Journal of Cleaner Production 415 (2023) 137873

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Review

From waste to value: Addressing the relevance of waste recovery to agricultural sector in line with circular economy

Fatima Haque, Chihhao Fan *, You-Yi Lee

Department of Bioenvironmental Systems Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Da-An District, 10617, Taipei, Taiwan

ARTICLE INFO

Handling Editor: Jian Zuo

Keywords:
Waste management
Agriculture
Circular economy
Business models
Anaerobic digestion
Stakeholders

ABSTRACT

The agricultural sector faces various challenges and barriers in transitioning from linear resource consumption to a circular economy. Based on the literature, four key areas of challenges are identified and discussed, conversion technology and research, business model and material flow in the supply chain, analytical tools for the circular economy, and stakeholder involvement. Among the reported studies, anaerobic digestion (AD) is a commonly-used organic waste conversion technology due to its applicability and cost-effectiveness. The success of AD depends on feedstock properties and operating conditions, which impact the quality and quantity of the digestate and biogas produced. Additional processes such as pretreatment, pyrolysis, and hydrothermal liquefaction can enhance biogas production and generate valuable byproducts. However, challenges remain in terms of feedstock composition, high operating temperatures, and the requirement for suitable infrastructure. The business model and material flow in the supply chain demonstrate another set of challenges. Efficient business models are essential for the circular economy in the agricultural sector. Complex circular business models, financial uncertainties, and stakeholders impede effective implementation. The establishment of a sustainable supply chain that ensures the availability of feedstock and byproducts in synchronization with demand is crucial. Suitable infrastructure, management expertise, and continuous training are also of specific importance. Analytical tools play a vital role in feasibility assessment for the circular economy. Life cycle assessment (LCA) is commonly used to quantify environmental impacts, and the related challenges include the limited availability of relevant data and the need to account for feedstock characteristics. Economic evaluation is another useful evaluation tool, but its application to agricultural waste management is limited. Stakeholder involvement, including government, farmers, and consumers, is another key to the success of a circular economy. Governments can incentivize the use of waste-derived products through policies and regulations. Farmers' willingness to adopt circular practices depends on their location, legislative rules, and available incentives. Overcoming these barriers requires collaborative efforts, innovative technologies, and effective communication among stakeholders. The integration of conversion technologies into existing infrastructure, designing sustainable supply chains, and developing appropriate analytical tools are key steps toward a successful agricultural circular economy.

1. Introduction

The agricultural sector is an integral entity responsible for human survival since it offers an indispensable resource of food to all mankind. Rising continuously, the world population is estimated to reach 9.8 billion by 2050 and up to 11.2 billion by 2100, implying an escalation in the consumption of global natural resources (United Nations, 2022). With the increasing demands for food, energy, and resources due to the growing population, maintaining the ever-lasting operation of production systems becomes critical. In line with the concept of environmental sustainability, the agricultural sector needs to step forward to practice waste valorization and cost-effective analysis in agriculture, realizing the circular economy (CE) as a contrast to conventional agriculture by using resources linearly. A linear economy follows the "taking, using and disposing of" route toward resource consumption (Ness, 2008), whereas the circular economy closes the loop by involving "sharing, renting, reusing, repairing, renovating and recycling existing materials as much as possible" (European Parliament, 2015). Since the natural resources are limited, the current consumption needs to consider the concept of circular economy in a cross-disciplinary framework to prevent resource

* Corresponding author.
E-mail address: chfan@ntu.edu.tw (C. Fan).

https://doi.org/10.1016/j.jclepro.2023.137873
Received 3 March 2023; Received in revised form 3 June 2023; Accepted 19 June 2023
Available online 20 June 2023

depletion, by shifting from the “end of life” (linear economy) model to the “cradle-to-cradle” (i.e., CE) concept (Ellen MacArthur Foundation, 2015).

