Impact of ICT on the Agricultural Sector's Sustainability: Evidence Based on Practices

Maria I. B. Ribeiro[1](✉), Teresa Guarda[2,3], Isabel M. Lopes[3,4], and António J. G. Fernandes[1]

[1] Centro de Investigação de Montanha (CIMO) e Laboratório associado para a Sustentabilidade e Tecnologia em Regiões de Montanha (SusTEC), Instituto Politécnico de Bragança, Campus Santa Apolónia, 5300-253 Bragança, Portugal
{xilote,toze}@ipb.pt

[2] Universidad Estatal Península de Santa Elena, La Libertad, Ecuador

[3] Algoritmi Centre, Minho University, Guimarães, Portugal
isalopes@ipb.pt

[4] Unidade de Pesquisa Aplicada em Gestão – Instituto Politécnico de Bragança, Bragança, Portugal

Abstract. Despite being an emerging phenomenon, the literature on how ICT impact the adoption of sustainable agriculture has aroused growing interest on the part of farmers, scientific and business communities and policy makers. Therefore, the main objective of this study was to investigate the state-of-the-art of ICT use in agriculture with an impact on the sustainability of the sector. In order to achieve this objective, a computer-assisted bibliographic search was performed in February, 2023. This search included all publications available in the Scopus database and was based on the words "Impact" OR "Contributions" AND "information" AND "Communication" AND "Technologies" AND "Sustainability" AND "Agriculture". Subsequently, publications were selected taking into account the following criterion: empirical studies that demonstrate evidence of the impact or contribution of ICT to sustainable agriculture. For each publication, it was collected information about authorship and publication date, place where the study was developed, type of study, methods, objectives and findings. All studies show positive contributions as a result of the use of ICT and artificial intelligence for the adoption of a sustainable agriculture with lower resources' consumption, namely, improvement of soil quality, greater efficiency in the use of water and energy with the use of solar energy, greater efficiency in the application of nitrogen, minimization of the use of inorganic fertilizers, reduction of food waste and improvement of food security, greater involvement of farmers with sustainability concerns and promotion of more sustainable consumption.

Keywords: Agriculture · Sustainability · ICT

1 Introduction

The agricultural sector is crucial to increase the economic growth and development of the countries and to reduce poverty, especially in developing countries whose economies depend heavily on this sector [1]. In addition, the role of agriculture in rural development

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is highly expressive, with regard to maintaining rural populations, protecting cultural heritage and agricultural trade, activities that shape the cultural heritage and identity of rural regions [2].

Worldwide, the use of ICT has been impactful in reducing poverty and in the economic empowerment of poor women and men in rural areas [3]. Furthermore, agriculture supports other industries by providing raw materials, leveraging demand for many products, allowing industrial expansion and wealth generation [4].

A potential mechanism to increase farmer's income is the use of improved agricultural technologies such as fertilizers, seeds and cultivation techniques. In this sense, digital technologies are most often considered as an opportunity to enable a sustainable future in agriculture and rural areas [5]. In the age of information technology, the numerous electronic devices and existing software applications can offer very important contributions to the challenges that agriculture, especially the food sector, faces such as sustainability, economy and food security [6]. However, to ensure that technological innovations increase productivity and guarantee the sustainability of the sector, Governments must promote locally sustainable ICT, such as mobile phones, Internet-based digital tools and services [4]. For example, precision agriculture is considered an instrument for more sustainable agriculture [7] that analyzes the spatial and temporal variability of agricultural fields using ICT with the aim of optimizing profit, sustainability and the protection of agro ecological services [8]. However, many farmers despite having the necessary technology to operate specifically on site, for whatever reason do not use it in practice and therefore the available ICT systems are not used to their fullest potential [7]. Thus, it is fundamental that several competences and scientific disciplines act together to help strengthen the sustainable development of agriculture through a transdisciplinary approach that can impact society in various domains. For example, the implementation of educational programs on ICT is important to ensure greater involvement of farmers and communities around sustainability issues [9].

Given the importance and recognition of the role of technologies, most countries have already adopted a national strategy for their use in the agricultural sector [10, 11]. In Europe, the European Commission has established as one of its objectives to fully connect farmers and the countryside to the digital economy in order to achieve a smarter, more modern and sustainable future for the food and agricultural sectors [12]. Despite its importance, the use of ICT to increase and ensure the sustainability of the agricultural sector is still an emerging area of research [13]. In addition, the impacts or contributions to the sustainability of agriculture are often only visible in the medium and long term. Such reasons may justify the existence of few articles in this line of research.

