Revolutionizing Agriculture: The Impact of Automation on Productivity and Efficiency

[1]Marie Pasteur and [2]Sophie Emilie
[1, 2] Computer Science and Quantum Information, Sorbonne University, Jussieu, Paris, France.
[2]sophili@outlook.com

Correspondence should be addressed to Sophie Emilie: sophili@outlook.com

Article Info
Journal of Robotics Spectrum (https://anapub.co.ke/journals/jrs/jrs.html)
Doi: https://doi.org/10.53759/9852/JRS202402003
Received 26 August 2023; Revised from 02 December 2023; Accepted 30 January 2024.
Available online 10 February 2024.

Abstract – The complex agricultural environment, together with the need for high levels of productivity, necessitates establishing robust systems that can be efficiently and economically developed. The absence of order and structure in the external environment heightens the probability of experiencing failures. Furthermore, it is often seen that equipment management is entrusted to those with little proficiency in technology. Therefore, the significance of intrinsic safety and reliability becomes a pivotal attribute. The issue of ensuring food safety requires using automated technologies that are both sterilized and reliable to minimize the risk of contamination leakage. This article examines the progress and prospects of automation in the agricultural sector, with a specific emphasis on the use of autonomous equipment, robotics, and artificial intelligence. The article examines the advantages of automation in enhancing the management of agricultural production, minimizing expenses, and achieving objectives related to environmental sustainability. Nevertheless, it is important to acknowledge the complexities associated with automation, as it brings to light several obstacles such as the repercussions on agricultural workers, possible disparities in social and environmental aspects, and the need for more investigation and advancement.

Keywords – Variable Rate Technology (VRT), Geographic Information System (GIS), Artificial Intelligence (AI), Global Navigation Satellite Systems (GNSS), Unmanned Aerial Vehicles (UAVs).

I. INTRODUCTION

The significant expansion of agricultural crop robotics over the last decade can be attributed to two key factors. Firstly, the convergence of advanced mechatronics technology has reached a level of maturity that enables the technological feasibility of automation in this domain. Secondly, there is a growing need for alternatives to human labor in the field of crop production. Globally, the recruitment and retention of agricultural laborers pose significant challenges [1]. The growing apprehension over environmental and food safety issues has prompted the agricultural sector to adopt more precise management and application strategies for inputs. The field of agricultural robotics within the engineering domain has seen significant development in recent decades. However, the comprehension of the economic ramifications associated with these advancements has not progressed at the same pace. The primary aim of this study is to conduct a comprehensive analysis of the existing body of research pertaining to the economic aspects of agricultural robotics. In doing so, this study seeks to identify any areas that need further investigation and highlight any gaps that currently exist in the literature. The findings of this study will have significance for scholars in the field of agriculture, agribusiness professionals, farmers, and policymakers involved in agricultural affairs.

There is ongoing disagreement around the meaning of the term “robot”. The term “robot” originates from the Czech language, namely from the phrase denoting a serf, laborer, or servant [2]. According to John and Tiegelkamp [3], a robotic system is a versatile and programmable manipulator that is specifically intended to execute a wide range of tasks by effectively moving materials, components, tools, or specialized equipment via a series of programmed operations. There exist varying perspectives and debates over the precise delineation of robotics, particularly pertaining to the need of mobility, level of autonomy (i.e., capacity to operate independently of human intervention), capacity for learning, scope of decision-making capabilities, and amount of pre-programmed functionality.

The attributes of agricultural robots have been delineated by Driessen and Heutinck [4]; yet, a universally accepted definition remains elusive. The primary objective of this study is to examine the economic aspects of utilizing robotics in crop production within open sectors. For the purposes of this research, a “field crop robot” is defined as a mechatronic device that is mobile, autonomous, and capable of making decisions. This device is designed to carry out various tasks related to crop production, like harvesting, soil preparation, pest control, seeding, weeding, and transplanting. The system functions under human oversight, yet does not need direct human intervention. The incorporation of mobility within the definition is of utmost importance, given the natural spatial distribution of field crops throughout the terrain. The necessity for autonomy is further emphasized by the inherent absence of absolute control over the field environment. One of the functions that a field agricultural robot may do is the differentiation between a cultivated plant and an undesirable plant species. Moreover, it can partake in the process of insect identification to choose the most appropriate pesticide for the aim of micro dosing. Moreover, the autonomous machine might potentially assume the task of discerning mature fruits or vegetables, in addition to promptly ceasing its activities if meeting an unusual obstacle.

In contemporary times, there has been an increasing inclination towards the adoption of automation within the agricultural sector. This entails the independent execution of diverse agricultural procedures, encompassing cultivation, inspection, spraying, trimming, and harvesting. The main purpose of this transition towards automation is to tackle the labor-related difficulties encountered by the agriculture sector. The term "automated agriculture" encompasses various technological components or machines designed to reduce or eliminate human involvement in agricultural activities. The main focus of agricultural automation revolves around the use of autonomous vehicle technology, including robots and tractors. These devices are designed to alleviate the challenging, dangerous, risky, and prolonged working circumstances experienced by farmers. Concurrently, they offer a methodical and efficient framework for managing and overseeing operations. Moreover, it is important to keep the integrity of both the caliber and volume of the production in order to guarantee its sustained excellence and appropriateness for human consumption. Therefore, the current research in the agricultural sector is primarily centered around the development of an efficient automation system to ensure the long-term sustainability of food security.

The utilization of automation has emerged as a viable alternative in light of the increasing need for enhanced worker productivity and the urgent requirement to tackle environmental sustainability concerns within the agriculture industry. The purpose of this article is to provide a detailed analysis of the present status of automation in the agricultural sector, elucidating its advantages and the obstacles that must be overcome to ensure its effective integration. By comprehending the promise and constraints of automation, governments, academics, and farmers may make well-informed choices on its adoption and guarantee its fair and environmentally responsible integration into agricultural practices. The subsequent sections of the article have been structured in the following manner: Section II reviews the aspect of robots penetration into the agricultural field. Section III discusses robotics and agricultural automation, identifying the present applications. Section IV discusses the challenges posed by the development of agricultural automation: unequal capacity, labour disruption, and environmental concepts. Lastly, Section V provides conclusions to the research on potential and challenges of automation in agriculture

II. ROBOTS PENETRATION INTO THE AGRICULTURAL FIELD

Over the last century, there has been a prevailing tendency in agricultural innovation towards the use of larger and more substantial machinery. The observable pattern of automation in open field farming is shown by the use of autonomous tractors and tractor-mounted “intelligent” sensors and equipment. These instruments often have a specific goal of minimizing or eliminating the need for human operators, which is connected to both societal issues and the agronomic co-evolution of machines and monocultures. Technological advancements in agriculture are frequently expedited by societal changes that diminish the pool of available agricultural labor and heighten the demand for labor efficiency. These societal transformations encompass events such as warfare, slavery abolition, alterations in immigration policies, and pandemics. Consequently, mechanization in agriculture has advanced, leading to the emergence of specific political ecologies that promote the establishment of extensive monocultures. This development, in turn, has significant environmental consequences and brings about social transformations.