The concept of circularizing agriculture revolves around minimizing the reliance on external resources, creating a closed-loop system for nutrients, and mitigating the environmental effects caused by waste discharges. For decades, waste from agricultural activities has been utilized as an energy source for agriculture. Biomass waste, including harvest remains and animal waste, can be transformed into fertilizers that are rich in nutrients (e.g., nitrogen, phosphorus, and potassium). By doing so, not only the reliance on synthetic fertilizers from external sources can be reduced, but also agricultural waste can be handled properly with resource recovery (Mieldažys et al., 2016). The waste of plant and animal biomass can be processed to generate biofuels, which can serve as a source of heat and electricity (Pragati et al., 2015). Utilization of biomass, as an energy source, can decrease dependence on fossil fuels and minimize the waste from entering landfills, thereby reducing the carbon footprint (ElMekawy et al., 2014). Efforts to reduce waste and enhance efficiency in agriculture also contribute to the promotion of the circular economy. Recently, precision agriculture plays a vital role in achieving this objective by incorporating fundamental research, remote sensing applications, and data collection techniques. By ensuring the precise application of substances in optimal amounts, timing, and locations, the need for resources was minimized while reducing the associated environmental impact (Yaqot et al., 2022). The concept of CE was first proposed in 1966 (Boulding, 1966), and the 3R’s Principles (reduction, reuse, recycle) were introduced as the founding base of CE (Sakai et al., 2011). An evolving concept of 5R’s Principles is now in practice, which includes reduction, reuse, recycling, recovery, and regeneration. These principles emphasize a scheme where waste valorization is carried out to reduce the waste outflow into the environment by reusing/recycling the waste as a resource. In such a scheme, high-value ingredients/components are recovered from the waste, resulting in lower environmental impacts due to less energy consumption and reduced emissions (Geissdoerfer et al., 2017; Velasco-Muñoz et al., 2021).

Successful implementation of circular economy principles in agriculture can already be observed. A variety of circular economy strategies implemented in different countries are shown in Fig. 1 (Preston and Lehne, 2017; Duque-Acevedo et al., 2020). It can be seen that the concept of circular economy is well implemented across the world, from Japan, China, and India in the East to USA, Canada, and Cuba in the West. For example, the concerns for waste generated from agri-food have urged the European Union (EU) to implement a zero-waste economy strategy by 2050. Meanwhile, World Business Council for Sustainable Development (WBCSD) specifies that a circular economy needs to identify the environmental priorities related to raw materials utilization and water/carbon footprints and to develop an innovative concept that can be integrated into the infrastructure of the existing industries and businesses (Ellen MacArthur Foundation, 2015). Ellen MacArthur Foundation proposes various concepts of circular economy, for changing the economic model at the industrial level to respond to the sustainable development agenda of the United Nations Sustainable Development Goals (SDGs). Realizing a circular economy model into the recycling of agricultural wastes would benefit the following SDGs: Zero Hunger (Goal 2), Decent Work and Economic Growth (Goal 8), Industry, Innovation, and Infrastructure (Goal 9), Sustainable Cities and Communities (Goal 11), and Responsible Consumption and Production (Goal 12) (United Nations, 2015). The emergence of sustainable development as an opportunity shifted the focus towards managing risks, saving costs, and promoting economic growth and innovation in addressing global challenges. The recognition of the nexus of waste and resource strategies has led to the understanding of synergies and trade-offs. Synergies highlight the belief in generating multiple benefits through strategic interventions that consider economic, environmental, and social factors. Trade-offs, on the other hand, acknowledge the challenges in replacing one resource with another due to their interconnected nature. The circular economy narrative is aimed at engaging businesses in sustainable practices, while the Sustainable Development Goals emphasize cooperation among states, businesses, experts, and civil societies, with a focus on government involvement in prioritizing environmental sustainability. The waste and resource debate has become increasingly complex, demanding comprehensive approaches (Blomsma and Brennan, 2017; Belmonte-Ureña et al., 2021). The study of Leipold et al. (2023) suggests engaging in joint studies that incorporate multiple viewpoints, such as optimist, reformist, and skeptical perspectives. Interdisciplinary collaboration and linking technical, environmental, managerial, and social aspects of CE research are of particular importance for developing