In this context, the main objective of this study was to investigate the state-of-the-art of ICT use in agriculture with an impact on the sustainability of the sector, based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

This article is organized into four sections. In the first section, the importance of the theme that is the object of the study is justified, the objective is presented, the methodology used is briefly described and the structure of the article is presented. In the second section, the literature review is organized. The third section describes with more detail the methodology used. The fourth section presents the results including detailed

content analysis. Finally, the fifth and last section presents the main conclusions and suggests guidelines for future research.

2 Background

From the 21st century, the digital paradigm brought with it a new way of thinking about innovation in the various sectors of activity through the introduction of the Internet of Things (IoT) and ICT [14]. The agricultural sector is currently facing the great challenge of increasing agricultural production to feed a growing and prosperous population in a scenario of reduced availability of natural resources and related problems. In fact, the water scarcity, the decline of soil fertility, the effects of climate change, and the rapid decrease of fertile agricultural land due to urbanization are some of the problems faced by current societies. Faced with such constraints, ICT in agriculture can provide or enhance the increase in efficiency, productivity and sustainability of the sector, providing information and promoting knowledge sharing [15]. The use of technologies, in particular emerging ones, provide multiple benefits to the agricultural sector, not only economically, but also with regard to sustainability of the use of natural resources [16].

Sustainability or sustainable development has been a topic of global interest in recent decades triggered by environmental disasters caused by human action that endanger life on the Planet. In this way, making the Planet more sustainable means harmonizing conflicts between the economic, environmental and social spheres through the rescue of ancient knowledge of traditional communities combined with the development of clean and innovative technologies capable of mitigating the impacts of human actions while, at the same time, generates financial returns and social well-being. Sustainability can be understood as meeting present human needs without compromising the needs of future generations [17]. The term "sustainable" covers other spheres in addition to the environmental issue, namely, economic, cultural and social issues [18]. The concept of agricultural sustainability encompasses valuing the internal resources of productive agricultural systems, their maintenance and, consequently, its productivity over time [19]. For agriculture to be sustainable, it will have to adopt a production model that minimally affects the environment, preserves the characteristics of agroecosystems for long periods, combines conventional and innovative practices in food cultivation, and worry about the social situation of farmers [20].

Promoting sustainability is part of the agenda of policy makers in all economies. In this sense, the impact of ICT, which have significantly increased the sharing of information, can be significant in reducing waste, increasing productivity and food security [21]. ICT are imperative to achieve long-term sustainable development [22]. Increasing agricultural production and optimizing the use of inorganic fertilizers are some of the most important objectives for agricultural and environmental sustainability [23]. Technology is an instrument of excellence to build relationships, mitigate environmental and climate impacts [24], as well as to increase environmental sustainability in regions, since it has the capacity to provide innovations and sustainability to the agricultural sector and increasing productivity as an alternative and complement to agricultural extension [10].

3 Methods

From a methodological point of view, a systematic review of the literature was carried out, which enabled data collection and subsequent analysis. For this, some criteria were defined that allow the collection of data in a reliable and replicable way [25] making the literature review process scientific and transparent [26]. The present systematic literature review was based on the PRISMA statement [27], as shown in Fig. 1.

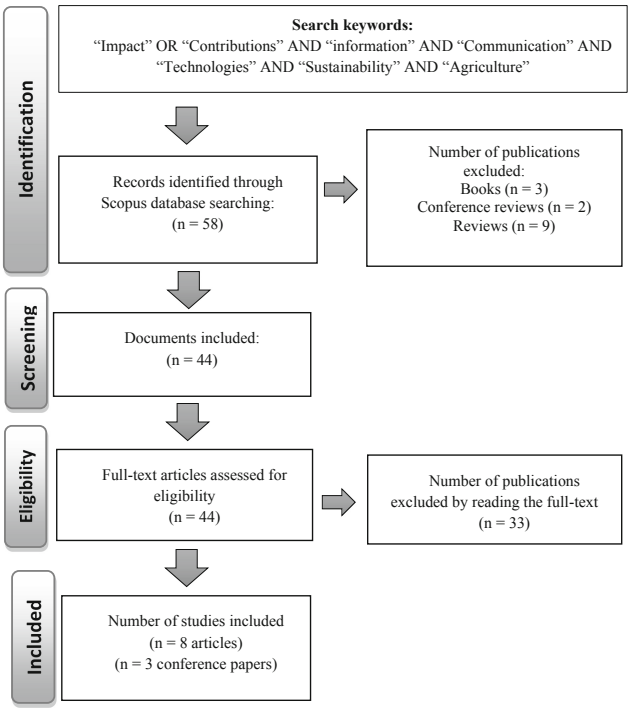

Fig. 1. PRISMA flow diagram of data collection process and analysis.