According to Shaikh, Rasool, and Lone [5], the use of automated equipment in lieu of human labor significantly decreases the time needed to carry out cultivation chores per hectare. This enables farmers to cultivate bigger areas of land by substituting manual jobs with mechanized operations. According to Giller et al. [6], farmers that make substantial investments in costly and sizable machinery often encounter a need to engage in specialization and expansion in order to optimize the efficiency of usage of resources, rivalry in economies of scale, and ensure the profitability of their investments. The feedback process described generates distinct socio-political modernization dynamics, wherein chemical and other resources are combined with capital demands and reliance on major agribusiness conglomerates. Consequently, rural, and migrant groups face the risk of disappearing as a result of diminished labor demands, which may be either reduced or limited to specific seasons.

The pursuit of large-scale machinery, whether automated or not, is primarily motivated by the objective of optimizing the uniformity of crop growth. The effectiveness of maize harvesting with a combine is contingent upon the uniformity of plant height, ear shape, and maturity over the whole crop stand. Moreover, an increased abundance of plants of the same species within a certain region might lead to a greater potential for production per unit of land or labor. Consequently, there has been a significant emphasis by seed providers and plant breeding programs, in conjunction with the use of chemical inputs, on enhancing growth attributes (such as height and crowding tolerance) that are pertinent to the optimization of monocultural, machine-managed cropping systems. Collectively, these elements provide a reciprocal feedback mechanism in which agricultural systems are purposefully constructed to allow the use of sizable machinery, while the machinery itself is specifically intended to effectively operate inside these established agricultural systems.

The convergence of efficiency and uniformity gives rise to the ultimate obstacle of achieving complete automation in arable farming, whereby human labor in the field becomes unnecessary. Furthermore, apart from the utilization of sizable autonomous tractors, the endeavor to address this issue is being actively pushed via the advancement of diminutive self-governing robots. These practices are in contrast to the prevailing trend of increased automation, which favors larger and heavier machinery. However, they often maintain a monocultural approach to crop husbandry, despite the possibility of establishing an alternative connection between agricultural systems and machines. The primary source of open-field robotic applications is derived mostly from the precision agriculture program. This program is centered on the application of technology and data to improve the efficiency of resource utilization and optimize output by implementing precise care at the individual plant level within monocultural systems. The use of robotic technology in agricultural operations is often presented as a potential remedy for issues related to inconsistencies in field conditions, excessive and inaccurate use of agrochemicals, soil compaction, as well as the economic burden and limited accessibility of agricultural labor.

The use of several autonomous ground units in applications often entails the reception and analysis of data from diverse sensor types. According to Bechar and Vigneault [7], the use of extensive data collecting by these robots is anticipated to assist farmers in attaining a heightened degree of consistency in their agricultural practices. This will be accomplished by the robots' ability to recognize, diagnose, and address variations at the individual plant level within the field environment, all while optimizing the allocation of resources. The widespread implementation of autonomous agricultural equipment would result in the transfer of manual labor responsibilities from human farm workers to robots. This shift has the potential to exacerbate the marginalized status of agricultural laborers in certain contexts, which is often influenced by race and gender. The optional nature of cognitive human demand may be brought about by advancements in artificial intelligence (AI), hence raising inquiries about the definition of a "good" farmer.

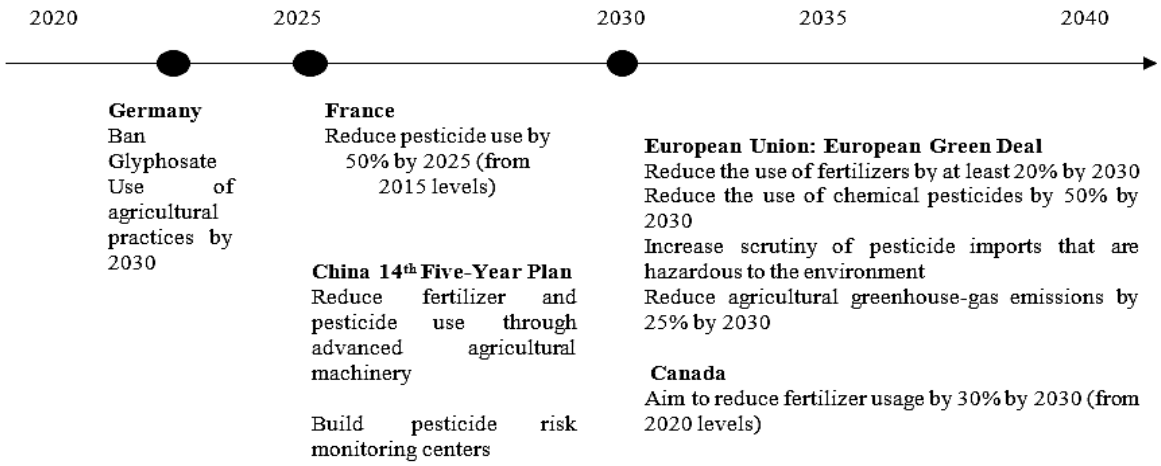


Fig 1. Stricter Fertilizers, Emission and Pesticide Regulations for Agricultural Automations.