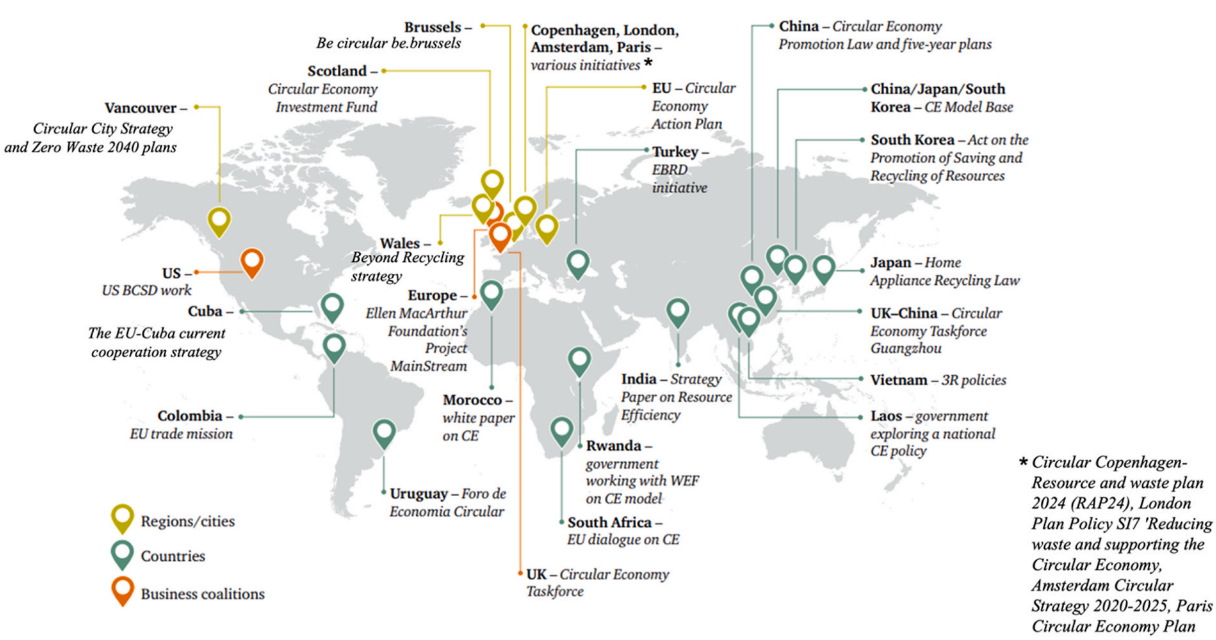

Fig. 1. Circular economy activity around the world (Preston and Lehne, 2017). CE: Circular Economy, EBRD: European Bank for Reconstruction and Development, USBCSD: United States Business Council for Sustainable Development, WEF: World Economic Forum.

systematic and holistic thinking. Researchers can draw upon sustainability science methods for reflexive, collaborative, and transdisciplinary research.

Even though the concept of a circular economy has been proposed decades ago and a number of circular economic strategies are being implemented across the globe, only 8.6% of the global economy is defined as “circular” currently (Economy C, 2021). Why the circular economy concept could not reach a higher implementation became an often-asked question. As mentioned in the beginning, to support the growing world population, the agricultural sector plays a critical role in implementing circular economy models in agricultural practices. Although the adoption of circular economy practices in agriculture is still in the early stage, there is strong potential for extensive application of these principles. Therefore, the primary goal of this study is to provide insight into the relevance of integrating agricultural waste into a circular economy. By understanding the current state of agricultural waste-to-value conversion technologies and existing circular economy business models, this manuscript throws insight into the roadblocks in the implementation of the circular economy concept, thereby contributing to the development of innovative approaches to support eco-friendly, sustainable, efficient, and smart agricultural waste management strategies. Agricultural waste offers a myriad of useful resources that can be converted into bioenergy, biofertilizers, and high-value products (upcycled products). Based on a thorough literature search, this study identifies the critical barriers which were categorized into a) existing conversion technologies (e.g., anaerobic digestion) to produce high-value products in an efficient, sustainable, and intensified manner; b) a business model and material flow in the supply chain; c) analytical tools for the circular economy-including life cycle analysis; and d) the involvement of stakeholders, including the government, farmers, consumers, and the general public. This manuscript addresses these four critical barriers to provide possible strategies for improvement and attempt to fill the knowledge gap that prevents the concept of circular economy from implementation. This manuscript also discussed possible solutions to these existing barriers in the circular economy practice concerning the agricultural sector, not only addressing the strategies for the technical aspects but also suggesting possible implementation on the government, business/industrial, and social dimensions (i.e., stakeholder involvement). Numerous obstacles persist in both technological advancements and consumer behaviors that need to be addressed before the realization of the circular economy can be achieved in agriculture. However, continuous developments in innovative technologies aiming at closing the waste loop are of particular interest and driving progress toward a sustainable environment realizing a circular economy.