In the context of the PRISMA Statement, the Scopus database was screened. The search was performed in February 25, 2023, using the keywords "Impact" OR "Contributions" AND "Information" AND "Communication" AND "Technologies" AND "Sustainability" AND "Agriculture". A total of fifty-eight publications were found (Fig. 1). Of these, fourteen documents were removed, namely, Books (n = 3), Conference reviews (n = 2) and Reviews (n = 9), as shown in Fig. 1.

Publications were selected taking into account the following criterion: empirical studies that demonstrate evidence of the impact or contribution of ICT to sustainable agriculture. After full reading the publications, 11 publications were considered (Fig. 1). Then, for each document, information was collected about authorship and publication date, place (country and continent) where the research took place, type of study, methodology used, study objectives and findings.

4 Results and Discussion

Table 1 presents all the included publications by ascending order of publication data. As mentioned before, this table also contains information about authorship, type of study, region/country/continent where the research was developed, sample size, objectives and contributions.

The selected studies were developed in Europe (5), Asia (3), America (2) and Africa (1). Most of the studies carried out on the European Continent [8, 28–31] were case studies [8, 28, 30, 31].

An experimental study developed in Andalucia, Spain involved the development of an easy-to-use application that allowed farmers to manage reusable water and fertilizers used in the olive grove more efficiently [28], as shown in Table 1.

Other researchers [8] tested it in Italy through the use of an unmanned aerial vehicle and satellite platforms, whether the images obtained were useful and reliable to assess the conditions of cultivated areas (Table 1).

Table 1. General data, objectives and findings of the articles selected for the systematic literature review.

Author (date) [Reference]	Place Type of study Methods	Objective of the study Findings
1. Aldakhil et al. (2019) [22]	- South Asia (Asia) - Secondary study - Quantitative study - Data: data times series from 1975 to 2016 - Robust Least Square (RLS) Regression	To examine the role of ICT (e.g. telephone, mobile phone and internet), advanced technological factors (e.g. farm machinery and high-tech exports, specific growth factors (e.g. research and development spending by *per capita* income, investment flows direct foreign exchange, trade openness and industrial added value)) and the resultant carbon impact of fossil fuel emissions The results show that landlines, mobile phones and internet servers significantly influenced fossil fuel carbon emissions. Furthermore, agricultural machinery, e.g. tractors, substantially increase fossil fuel carbon emissions in a region
2. Jimenez & Castro (2019) [16]	- Colombia (America) - Experimental study - Quantitative study - Case study	To propose a prototype identification system, designed and validated to provide an information system for monitoring African oil palm crops to implement precision agriculture The results were promising and provide a good basis for the implementation of Precision Agriculture

(*continued*)

Table 1. (*continued*)

Author (date) [Reference]	Place Type of study Methods	Objective of the study Findings
3. Alcaide Zaragoza et al. (2020) [28]	- Andalucia, Southern Spain (Europe) - Quantitative study - Experimental study	To develop a mobile application for Android devices, the REUTIVAR-App, which provides farmers and technicians with an easy-to-use tool that facilitates the management of fertirrigation using reused water to irrigate olive groves The mobile application adapted the scheduling of fertirrigation to real weather conditions and adjusted the allocation of water throughout the irrigation season, avoiding additional costs to the farm. The REUTIVAR-App also showed that, thanks to the nutrient applied via water, no additional application of fertilizer was necessary, saving 100% of the fertilizers used by the farmer. In summary, the use of the application improved the efficiency of water and fertilizer use and increased farmers' involvement with sustainability concerns
4. Broad (2020) [32]	- Brooklyn, New York, United Sates (America) - Qualitative study - Case study	To examine the work of Square Roots, a Brooklyn-based vertical farming company co-founded by the entrepreneur Kimbal Musk and tech CEO Tobias Peggs Proponents of indoor vertical farming presented the enterprise as the key to the future of food, an opportunity to use technological innovation to increase local food production, bolster urban sustainability and create a world where there is "real food" for everyone. At the same time, critics have raised concerns about the costs, energy use, social impacts and overall agricultural viability of these efforts
5. Espelt (2020) [29]	- Barcelona, Spain (Europe) - Primary study - Qualitative study: qualitative interviews with the main stakeholders (CSA and suppliers) Data: Agro-ecological network generated by the 56 CSA in Barcelona, and their 177 providers	To identify Community Supported Agriculture (CSA) models with greater potential for the consumer, highlighting the role of ICT in meeting this challenge The results show that, when communities are professionalized, with optimized adoption of ICT and constituted as agro ecological platform cooperatives, they have a greater impact and greater potential to promote a model of food consumption based on agro ecology