Governments throughout the globe have established lofty objectives aimed at fostering greater environmental sustainability. The European Green Deal aims to bring about a significant overhaul of European agriculture by the year 2030. This includes a targeted decrease of 50 percent in pesticide usage, as compared to the levels seen in 2020 [8]. Furthermore, the proposed strategy aims to convert 25% of the total agricultural acreage into organic farming practices with the objective of reducing the reliance on synthetic fertilizers and pesticides. Similarly, Canada has set a target for farmers to reduce their fertilizer use by 30 percent by the year 2030, in comparison to the levels seen in 2020 (refer to **Fig. 1**). Canadian agricultural producers who fail to attain the specified objective would face the potential consequence of forfeiting access to a substantial sum of $1.1 billion in government assistance and subsidies designated for the acquisition of environmentally friendly farming equipment [9]. Automation is a substantial tool for fulfilling these criteria. The integration of automated precision-spraying technology with automated weeding or mowing solutions is a promising approach for farmers to significantly decrease their reliance on pesticides and fertilizers, and in certain cases, completely eliminate their use.

III. ROBOTICS AND AGRICULTURAL AUTOMATION: PRESENT APPLICATIONS

The use of automation in agricultural practices has facilitated the effective management of crop production for farmers, resulting in reduced energy consumption and costs. The advancement of autonomous models in agricultural has garnered attention from farmers and academics due to several factors, including the scarcity of agricultural labor, the aging farmer population, and the rising agricultural pay. The execution and advancement of agricultural automation have been carried out via the use of agricultural machinery and autonomous robots, such as tractors that are often equipped with chisel plows, cultivators, cultipackers, and planters. In their publication, Bechar and Vigneault [10] provided a description of several agricultural robots and machinery that need automation to enhance the general efficiency of agricultural operations. The use of automation and robots in the agricultural sector exhibits considerable diversity. The implementation of agricultural operations necessitates the use of various robotics and vehicle structures that are tailored to the specific characteristics of the land and operational demands.

Various types of robots and vehicles possess distinct structural characteristics, each of which is accompanied by its own set of limitations. These limitations need the use of additional machinery in order to address them effectively. The robotic structure's ability to perform highly demanding tasks in agriculture is limited by its sensitivity to water and muck. Hence, the utilization of the tractor is warranted for the completion of said duty, owing to its exceptional capacity to navigate over the mire-laden terrain and its relatively lower susceptibility to damage to electrical circuitry. However, the utilization of tractors is restricted to expansive regions as a result of their substantial size. Therefore, the use of the compact region necessitates the implementation of a mobile robot. The usage of drones is mostly suitable for open areas, whereas their use in confined environments, such as greenhouses, is limited due to an increased risk of collisions. In order to further investigate the current use of automation and robots in agriculture, a classification was conducted according to various agricultural operations.

Advances in Automation for Crop Production

The use of precision agricultural technologies, like VRT, GNSS, robotics, UAVs, and artificial intelligence (AI), plays a pivotal role in the crop production automation. The acquisition of geographical data via the use of a geographic information system (GIS) may be important for these purposes. This data may be combined with information derived from models of crop simulation in order to determine the optimal quantity of inputs required to achieve maximum yield and profitability. The applications discussed in this context rely on the use of sensors, which include proximate sensing techniques such as the measurement of nitrogen levels in the soil, as well as distant sensing methods like satellite photography. The sharing of data with stakeholders may be facilitated by operators via the use of smartphones and user-friendly applications, which show the data in a simplified format, contingent upon connection. The use of the GNSS robot in agricultural production is shown in **Fig. 2**.

(a) Partial view of GNSS (b) GNSS application in the field

Fig 2. GNSS Robot Used in Crop Production.

The term GNSS technology pertains to a methodology used for the purpose of enhancing the precision of locating within the context of GNSS. The distance correction value between the reference station and the satellite is determined and promptly disseminated based on the accurately established coordinates of the reference station. During the process of GNSS observation, the user receiver is capable of receiving the correction data sent by the reference station. This correction data is then used by the user receiver to refine its positioning results, hence enhancing the overall accuracy of the positioning.

The GNSS and VRT are extensively used in the agricultural sector for the purpose of implementing autosteer capabilities and facilitating the real-time application of inputs via motorized equipment. The introduction of GNSS-based technologies is primarily motivated by their ability to effectively apply inputs, such as fertilizer, by preventing both unintentional skipping and overlapping of plants. This results in significant savings in input use. Additional factors contributing to the adoption of autonomous vehicles are decreased operator fatigue, extended working hours for family members, increased flexibility in driver recruitment (as highly skilled or experienced individuals are not necessarily required), and environmental advantages resulting from reduced overlapping applications. Furthermore, there are additional benefits that are challenging to quantify and can be considered as secondary effects of autonomous vehicle implementation.

The rapid recognition of the advantages of GNSS guidance, such as instant input savings resulting from less overlap, and the visibility of these benefits to both farmers and neighboring individuals, for instance, the disapproval of weed strips caused by herbicide skips throughout the agricultural community, have further facilitated the use of this technology. VRT (Variable Rate Technology) systems have the potential to decrease the amount of inputs used in agricultural practices while simultaneously enhancing crop productivity. This technology may also have positive environmental implications, particularly when it leads to a reduction in excessive input application. The profitability of variable rate technology (VRT) fertilizers has been subject to conflicting findings in the literature, as shown by Stefanini et al. [11] and Fabiani et al. [12]. This discrepancy in evidence helps to explain the limited global adoption of map-based VRT fertilizers, which is mostly seen in cases where profitability remains stable, such as in the context of nitrogen application for sugar beet cultivation.

Autonomous agricultural robots have just lately been introduced into commercial applications under the most sophisticated automation category. They are mostly found in high-income nations, such as France, where they are used for the purpose of removing unwanted plants from sugar beet crops. The Hands Free Hectare project, initiated in the United Kingdom in 2016, aims to advance and exhibit automation of agriculture [13]. It is the first public exhibition of self-governing agricultural machinery engaged in the cultivation and harvesting of a commercially viable crop. Subsequently, manufacturers have made public declarations on the production of autonomous machines, with more than 40 emerging start-ups already engaged in their development. Autonomous agricultural robots have been linked to labor-saving benefits, enhanced operational timing, increased precision in input delivery, and decreased soil compaction, particularly when implemented with smaller swarm robots. An examination of 19 examples revealed that the use of autonomous agricultural robots for the purposes of harvesting, sowing, and weeding demonstrated economic viability under certain conditions [14].