2. Literature search method

The literature search for this review was conducted by retrieving the academic studies using the Web of Science (WoS) database to identify the concerns in the successful implementation of a circular economy for the agricultural sector. Article search was performed by setting up the ‘Topic’ field in WoS which filters search based on the title, keywords, author, abstract, and keyword plus. The keywords used in the search were: circular economy and agricultural waste. This resulted in 497 articles. The sample size for the number of articles was reduced to 360 by including only research articles. The research was carried out in May 2022 and was confined to the years after 2015, which was considered appropriate based on the trend in the publication years. Most relevant articles were screened by abstracts and titles, followed by an inspection of the full text to ensure included papers related to the topic under investigation and papers that are not related to the circular economy in the agricultural sector were eliminated. This reduced the number of articles to 77, and additional articles were cited to support their applicability and the information presented in this manuscript. Based on such an extensive literature search, it was seen that there are knowledge gaps prevailing in the areas of waste conversion technology, supply chain, analytical tools, and stakeholder role. Therefore, these were the main critical barriers that have been discussed.

3. Waste-based agricultural circular economy

Based on the studies related to the recycling of agricultural waste, the biorefinement applications, viewpoints from major stakeholders, and value chain investigations (Sheldon, 2020; Chorolque et al., 2021; Czekała et al., 2020; Donner et al., 2020; Santolini et al., 2021; Zannini et al., 2021), a circular economy framework should consider the perspectives on the project proposition, materials acquisition, waste valorization, and performance assessment.

3.1. Project proposition

Moving toward a circular agricultural system is important in terms of its role in greenhouse gas emissions as well as the water and energy footprints of the agricultural sectors. Agricultural wastes are rich in organic fractions and the process of extracting resources or value from waste is termed waste valorization (Gemar et al., 2021). These valorization techniques include biological processing (for example, fermentation), and energy recovery (for example, anaerobic digestion) (Demirbas, A., 2011). The first step in circular economy model implementation to utilize agricultural waste is to identify a suitable waste conversion approach and to understand the end use of the (by-)products formed through raw material characterization. For example, the raw material rich in cellulose can be converted via fermentation or anaerobic digestion to produce bioethanol or biogas, respectively, which can be used as an energy source (Girotto et al., 2015). The most favorable waste conversion technologies include composting and anaerobic digestion that applies to agricultural wastes to produce energy or organic-rich soil additives (Demirbas, A., 2011). The second step for a successful implementation of a circular economy includes designing the transition pathway from a linear form to a circular economy to support waste management and reuse. A suitable circular economy pathway needs to consider waste quality and local conditions, ensuring the lowest life cycle cost, and least infrastructure requirement such as land area, choosing a waste conversion technology that discharges a negligible amount of pollutants and demonstrates energy efficiency with maximum waste conversion. To evaluate the circularity of the agricultural waste system, it is necessary to identify the appropriate tools, such as economic evaluation and life cycle assessment, for accurate and timely monitoring that would help in making decisions (Corrado et al., 2017). For example, on a farm located in Pakistan, the soil quality was low in organic content, fertility, and carbon/nitrogen ratio. Hence, it will be reasonable to use on-farm composting of agricultural wastes to restore soil fertility by recycling the valuable ingredients in the waste, and utilizing the high local temperature (~43 °C) for the composting process, thus maximizing the life cycle efficiency (Hashim et al., 2022).

