices in financial and technical context. These practices could include investments in water and soil conservation, integrated pest management and appropriate mechanization. More recently, Kotu et al. [54] analyzed small farmers' preferences according to three capitals including social, economic and environmental aspects by developing three econometric models. The main indicators presented in this study are soil fertility effect, labor and cash requirement, nutritive value of output, risk and yield. New enabling methodologies and technologies are essential for the survival of smallholders, reduce the barriers to enter the market as well as assure sustainability and new approaches are developed to evaluate the potential of sustainability with focus on implementation in farm level [55]. Finally, for the sustainability assessment, different approaches are proposed in the litterature. Some specific sustainability assessment frameworks developed for the agri-food sector include farm economic costing (FEC) [56]. Another sustainable approach concerns the farm sustainability indicators (FSIs) [57].

## 6. State of the art about the use of simulation approaches to support smallholders

Smallholders are producing about one-third of the population's food supply [58]. With the increase in population, food production should be doubled by the year 2025 in order for the market to meet this growing demand [59]. However, increasing yield is not the only problem that smallholders face as they face challenges in production, delivery, and increase in raw material price due to the COVID-19 pandemic [60-61], climate change [62-63], and political instability [64-65]. Therefore, there is an urgent need to optimize different fronts in the agriculture supply chain, from allocating land to different crops [66] up until pricing the product [67]. Unfortunately, many of these challenges are intractable and special algorithms need to be deployed in order to overcome them [68]. Specifically, researchers turned to simulation and optimization to find suitable solutions to the problems at hand in sustainable time. Whereby these two techniques were able to overcome multiple challenges. For more details, interested readers can refer to several literature reviews [69-73].

Using simulation to tackle agricultural challenges is not considered a recent approach. Many tools were developed throughout the years to help improve the productivity of farmers and warn them of possible dangers. We cite below a few of these works. In 1995, McCown et al. [74] were among the first to deploy the Agricultural Production Systems sIMulator (APSIM) in Australia and Africa. This tool helps find better farming strategies under uncertainty such as the cases when rainfall inadequacy, fertility depletion, and soil erosion are possible. In Ziervogel et al. [75], the authors proposed an agent-based social simulation model to study how smallholders react to climate prediction in Lesotho. In Berger et al. [76], the authors study the viability of smallholders in the face of climate variability in Ethiopia. Their work introduced mathematical programming-based multi-agent systems to study the effects of climate and price variability as well as innovations and production-related policy interventions for the welfare of the farm and population. Lastly, based on the Monte Carlo method, Bizimana and Richardson [77] proposed a farm simulation model to evaluate the use of different farming technologies such as water lifting technology and fertilizers to predict the yield of vegetable growth. Their work took into consideration multiple factors such as the cost of the technology used and the net profit earned to find the optimal configuration for each case.

Although simulation was able to answer many questions and help smallholders in decision-making, some problems were better tackled using optimization methods. For example, Pakawanich et al. [78] worked on crop production scheduling to distribute the revenues evenly among all smallholders. Their work focused on multiple crops, farmers, and periods, It employed a priority-based max-min heuristic that successfully minimized the standard deviation of the revenues per greenhouse by reallocating the crops among greenhouse farmers. In Onggo et al. [79], the authors focused on delivering perishable products from suppliers. They attempt to minimize the inventory, transportation, food waste, and stock-out costs by modeling the problem using a mixed integer program and a heuristic that integrated Monte Carlo simulation with iterated local search. Recently, Azadi et al. [67] attempted to reduce product waste by using stochastic optimization to price perishable goods. Based on Benders-decomposition method and McCormick relaxation, the proposed model maximizes the profit by pricing older produce lower than the fresher ones.

This sample of agricultural problems are a fraction of the barriers that still hinder the work of smallholders. More work is needed to help them reach their full production capacity. Therefore, in this project, we propose combining simulation and optimization to put forward more powerful techniques that can push the boundaries of crop production while keeping in mind the cost, selling prices, lead times, ergonomics and CO2 emissions. These methods would take more risk factors into account than the ones previously mentioned while attempting to meet the market's demand, maximize the farmer's profit and ergonomics, and minimize environmental damages and costs.

## 7. Conclusions

In recent years there has been a significant scientific interest in the problems surrounding smallholders, who often have considerable difficulty in competing with the largest players for several reasons. This paper has provided an overview of the methodologies and approaches currently available in the literature to support the activities of smallholders. Five different areas have been considered. The main emergent challenges are listed below:

- It is extremely important to facilitate the spread of ICT tools also and above all among small-scale farmers, especially in the developing countries. The massive use of ICT platforms (i.e., the adoption of web-applications and mobile-applications) could solve various issues, such as water management, efficient sharing of information between actors in the same supply chain, better planning of agricultural practices.
- Blockchain technology is extremely promising, especially in the agri-food sector for traceability purposes. It is important to stimulate its diffusion even among small farmers, as it could increase the value of the finished product (i.e., the price to the final consumer), through the certification of a set of information along the supply chain. There is a need for practical cases, which can constitute guidelines for implementation even among non-expert farmers.
- The literature on Business Models is quite rich. Many of them focus on industry 4.0 issues and promote collaboration between multiple actors. Today, the main need is to apply them more to real case studies related to small agricultural producers, in order to better evaluate their advantages and disadvantages.
- In the literature, there are various definitions of economic, environmental and social sustainability indicators. However, a performance assessment approach based on multi-capital sustainability indicators is still missing.
- There is an abundance of simulation-based approaches in the literature to solve various issues related to agri-food supply chains. However, it is important to provide small-scale farmers with clear guidance on how to implement them.

Future research developments, by the SMALLDERS consortium, will include the proposal of an ICT Platform, which sees the integration of multiple methodologies and technologies to support smallholders: web and mobile applications, novel business models, adoption of IoT paradigm, definition and application of multi-capital sustainability indicators, use of Modeling & Simulation approach and digital twin.

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