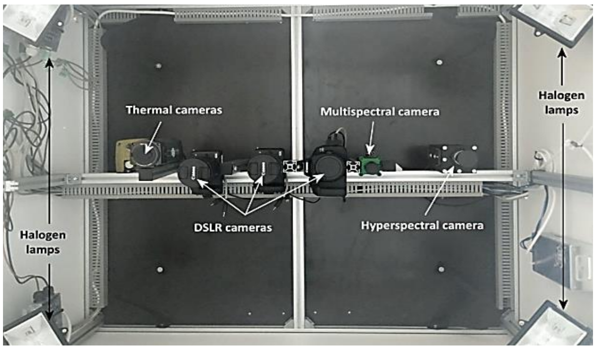
In many nations, the use of autonomous agricultural machines necessitates continuous on-site human oversight, hence potentially rendering traditional equipment a more advantageous option for farmers. According to Darwin et al. [15], the effectiveness of remote supervision, such as monitoring from a farm office, is contingent upon the smooth functioning of autonomous operations. The statement underscored the need to enhance AI capabilities in order to empower autonomous machines to address a wider range of problems without requiring human involvement. Likewise, the presence of speed limitations on autonomous agricultural machinery, such as those seen inside the United States of America, might render them economically nonviable [16].

There have been suggestions to create compact and affordable autonomous agricultural machinery for medium-and small-sized farms, aiming to address the scarcity of agricultural workforce in middle-and low-income nations. This initiative has promise, particularly for rural youth. However, there is a lack of feasibility evaluations available for middle-and low-income nations. However, the existing body of literature suggests that the implementation of autonomous robots in these nations can yield several potential advantages. Firstly, it can alleviate the demand for human labor in regions where such resources are limited. Secondly, it can lead to cost reductions and diminished economies of scale, thereby making technological advancements more accessible to smaller farms that rely on conventional mechanization. Lastly, the utilization of these technologies can effectively address the challenges posed by irregularly shaped fields, as it eliminates the need to reshape rural landscapes into large rectangular fields, which is the most efficient method for traditional mechanization but can disrupt local communities.

Drones are used for the purpose of data collection and the automation of input application, akin to the utilization of map-based Variable Rate Technology (VRT). Nevertheless, the use of these substances is often governed by stringent laws as a result of apprehensions over the excessive application of inputs, the potential for pesticide drift, and the associated threats to aviation. In the United Kingdom, the use of drones for herbicide application is only permitted in remote areas with limited accessibility and subject to stringent regulations. In contrast, Switzerland has implemented a more lenient approach towards the use of drones, so potentially serving as a catalyst for other European nations to adopt similar policies. In 2021, around 14% of agricultural shops in the United States of America offered drone input application services. It is projected that this figure would rise to 29% by the year 2024 [17]. The use of drone technology is prevalent in middle-income nations, like Brazil and China.

Advances in Automation for Plant Inspection

The process of inspection in agriculture involves the systematic examination and observation of plants to identify any potential illnesses or quality faults. In the domain of agriculture, plant diseases have a significant role in the decline of crop yield, leading to substantial economic losses. The agricultural environment has a dynamic nature, hence subjecting plants, and their products to several unforeseen and unconventional pressures. The stressors encompass variations in temperature, humidity, water levels, the emergence of illnesses, and the existence of pests. Failure to immediately treat these anomalies might potentially lead to significant and irreparable harm. To conduct the examination, farmers often rely on their visual perception to manually detect any irregularities in plants. In recent years, there has been an observable trend of growing age among farmers. Consequently, the efficacy of inspection operations has seen a decline due to the deterioration of the human visual system associated with aging.



(**a**) From the perspective of the plant

(**b**) the external appearance of the robot.

Fig 3. A Remotely-Operated RobHortic Device being Utilized in a Field of Carrots.

The remote-controlled field robot known as RobHortic [18], seen in **Fig. 3**, has been designed for the purpose of examining horticultural crops to detect the occurrence of pests and diseases. This is achieved via the use of proximal sensing techniques. The robot is outfitted with cameras capable of capturing color, multispectral, and hyperspectral imagery within the wavelength range of 400 to 1000 nm. These cameras are positioned to observe the ground, specifically focusing on the plants. In order to mitigate the adverse effects of direct sunshine, the set was lighted by a quartet of halogen lights and shielded from ambient light by the use of a tarp. The geolocation of the field photos was achieved by the use of a Global Navigation Satellite System (GNSS). The connection of all sensors was established using an on-board computer system. The designed software expressly for this purpose successfully obtained the signals from encoders, which was linked to the motor, in order to coordinate the buying up of the photos with the movement of the robot. Once the signal is received, the cameras are activated, and the acquired pictures are saved in conjunction with the GNSS information.

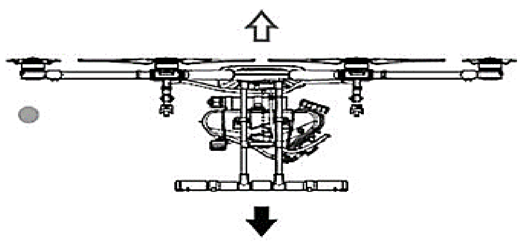
The successful integration of automation in agricultural inspection necessitates the development of a system that can effectively replicate the visual capabilities of human beings in order to carry out the inspection process. Hence, computer vision has been extensively used as a substitute for human vision in the context of agricultural plant inspection. Computer vision is a sophisticated technology used for the analysis of images, displaying promising results and exhibiting significant promise in supplanting human vision for intricate tasks within the inspection process. The integration of a computer vision system has seen extensive use across several diverse fields, including the agricultural sector. Within the field of agriculture, it is important to acknowledge the significant growth of image processing and computer vision applications. This growth may be attributed to many factors, including the decrease in equipment prices, the rise in computing capacity, and the growing interest in non-destructive ways for assessing food quality.

Progress in Automating The Watering of Crops

The utilization of pest-control chemicals, fertilizers, or growth medium through the process of spraying is a widely employed method in agricultural practices. The method described entails the application of these compounds in the form of a finely dispersed mist onto plants, fulfilling various objectives such as disease control and plant development regulation. When conducting an assessment of unmanned aerial vehicle (UAV) systems, it is important to consider several parameters, including the flow rate of the nozzles, the flight path, the velocity of the flight, the altitude at which spraying occurs, the orientation and quantity of the nozzles, and additional relevant variables.