3.2. Materials acquisition

In the past, agricultural wastes were incinerated or allowed to rot in landfill which results in air and land pollution (Demirbas, 2011). In fact, agricultural wastes can be utilized to generate high-value products such as nutrient-rich materials or energy because they contain cellulosic fibers, high carbon content, and other multifunctional groups (Rao and Rathod, 2019). Generally, the waste generated from agricultural sectors can be categorized into livestock waste (such as animal manure), cropping waste (such as branches), remains of plant harvests (plant litters and stems), dried leaves, and others (García-Rodríguez et al., 2019; Bakan et al., 2022; Taifouris and Martin, 2021). In contrast to domestic and industrial wastes, agricultural wastes contain useful or valuable ingredients such as nutrients (e.g., N, P, K, source of fertilizer) or functional molecules (e.g., anti-inflammatory, anticancer, cardioprotective, and anti-oxidant molecules) (Bas-Bellver et al., 2020; Chebbi et al., 2021). Agricultural processing facilities (e.g., the maize processing plant) also generate processed wastes (e.g., corn cobs, plant waste) and wastewaters which might be also rich in nutrients (e.g., meat processing and production) (Thornton PK, 2010; ElMekawy et al., 2013; Rekleitis et al., 2020; Bakan et al., 2022). Hence, these wastes are suitable raw feedstock to convert into nutrient-rich digestate or compost. Also, many vegetable wastes (such as remnants from muskmelon, tomato, carrots, leeks, celery, and cabbage) are sources of organic-rich ingredients (Bas-Bellver et al., 2020; Chebbi et al., 2021; Truzzi et al., 2022), which enhance the biochemical transformation through microbial reactions. These wastes also contain bioactive compounds, such as phenolic compounds which are secondary metabolites in plants, possessing properties such as antioxidant, anti-inflammatory, cardioprotective, and anticancer potential. The extraction of such compounds from agricultural wastes offers market opportunities because of their potential applications as food and feed additives, functional foods, nutraceuticals, and cosmeceuticals (Jimenez-Lopez et al., 2020).

3.3. Waste conversion through biological processes

To facilitate the recycling of useful ingredients in agricultural waste, several related conversion techniques were used to transform waste into primary products through physical, chemical, or biological processes. Table 1 summarized several transformation products of agricultural waste and their utilization and roles in the closed loop of the circular economy. Biochar and nanolignin were produced from biomass by non-biological methods and were widely used in cropping as soil amendments. Biological processes such as composting, anaerobic digestion (AD), and fermentation which were supposed to be implemented with less energy consumption could generate biofuel and digestate to achieve the economical feasibility of waste valorization (Chiarelotto et al., 2021; Wang et al., 2022).

Composting is an aerobic process that converts organic constituents in agricultural waste into products with shorter molecular chains. The composting process usually finds its application in agricultural cropping systems to improve soil organic content (Shilev et al., 2007). This process operates with microorganisms, either present in agricultural wastes or externally supplemented, including bacteria, fungi, and actinomycetes (Tuomela et al., 2000).

AD is a valorizing process, consisting of four stages hydrolysis, acidogenesis, acetogenesis, and methanogenesis, that converts organic constituents into biogas and digestate (Monlau et al., 2015; Rekleitis et al., 2020). Biogas is a renewable energy source that can be used in a variety of ways, including fuel for engines, producing mechanical power, heat, and electricity. Digestate is a mixture rich in nutrients and can be used as fertilizer for crops. AD process can be applied to industrial (such as food waste treatment plants) and on-site (for example on-farm plants) purposes. Agricultural wastes can be used to extract high-value functional molecules such as bioactive materials.

Fermentation is an anaerobic process in which microorganisms are engaged in breaking down organic wastes to form energy and value-added products such as antibiotics, biosurfactants, enzymes, pigments, as well as plastics (Hadj Saadoun et al., 2021). For example, energy products such as bioethanol can be produced by fermentation of starchy and lignocellulosic raw materials after pretreating them with enzymes to break the large starch and cellulose polymers into glucose monomers, followed by metabolization by *Saccharomyces cerevisiae* (Girotto et al., 2015).