(*continued*)

Table 1. (*continued*)

Author (date) [Reference]	Place Type of study Methods	Objective of the study Findings
6. Messina et al. (2020) [8]	- Italy (Europe) - Experimental study - Case study	To evaluate the reliability of multispectral images (MS) collected at different spatial resolutions by an unmanned aerial vehicle (UAV) and PlanetScope and Sentinel-2 satellite platforms in monitoring onion crops ("Cipolla Rossa di Tropea" Protected Geographical Indication) on three different dates. Two types of soil cover, namely, bare soil and onions were spatially identified using object-based geographic classification, and their spectral contribution was analyzed by comparing the Soil-Adjusted Vegetation Index (SAVI) calculated considering only the crop pixels (i.e. SAVI onions) and which was calculated considering only uncovered soil pixels (i.e. SAVI soil) with the SAVI of the three platforms The results showed that the satellite images, coherent and correlated with the UAV images, can be useful to evaluate the general conditions of the field while the UAV allows to discriminate localized circumscribed areas that the lower resolution of the satellites lost, where there are conditions of heterogeneity in the field, determined by abiotic or biotic stresses
7. Mylona et al. (2020) [30]	- Egeia Island of Andros (Greece) - Experimental study - Case study	To present a case study of the re-cultivation of abandoned terraces on the Aegean Island of Andros, using a climate-smart agriculture system, which involves the establishment of an extensive meteorological network to monitor the local climate and hydrometeorological forecast. Along with terrace site mapping and soil profile, the performance of cereal and legume crops was evaluated in a low-intake farming system The results revealed that terrace soil quality could be improved through cultivation to support food security and prevent land degradation. In line with global studies, this study suggests that marginal terrace cultivation is opportune through a climate-smart agriculture system as a holistic approach to improving land quality and serving as a means of combating the impacts of climate change

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Table 1. (*continued*)

Author (date) [Reference]	Place Type of study Methods	Objective of the study Findings
8. Fatumo et al. (2021) [21]	- Eastern Cape province, South Africa (Africa) - Primary study - Quantitative study - Case study - Data: 104 farmers out of 120 - Descriptive statistics; binary regression model; Spearman Rho correlation	To analyze the level of knowledge and the impact of ICT in the practice of family farming The results show that few farmers use some ICT tools in agriculture improving food security in their own way. Farmers share information about the availability of their individual products, resulting in waste, jeopardizing food security. However, the result of using ICT was considered beneficial
9. Khan et al. (2021) [23]	- Afghanistan (Asia) - Observational study - Primary study - Quantitative study - Data: National dataset from 7987 rural households - Regression analysis	To evaluate the potential of the mobile phone, mobile phone promotion policy, and whether the mediation role of human capital in reducing the application of inorganic fertilizers, ensuring environmental and agricultural sustainability goals The results showed that the use of the mobile phone significantly reduced the use of inorganic fertilizers by improving the human capital of farmers. In addition, evidence from the technique showed that mobile phone promotion policies decreased the application of inorganic fertilizers
10. Li et al. (2022) [33]	- Zhejiang, China (Asia) - Observational study - Primary study - Quantitative study - Data: 400 agricultures	To investigate the association between a digital extension service (“Zhe’ yang’ shi” WeChat app) and the adoption of soil testing and fertilization, a precision fertilization technology The empirical results show that the use of the “Zhe’ yang’ shi” WeChat application significantly increases the adoption of soil testing and formula fertilization. The findings enrich the literature on the influence of ICT on the behavior of farmers in adopting sustainable agricultural technology. It provides a valuable example for developing countries to promote sustainable agriculture through the use of digital technology

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Table 1. (*continued*)

Author (date) [Reference]	Place Type of study Methods	Objective of the study Findings
11. Medel-Jiménez et al. (2022) [31]	- Vienna, Austria (Europe) - Experimental study - Case Study	To present a comparative life cycle assessment of a conventional winter wheat production system with and without the use of a crop sensor for variable rate nitrogen application The results demonstrate that using optical crop sensors for variable rate nitrogen application could have a limited but positive environmental impact and highlights the importance of applying site-specific soil models to estimate field emissions (ICT components contributed less than 1% to all impacts assessed, namely, environmental impacts of the fertilization process only; and comparison of soil emissions simulated by DeNitrification-DeComposition with soil emissions from a production process of reference wheat), and highlights the importance of applying site-specific soil models to estimate field emissions

Another study [30] presents the case of the re-cultivation of abandoned terraces on the Aegean Island of Andros, Greece using a smart farming system to monitor and review the local climate. The results proved that the re-cultivation of marginal terraces was feasible with the use of a smart agriculture system and, this way, it was possible to improve soil quality and combat the impacts of climate change (Table 1).