Numerous commercially accessible smart spraying systems are already available, among which the DJI Agras stands out as a well acknowledged all-in-one solution. The MG-1 possesses a sturdy build, demonstrating durability against particulate matter, moisture, and chemical agents such as insecticides. The drone possesses a body that is sealed in a hermetic manner, ensuring airtightness. Additionally, it is equipped with an inbuilt centrifugal cooling system that is further improved by the inclusion of filters. These filters serve the purpose of preventing the entry of corrosive substances and aiding in the efficient dissipation of heat from the drone's various components. The nozzles have a notable degree of durability and may function for prolonged durations, sustaining their efficiency without undergoing any deterioration. Upon the conclusion of the procedure, the farmer is afforded the choice to cleanse the vehicle by means of employing a water hose.

(a) DJI Agras MG-1 business plane



(b) DJI Agras representation

Fig 4. DJI Agras MG-1 for Crop Spraying.

The MG-1 has a small design that facilitates convenient transportation, since it can be folded to accommodate automobile storage. Additionally, its construction employs carbon fibre material, which imparts both lightweight properties and robustness. Therefore, the MG-1 has a high level of suitability for deployment in agricultural settings. The architecture of the system is user-friendly and its controls are easy, allowing for single-person operation. Furthermore, the remote control of the device exhibits water and dust resistance, while the LCD screen is designed to be energy efficient and offers real-time flight information. Individuals have the option to choose an intelligent mode in which flight planning may be conducted without the need for mapping, and previous coordinates are stored in the event of operational interruptions. The spray system has four sprinklers positioned on both sides of the aircraft. The aircraft's diameter is 1520 mm, and its configuration has eight rotors arranged in a single plane, as seen in **Fig. 4**.

In the majority of agricultural methods, pesticides are often administered in a consistent manner over the whole of cultivated areas in order to mitigate the proliferation of illnesses [19]. This strategy is implemented despite the presence of many pests and illnesses that have an uneven geographical distribution, particularly in the first phases of growth. Hence, in order to reduce the expenses associated with the use of pest-control chemicals in agricultural practices, the implementation and examination of selective spraying methods have been undertaken during the course of the last twenty years. The automated selective spraying system, often implemented using advanced automated machinery or mobile robots, enables the precise administration of pesticides only in certain areas and at specific times, therefore optimizing efficiency and minimizing waste. The primary aim of this targeted intervention is to minimize the use of pesticides and mitigate the occurrence and rapid dissemination of infections inside the greenhouse. Previous studies in the field of autonomous selective spraying have mostly concentrated on the construction of a highly efficient spraying system that incurs little operating expenses. In order to attain the previously stated objective, a variable rate spraying technique has been advanced. This approach enables farmers to automatically modify the volume rate of pesticides or herbicides according to the specific target, taking into consideration the size of the canopy and the treatment needs.

In addition to the reduction of pesticide use, some studies are also dedicated to the management of navigation. The primary aim is to minimize the operating expenses of the robot, including time and energy, while ensuring accurate location monitoring. This study domain has significant importance in ensuring the exact navigation of robots towards a target, while minimizing travel costs during the execution of spraying operations. In order to minimize operating expenses, a study by literature suggests the use of a multi-objective method known as the Non-dominated Sorting Genetic method utilizing Reference Point Based. This algorithm aims to maximize many goals, including journey time, distance, and routing angle. The study done in [20] examines the impact of robot travel velocity on the mass discharge flowrate of pineapple leaf fibre. Multiple robot velocities were investigated in order to determine the optimal velocity for the composite spray operation.

In [21], a route planning technique using Simulated Annealing is proposed by Kuo. This algorithm takes into account many goals, including distance, fuel consumption, herbicide volume, input cost, and time. In addition to striving for cost reduction in the design of navigation systems for spraying operations, researchers are also placing emphasis on the preservation of high location accuracy for agricultural robots. The study presented in [22] focuses on the design and development of a wheel-type robot tractor specifically intended for the purposes of weeding and spraying. In order to enhance the auto steering system's navigation accuracy to a level below 0.05 m, the Real-Time Kinematic GPS (RTK-GPS) and integration of Inertial Measurement Unit (IMU) is used as the attitude and position sensor for the navigation system. The high cost of RTK-GPS in the context of robot development has been identified as a challenge. In response, Dogru and Marques [23] suggest a data fusion technique that utilizes MSPI to effectively filter out noise from raw data obtained from low-cost sensors, including Differential vision, IMU, and GPS sensors. This approach is specifically designed for use in a vineyard pesticide spraying robot.

Advances in Automation for Harvesting

Within the realm of agriculture, the act of harvesting entails the labor-intensive process of gathering agricultural commodities with the intention of further processing or commercialization. In order to begin this procedure, it is necessary to gather and store the fruits or vegetables for further processing, or alternatively, they may be immediately sold to potential purchasers. Due to the need for meticulous observation and repeated procedures, this method is well recognized as being both time-consuming and labor-intensive. Hence, extensive research and development efforts have been dedicated to the advancement of autonomous harvesting systems in recent decades. In recent years, several implementations have been conducted for a range of crop varieties, including strawberry, tomato, apple, kiwi, grape, capsicum, litchi, citrus, pumpkin, and heavyweight crops.

(a) The sweet-pepper-harvesting robot SWEEPER

(b) Experimental sweet pepper robot used in the field

Fig 5. The Sweet-Pepper-Harvesting Robot SWEEPER for Crop Harvesting.

In order to exemplify contemporary research endeavors, we will go into the field of tomato, strawberry, and sweet pepper harvesting. The development of a sweet pepper harvesting robotic system was undertaken under the EU projects Crops and its subsequent project SWEEPER. The system is shown in **Fig. 5** and further information may be found in [24]. The system consists of a single 6 degrees of freedom (DOF) industrial manipulator equipped with a specifically an RGB-D camera integrated with a GPU computer, a designed end effector, and a compact receptacle for storing picked fruit. During a span of four weeks, an assessment was conducted by Arad et al. [25] on a total of 262 fruits. The findings revealed a harvest success rate of 61% under ideal crop circumstances, however under prevailing commercial settings, the success rate was just 18%. These results underscore the need for cultivation systems that are purposefully tailored for robotic harvesting. The average cycle time, which encompasses both fruit discharge and platform movement, was recorded to be 24 seconds. The effective use of deep-learning approaches for picture segmentation and identification is contingent upon the presence of objects of interest inside the camera view.