Growing in a nutrient-rich environment, microorganisms (bacteria and microalgae) consume organics (e.g., N and P in the agro-waste) and generate biomass and other high-value byproducts in return (Gupta et al., 2019). For example, *Haematococcus pluvialis* cultured in a bioethanol waste stream can produce astaxanthin (carotene-rich antioxidant). *Chlorella vulgaris* can produce bioenergy-rich biomass (Chinnasamy et al., 2009; Haque et al., 2016, 2017) or protein-rich animal feed (Bertoldi et al., 2008), which can be used as coloring and flavoring agents or food additives in the food industry (Sagar et al., 2018; Ahmed et al., 2022).

3.4. Product reuse and performance assessment

To realize the circular economy loop, the end product generated as a result of the waste conversion should be in demand by the agricultural sectors or other customers. For example, anaerobic digestion of organic wastes generates biogas and solid digestate. Biogas is a mixture of methane and carbon dioxide, which can be recycled back into the agricultural sectors as an energy source. Biogas can help to reduce the dependency on fossil-based non-renewable energy and contribute to

Table 1
Summary of agriculture wastes transformation techniques.

Transformation products	Methods	Utilization	References
Biochar	● Pyrolysis ● Gasification	● Biosorbents for soil bio and phytoremediation ● Soil amendments for improving soil fertility ● Precursor for manufacturing catalysts ● Fuels	Rahimi et al., 2022; Takolpuckdee, 2014; Van Nguyen et al., 2022
Nanolignin	● Lignin-based nanobiotechnologies	● Nanocarrier of insecticides and fungicides for plant disease control ● Nanocarbon for soil modifier ● Nanocomposite for agricultural mulching ● Nanofertilizers and nanobiostimulants for plant physiology regulation	Fu et al., 2022
Biofuel (including biohydrogen, biomethane, biomethanol, bioethanol, biobutanol, and biodiesel)	● Hydrolysis ● Fermentation ● Saccharification ● Anaerobic digestion ● Biophotolysis ● Microbial electrolysis ● Transesterification	● Renewable fuels for heat and electricity generation	Awogbemi and Kallon, 2022; Lee et al., 2019
Lignocellulose degradation products	● Ligninolytic enzymes transformation (e.g., white-rot fungi)	● Depolymerize and mineralize lignin products for use in animal feed, pharmaceutical, chemical, and biofuel industries	Rahimi et al., 2022
Digestate	● Anaerobic digestion	● Bio-chemicals generation to replace fossil-based chemicals ● Nutrients separation and refinement as organic fertilizers ● Transform to value-added bio-products	Pan et al., 2021

carbon emission reduction (Budzianowski and Postawa, 2017). On the other hand, the digestate can be used in land application as a soil amendment since they are usually rich in nutrients (Igoni et al., 2008; Jingura and Matengaifa, 2009; Dahlin et al., 2017; Aso, 2022). Other uses of digestate include as the nutrients for hydroponic cultivation (Rufí-Salís et al., 2020; Pelayo Lind et al., 2021) or animal feed (Fuentes-Grünewald et al., 2021). The use of digestate can reduce the burden on the external supplementation of fertilizer. Therefore, a successful circular economy business model should enable the reuse of the products to meet the demand and flow in the supply chain while designing the model. That is, the products should be in demand by the industrial or agricultural sectors and other stakeholders such as farmers and consumers. Lastly, a performance assessment of the circular economy should be conducted to estimate the environmental benefits (for example, using Life Cycle Assessment, LCA) as well as the market value (for example, using Cost Benefit Analysis). LCA quantifies the environmental impact of agricultural waste and its conversion into value-added byproducts (Vaneeckhaute et al., 2018), It uses an in-built algorithm to quantify the prospective impacts of the product on the environment (Colley et al., 2021). The economic evaluation, which is the main driver for the success of a business, usually involves the prediction of the monetary budgeting, including the consideration of the cash flow along the supply chain (from raw materials to conversion technology, to product reuse) (Vaneeckhaute et al., 2018).