Finally, another study [31] proved that the use of a crop sensor for nitrogen application has very positive environmental impacts. On the European Continent, other study [29] of observational and qualitative nature aimed, using ICT, to identify Community Supported Agriculture models with the potential to promote a more sustainable food consumption model (Table 1).

The three studies developed on the Asian continent are of observational nature [22, 23, 33], two are primary studies [23, 33] and one is a secondary study [22]. While a study [23] evaluated the potential of the mobile phone in the application of inorganic fertilizers in Afghanistan, other study [33] tested the use of a precision technology for soil and fertilization testing. The study which was based on data from a time series from 1975 to 2016 in South Asian countries [22], proved the need to develop green technologies in order to promote more sustainable agriculture. The authors support their study by stating that the technological footprint was considered the main factor that negatively affected the environment, sabotaging the United Nations Sustainable Development Goals [22]. Given the above, the authors argued that more efficient green technologies are needed to conserve the natural environment. In this context, the authors examined the role of ICT, advanced technological factors and specific growth factors and the resulting impact

of fossil fuel carbon emissions in South Asia. Results proved that only specific growth factors, i.e. research and development spending, were negatively correlated with carbon emissions, reinforcing the premise that greener technologies and equipment are needed to adopt more sustainable agriculture.

In the American continent, two experimental studies were developed, one quantitative [15] and the other qualitative [32]. The quantitative study, carried out in Colombia, consisted of testing a prototype designed to monitor African oil palm crops, providing data that would support the implementation of precision agriculture in this agricultural sector [15]. The qualitative study was based on examining the work of a company located in Brooklyn that is committed to Vertical Agriculture. While advocates of this type of agriculture consider it an innovative opportunity that makes use of technology to increase local production of healthier and more sustainable food, the most skeptical question its viability due to the high energy and social costs. This situation will be overcome if this type of agriculture resorts to the use of solar energy [32].

Finally, it is worth mentioning the primary and quantitative study carried out on the African continent [21], which aimed to assess the level of knowledge and the impact of ICT on family farming based on the application of a questionnaire to 104 farm owners or respondents of a total of 120. The results showed that small farmers from a small rural community in South Africa are highly information deprived, which significantly affects their ICT awareness. And, although there are very few who use ICT, the results are beneficial. In this context, it is necessary to raise awareness among farmers about the role of ICT to improve agricultural productivity and the level of sustainability in agriculture [21].

5 Conclusion

This study intends to be another contribution to the growing academic research on the impact or contribution of ICT in the adoption of sustainable agriculture, allowing a better understanding of the phenomenon. For this, a systematic literature review was performed according the PRISMA statement. In this context, a computer-assisted bibliographical search was carried out in the Scopus database on February, 2023. The search involved the use of keywords such as: impact, contributions, information, communication, technologies, sustainability and agriculture. After applying the PRISMA statement, of the initial 58 publications, only 11 were included in this study, namely, 8 articles and 3 conference papers.

The results allowed to conclude that all publications show positive contributions, at an environmental, economic and social level, as a result of the use of ICT, namely, mobile phone, internet, APPS, sensors, servers, unmanned aerial vehicles and prototypes. Also, the publications show the contribution of AI for the adoption of a more sustainable agriculture that use less resources. Examples of this are: the improvement of soil quality and its homogeneity; greater efficiency in the use of water; the use of reusable water; greater efficiency in the use of energy; greater use of solar energy; greater efficiency in the application of nitrogen; minimization of the use of inorganic fertilizers; reduction of food waste; improvement of food security; increase of farmer engagement with sustainability concerns; and promote a more sustainable consumption.

This research is supported only by publications from the Scopus database. Despite this limitation, the quality of the systematic literature review is not affected because this is considered the most comprehensive bibliometric database in terms of peer-reviewed publications. However, other international databases, such as Web od Science should be included in future research that will support an empirical research whose study object should be the Portuguese farmers. In fact, it is intended to survey young Portuguese farmers affiliated in the association of young farmers of Portugal (AJAP). The main objective of the study should be: to verify if young farmers are concerned about the sustainability of the agriculture they practice and, to what extent, do they use ICT in their daily lives in order to achieve the agriculture sustainability.

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