Nevertheless, the identification and approach of fruits often encountered challenges under commercial crop circumstances, mostly attributed to the significant occlusion present. Another concern that arose under these circumstances was the collision between the plant and the end-effector. In a previous study, the robot named Harvey was created and assessed using a sample size of 68 sweet peppers. Kootstra et al. [26] achieved a harvesting success rate of approximately 76% in a genetically modified crop and 46% in a non-modified crop, with a cycle time of 36 seconds, omitting the time required for platform navigation. The efficacy of the peduncle and fruit identification system, which relies on DL and 3D processing, was shown to be satisfactory in the changed crop. However, it encountered challenges in the form of clutter and occlusion when applied to the unmodified crop. In a similar vein, the personalized harvesting tool encountered challenges due to intricate unaltered circumstances, leading to detrimental effects on both fruits and plants, as well as comparatively diminished rates of attachment and detachment. In a separate study, a closed-loop control system using image-based technology was implemented for the purpose of sweet pepper harvesting. The system demonstrated a general success rate of approximately 53%, and mean cycle time of 51.1 seconds.

The majority of implementations in this field prioritize improving the accuracy of harvesting systems via the introduction of various approaches and methodologies, using distinct software and hardware structural architectures. In order to carry out an autonomous harvesting procedure, a number of sequential actions must be undertaken. Initially, it is important for the mobile robot to possess the capability to accurately determine the target position in order to discern the specific item or place that necessitates harvesting. Subsequently, the robotic arm will be meticulously maneuvered towards the designated destination, ensuring the avoidance of any potential obstructions. The cutting process is initiated by the mobile robot gripping the fruit, followed by cutting the stem. The harvested product is then placed in a storage chamber located inside the framework of the robot. Hence, the many stages involved in the autonomous robotic harvesting procedure provide distinct obstacles that need optimization and resolution by agricultural experts in order to create a proficient harvesting robot.

Several studies have been undertaken in recent years to ascertain the optimal site for agricultural harvests. The majority of the executed studies use the capabilities of the visual system in order to ascertain the precise position of the fruits. The created vision system has been built to address two intricate challenges. These challenges pertain to the diverse range of detected objects, which exhibit natural features, as well as the complicated and loosely organized workspace. The workspace is characterized by significant variations in light and the degree of object occlusion. Hence, it is necessary to use diverse vision strategies in order to address a particular issue related to target recognition throughout the harvesting process.

The agricultural practice of harvesting has significant importance, since the manner in which it is carried out directly impacts the quality of the harvested crop, given its delicate nature. The quality of the product cannot be guaranteed to be satisfactory even if the plants are adequately cared for throughout the growth phase, since there is a possibility of harm occurring during the harvesting process due to the use of robotic and automated systems. Hence, a multitude of ongoing studies are currently being undertaken to ascertain that the efficacy of automation and robotic systems in the harvesting process is comparable to the performance of human labor in terms of timely agricultural product collection, while maintaining its quality.

IV. CHALLENGES POSED BY THE PROGRESS OF AGRICULTURAL AUTOMATION

Similar to any other technological advancement, the use of agricultural automation might give rise to adverse social and environmental outcomes. Hence, while the aforementioned advantages are anticipated, their realization is not guaranteed and is contingent upon effective administration. The equitable and sustainable adoption of agricultural automation may face obstacles due to many structural variables within the agriculture sector and the broader economy. Land fragmentation is a significant limitation in several places, making agricultural automation economically unfeasible. The absence of supportive infrastructures, such as transportation networks, digital connection, and access to energy, may also influence the acceptance of new technologies and hinder the participation of producers operating in economically challenged and geographically inaccessible regions. Under some circumstances, the implementation of automation of agriculture which has the potential to displace rural labor and result in adverse habitat challenges, including the loss of biodiversity and land degradation.

Unequal Capacity

The potential advantages of implementing agricultural automation may not be equitably distributed among various stakeholders, so increasing existing social disparities and maybe generating new ones. This might occur due to the tendency of automation to disproportionately favor already influential players within the realm of food production. This scenario is more likely to occur when technological corporations, particularly those that are already sizable and possess significant market influence, maintain ownership of data and use it in ways that do not align with data protection regulations.

Consequently, this may result in the establishment of data monopolies. Inequalities may be further amplified when producers who possess higher resources, such as financial means, rural infrastructure, and educational attainment, are able to invest in advanced technology or acquire new skills via retraining. It is evident that a considerable number of farmers may possess insufficient proficiency in using digital automation technologies or comprehending their operational mechanisms. It is important to note that possessing expertise in digital technologies is not a prerequisite for becoming a proficient agricultural practitioner, as well as for extension workers and service providers. The development of capacity and adaptability in agricultural practices plays a crucial role in facilitating the adoption and effective use of automated equipment. It is only through the acquisition of necessary skills and knowledge that farmers can fully harness the benefits and capabilities offered by automation.

In this context, women often experience more marginalization in terms of educational prospects and have less access to financial resources compared to males. There is a tendency for males to assume control over the procurement and trade of agricultural goods, as well as the ownership and operation of modern machinery. Consequently, this diminishes women's authority over the generated money and confines them to more physically demanding responsibilities such as weeding and transplanting. In a similar vein, rural adolescents, particularly women, encounter substantial barriers when it comes to acquiring high-quality training and education, as well as gaining access to property, loans, and markets.

Labour Disruption

Recent findings from various industries indicate that the implementation of automation could potentially lead to an upsurge in the need for higher-paying occupations that necessitate secondary education [27], and [28]. These jobs typically involve tasks such as data management and analysis, areas where humans possess a comparative benefit over machines. Conversely, the demand for jobs involving routine tasks, such as harvesting and planting, may experience a decline as a result of automation. As nations undergo the process of development, there is a noticeable decrease in the overall employment figures within the agricultural sector. However, it is important to note that a substantial number of around 300-500 million individuals, who are engaged in paid labor, continue to rely on employment opportunities within the farming industry. The agricultural sector in several countries continues to employ a significant proportion of the workforce. For instance, Uganda, the Niger, Chad, Malawi, Somali, and Burundi exhibit high percentages of workers engaged in agriculture, with figures reaching 72%, 73%, 75%, 76%, 80%, and 86%, respectively [29]. This trend is frequently associated with elevated levels of illiteracy, poverty, and gender disparities.