3.5. Exemplary study or prototype study

An example of agricultural waste management in a circular economy is illustrated in Fig. 2, showing how agricultural waste can be valorized and re-used under the circular economy concept. An outline of the implementation of an innovative recycling framework was presented to establish a prototype of resource circulation with economic benefits by regenerating agricultural waste. The agro-organic resource recycling can be achieved through anaerobic digestion, and the generated products, by-products, digestate, and biogas could be utilized as a soil amendment, hydroponic cultivation, animal feed, or as a source of energy, respectively, from the perspective of the circular economy. The proposed example shall enhance the benefit of organic material recycling and reduce the consumption of energy and resource. Another route to the utilization of agricultural wastes in this example includes the extraction of high functional value molecules such as bioactive and antioxidants that finds major application in the pharmaceutical and cosmetic industries. The utilization of agricultural wastes and the generation of new products would benefit the environment, economy, and society. Therefore, the impact analysis on the environment and economy should be part of the circular economy model in combination with stakeholder engagement. The recycling of agricultural resources can enhance the value of by-products and establish inter-industrial links. Meanwhile, processing agricultural resources also implies concerns about increased energy, resource consumption, and pollution emissions at the production stage. Therefore, life cycle assessment (LCA) is necessary to quantify energy use, material consumption, and pollutant emissions during the production and consumption of agricultural resources. LCA shall provide a crucial analysis to understand the impact of circular economy implementation on the environment. Economic evaluation models, such as cost-benefit evaluation methods, can be included in addition to the LCA models to evaluate the energy, cost, and environmental benefits of production.

Despite the promotion of agricultural waste recycling under the circular economy framework, the related practical explorations and field experiences identified challenges and barriers (such as logistics of resources and products, the introduction of re-generated products to the supply chain, *etc.*) to the success of the circular economy in the agricultural sector, which should be addressed to improve the development of waste management in the agricultural circular economy.

4. Barriers to the agricultural circular economy

This section identifies and summarizes the factors restricting the development of an agricultural circular economy based on the literature. Four areas that pose challenges to the successful implementation of a circular economy in the agricultural sector were identified. These challenges and barriers are discussed in Sections 4.1 to 4.4 and summarized in Table 2.