In such nations, a decrease in the per unit of output direct labor demands has the potential to generate or exacerbate inequities. Due to certain circumstances, agricultural automation may be seen as politically unfavorable and impractical in some scenarios. The ultimate influence on labor and salaries will be contingent upon a multitude of elements, including the ability to produce novel and appealing work opportunities or viable alternative forms of satisfactory employment outside the realm of agriculture. The outcome will also be contingent upon the relative dominance of scale effects, which include farmers expanding their production scale and hence increasing their revenue, compared to substitution effects, which result in labor being displaced from the sector. However, by implementing appropriate policies and establishing a legal and regulatory framework, agricultural automation has the potential to generate economic prospects, promote fair job possibilities that provide sustainable incomes and favorable working conditions, and attract young people to engage in the agricultural industry.

Environmental Concerns

There exist apprehensions regarding the potential negative impacts of certain forms of agricultural automation, particularly those reliant on bulky and extensive machinery. If not effectively regulated, these practices may pose a threat to environmental sustainability and resilience. Such concerns stem from the potential contributions of agricultural automation to various detrimental outcomes, including deforestation, the promotion of monoculture in farmland, the loss of biodiversity, erosion, soil compaction, and land degradation, the accumulation of salinity, and malfunctioning of drainage systems. While it is crucial to acknowledge and address these problems, it is possible to mitigate or reduce their impact via the implementation of suitable regulations and laws. In addition, recent progress in automation technology, namely in the domain of small-scale equipment powered by artificial intelligence (AI), holds promise for alleviating the negative habitat effects linked to obsolete automation machinery.

The potential consequences, advantages, and problems related to agricultural automation are dependent on the specific technology employed, its configuration, and its compatibility with local conditions and adjustments to the local context. Moreover, the application of efficient technology is based on the level of socioeconomic advancement, along with political and institutional constraints. The ramifications of agricultural automation, encompassing both advantageous and detrimental outcomes, are intricately contingent upon the specific contextual factors at play [30]. Before suggesting specific automation solutions, it is imperative to assess the political, social, and habitat conditions that exist in each country or region. It is important to acknowledge that the applicability of automation technologies is not uniformly uniform across all contexts, hence necessitating the consideration of modified iterations that are more suitable for specific situations.

V. CONCLUSIONS

This essay explores the importance of automation in the agricultural industry and its potential to improve crop production management. The use of automation within the agricultural domain has been driven by several factors, such as the scarcity of available workforce, the advancing age of individuals engaged in farming activities, and the rising compensation within the agricultural sector. Various technologies, including robotics, unmanned aerial vehicles (UAVs), and AI, are currently being employed to automate the food production process. Precision agricultural technologies, including VRT, GNSS, and sensors, are currently being employed to optimize operating efficiency and increase resource usage. The utilization of GNSS technology has demonstrated significant efficacy in the mitigation of unintended plant skipping and overlapping, leading to notable savings in input utilization. Autonomous agricultural robots have been used in high-income nations for the purpose of executing various activities, notably the eradication of undesirable vegetation from cultivated fields. These robotic systems provide advantages in terms of reducing labor requirements, improving operational efficiency, and enhancing the accuracy of input delivery.

The use of automation in plant inspection is evident, since robots employ proximate sensing methods and computer vision to identify pests and illnesses in crops. This technology has potential in substituting human eyesight for complex inspection jobs. The use of automation in agricultural spraying is becoming prevalent, since it incorporates selective spraying methods and variable rate spraying techniques to enhance efficiency and mitigate unnecessary resource consumption. Scholars are now directing their attention on enhancing the precision of agricultural robots' positioning by using RTK-GPS and IMU sensors. Automation in the field of harvesting is now undergoing development, whereby autonomous systems are being designed and deployed for the harvesting of different types of crops. In commercial crop circumstances, there are certain obstacles that need to be addressed, such as occlusion and collision between the harvesting robot and the plant. Although agricultural automation holds promise for several advantages, its implementation is not without challenges.

Some of the challenges that need to be considered in this context include land fragmentation, inadequate infrastructure, possible social and environmental consequences, and inequities among various stakeholders. Women and rural adolescents have challenges when it comes to obtaining education, training, and resources within the framework of automation. The use of considerable gear in automation gives rise to environmental problems as well. In order to address these difficulties, it is imperative to enact suitable rules and legislation, as well as recognize that not all automation technologies has universal applicability. Additional investigation and advancement are required in order to completely actualize the possibilities of automation within the agricultural sector.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

Funding

No funding agency is associated with this research.

Competing Interests

There are no competing interests.

References

[1]. A. Rodríguez-Pose and D. Hardy, “Addressing poverty and inequality in the rural economy from a global perspective,” Applied Geography, vol. 61, pp. 11–23, Jul. 2015, doi: 10.1016/j.apgeog.2015.02.005.

[2]. T. W. Kim, F. Maimone, K. Pattit, A. J. G. Sisón, and B. L. Teehankee, “Master and Slave: the Dialectic of Human-Artificial Intelligence Engagement,” Humanistic Management Journal, vol. 6, no. 3, pp. 355–371, Dec. 2021, doi: 10.1007/s41463-021-00118-w.

[3]. K. H. John and M. Tiegelkamp, IEC 61131-3: Programming Industrial Automation Systems. 2010. doi: 10.1007/978-3-642-12015-2.

[4]. C. Driessen and L. F. M. Heutinck, “Cows desiring to be milked? Milking robots and the co-evolution of ethics and technology on Dutch dairy farms,” Agriculture and Human Values, vol. 32, no. 1, pp. 3–20, Jun. 2014, doi: 10.1007/s10460-014-9515-5.

[5]. T. A. Shaikh, T. Rasool, and F. R. Lone, “Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming,” Computers and Electronics in Agriculture, vol. 198, p. 107119, Jul. 2022, doi: 10.1016/j.compag.2022.107119.

[6]. K. E. Giller et al., “The future of farming: Who will produce our food?,” Food Security, vol. 13, no. 5, pp. 1073–1099, Sep. 2021, doi: 10.1007/s12571-021-01184-6.

[7]. A. Bechar and C. Vigneault, “Agricultural robots for field operations: Concepts and components,” Biosystems Engineering, vol. 149, pp. 94–111, Sep. 2016, doi: 10.1016/j.biosystemseng.2016.06.014.

[8]. C. Johnson et al., “The Bio-Based Industries Joint Undertaking as a catalyst for a green transition in Europe under the European Green Deal,” EFB Bioeconomy Journal, vol. 1, p. 100014, Nov. 2021, doi: 10.1016/j.bioeco.2021.100014.

[9]. E. Vinco, N. Morrison, J. Bourassa, and G. Lhermie, “Climate policy and Canadian crop production: A qualitative study of farmers’ attitudes and perceptions towards nitrous oxide reductions,” Journal of Cleaner Production, vol. 418, p. 138108, Sep. 2023, doi: 10.1016/j.jclepro.2023.138108.

[10]. A. Bechar and C. Vigneault, “Agricultural robots for field operations. Part 2: Operations and systems,” Biosystems Engineering, vol. 153, pp. 110–128, Jan. 2017, doi: 10.1016/j.biosystemseng.2016.11.004.

[11]. M. Stefanini et al., “Effects of optical sensing based variable rate nitrogen management on yields, nitrogen use and profitability for cotton,” Precision Agriculture, vol. 20, no. 3, pp. 591–610, Sep. 2018, doi: 10.1007/s11119-018-9599-9.

[12]. S. Fabiani et al., “Assessment of the economic and environmental sustainability of Variable Rate Technology (VRT) application in different wheat intensive European agricultural areas. A Water energy food nexus approach,” Environmental Science & Policy, vol. 114, pp. 366–376, Dec. 2020, doi: 10.1016/j.envsci.2020.08.019.

[13]. J. Lowenberg-DeBoer, K. Franklin, K. Behrendt, and R. J. Godwin, “Economics of autonomous equipment for arable farms,” Precision Agriculture, vol. 22, no. 6, pp. 1992–2006, May 2021, doi: 10.1007/s11119-021-09822-x.

[14]. D. C. Slaughter, D. K. Giles, and D. Downey, "Autonomous robotic weed control systems: A review," Computers and Electronics in Agriculture, vol. 61, no. 1, pp. 63–78, Apr. 2008, doi: 10.1016/j.compag.2007.05.008.

[15]. B. Darwin, P. Dharmaraj, S. Prince, D. Popescu, and D. J. Hemanth, "Recognition of Bloom/Yield in Crop Images Using Deep Learning Models for Smart Agriculture: A review," Agronomy, vol. 11, no. 4, p. 646, Mar. 2021, doi: 10.3390/agronomy11040646.

[16]. H. Mousazadeh, "A technical review on navigation systems of agricultural autonomous off-road vehicles," Journal of Terramechanics, vol. 50, no. 3, pp. 211–232, Jun. 2013, doi: 10.1016/j.jterra.2013.03.004.

[17]. S. R. Edulakanti and S. Ganguly, "Review article: The emerging drone technology and the advancement of the Indian drone business industry," The Journal of High Technology Management Research, vol. 34, no. 2, p. 100464, Nov. 2023, doi: 10.1016/j.hitech.2023.100464.

[18]. S. Cubero, E. Marco-Noales, N. Aleixos, S. Barbé, and J. Blasco, "RobHortic: a field robot to detect pests and diseases in horticultural crops by proximal sensing," Agriculture, vol. 10, no. 7, p. 276, Jul. 2020, doi: 10.3390/agriculture10070276.

[19]. K. Sangaiah, A. Javadpour, C.-C. Hsu, A. Haldorai, and A. Zeynivand, "Investigating Routing in the VANET Network: Review and Classification of Approaches," Algorithms, vol. 16, no. 8, p. 381, Aug. 2023, doi: 10.3390/a16080381.

[20]. M. S. A. Mahmud, M. S. Z. Abidin, A. A. Emmanuel, and H. S. Hasan, "Robotics and Automation in agriculture: Present and future applications," DOAJ (DOAJ: Directory of Open Access Journals), Apr. 2020, [Online]. Available: https://doaj.org/article/69ed706740c0400bba3bd20df0e69871

[21]. Y. Kuo, "Using simulated annealing to minimize fuel consumption for the time-dependent vehicle routing problem," Computers & Industrial Engineering, vol. 59, no. 1, pp. 157–165, Aug. 2010, doi: 10.1016/j.cie.2010.03.012.

[22]. S. Ayub, N. Singh, Md. Z. Hussain, M. Ashraf, D. K. Singh, and A. Haldorai, "Hybrid approach to implement multi-robotic navigation system using neural network, fuzzy logic, and bio-inspired optimization methodologies," Computational Intelligence, vol. 39, no. 4, pp. 592–606, Sep. 2022, doi: 10.1111/coin.12547.

[23]. S. Dogru and L. Marques, "Evaluation of an automotive short range radar sensor for mapping in orchards," 2018 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC), Apr. 2018, doi: 10.1109/icarsc.2018.8374164.

[24]. "SWEEPER, the sweet pepper harvesting robot," WUR. https://www.wur.nl/en/project/sweeper-the-sweet-pepper-harvesting-robot.htm

[25]. B. Arad et al., "Development of a sweet pepper harvesting robot," Journal of Field Robotics, vol. 37, no. 6, pp. 1027–1039, Jan. 2020, doi: 10.1002/rob.21937.

[26]. G. Kootstra, X. Wang, P. M. Blok, J. Hemming, and E. Van Henten, "Selective Harvesting Robotics: current research, trends, and future directions," Current Robotics Reports, vol. 2, no. 1, pp. 95–104, Jan. 2021, doi: 10.1007/s43154-020-00034-1.

[27]. S. V. Ilyukhin, T. A. Haley, and R. K. Singh, "A survey of automation practices in the food industry," Food Control, vol. 12, no. 5, pp. 285–296, Jul. 2001, doi: 10.1016/s0956-7135(01)00015-9.

[28]. M. Colla, T. Leidi, and M. Semo, "Design and implementation of industrial automation control systems: A survey," 2009 7th IEEE International Conference on Industrial Informatics, Jun. 2009, doi: 10.1109/indin.2009.5195866.

[29]. G. Barrett, M. I. Caniggia, and L. Read, "'There are More Vets than Doctors in Chiloé': Social and Community Impact of the Globalization of Aquaculture in Chile," World Development, vol. 30, no. 11, pp. 1951–1965, Nov. 2002, doi: 10.1016/s0305-750x(02)00112-2.

[30]. D. Bechtsis, N. Tsolakis, D. Vlachos, and E. Iakovou, "Sustainable supply chain management in the digitalisation era: The impact of Automated Guided Vehicles," Journal of Cleaner Production, vol. 142, pp. 3970–3984, Jan. 2017, doi: 10.1016/j.jclepro.2016.10.057.