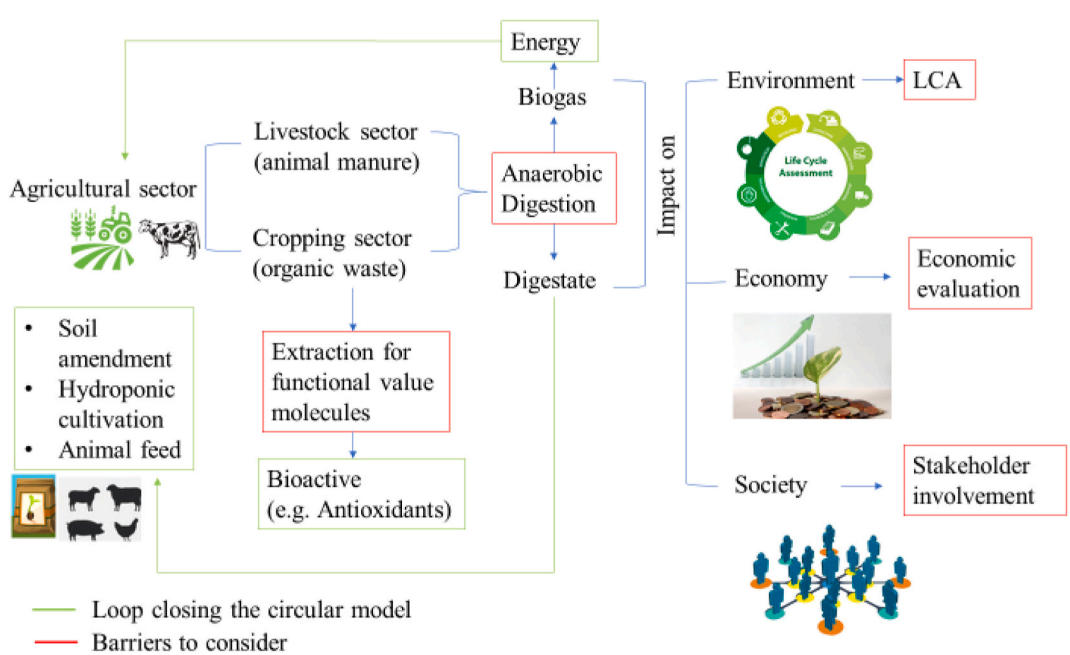

Fig. 2. Conceptual framework: a circular economy approach to the agricultural sector, waste conversion technique using AD into high-value products, biogas, and digestate. It also shows the impact on the environment, society, and economy.

Table 2
Summary of barriers to an agricultural circular economy.

Barriers	Summary/Key points	Recommendation
Upgrade of existing conversion technologies	• Optimized performance of a waste conversion process, for example, anaerobic digestion (AD), depends on the chemical characteristics of the feedstock • Understanding the chemical composition of the raw waste material and the byproduct is lacking	• Identify waste conversion techniques that can be integrated together, such as fermentation-AD, pyrolysis-AD, and hydrothermal liquefaction-AD
Business model and material flow in the supply chain	• Financial uncertainties and complex circular business models lead to the inefficient implementation of a circular economy concept	• Identify the factors that lead to business collaborations for the successful running of a business model
	• Absence of suitable infrastructure supporting the business model and lack of management expertise restricts the material flow in the supply chain • Understanding the waste and byproduct flow in the supply chain. A need to identify the main elements in the supply chain, resource distribution, and production and consumption phases	• Identify the external factors that drive the flow of the material along the supply chain such as geographic location and customer
Analytical tools for the circular economy	• Lack of prediction tools that can provide clear guidance to policy makers and stakeholders (e.g., farmers and industries)	• Consideration of costing of byproduct and raw material handling in the analytical tools, and understanding how this parameter affects the overall circular economy business model
	• Inaccurate LCA modeling techniques and economic evaluations because of negligence in omitting agricultural waste supply and byproduct production along the supply chain • Lack of a specific database on wastes results in inaccurate LCA predictions. This results in stereotyping of a particular LCA study for a specific circular economy model for the entire agricultural waste sector	• Identification of the financial barriers associated with agricultural waste-based circular economy
Stakeholder involvement	• Identification of the key stakeholders involved in a circular economy	• Identify and propose concise government policies to incentivize the use of byproducts produced from wastes
	• Lack of effective policy framework to maximize waste utilization to manufacture high-value product • Understanding farmer's willingness to use and/or purchase the upcycled product such as anaerobic digestate to use as animal feed or soil amendment • Understanding customer's inclination towards byproducts manufactured from wastes	• Conduct survey studies to assess the willingness of the farmers and customers to buy byproducts produced from wastes • Assess to what extent government regulations affect the implementation of the circular economy model

4.1. Conversion technology and research: anaerobic digestion and its product

Anaerobic digestion (AD) is the most widely-used organic waste conversion technology owing to its ease of design and operation. Anaerobic digestion can occur naturally in the landfill or an enclosed controlled digestor under a wide range of temperatures (10–71 °C) (Demirbas, A., 2011). Secondly, it is less costly and energy intensive compared to other biochemical waste conversion technologies such as composting or fermentation. Therefore, this section discusses the technical and research barriers related to the AD process. The performance of an AD process depends on the properties of the feedstock (for example, carbon:nitrogen ratio) and operating conditions (for example, pH and temperature). They determine the quality and quantity of the end product, i.e., the digestate (with high nutrient value) and the biogas (with energy value) (Chodkowska-Miszczuk et al., 2021; Pan et al., 2021; Merlin and Boileau, 2013; Rekleitis et al., 2020). Feedstock composition not only determines the quality and composition of the digestate produced but also affects biogas (methane) generation (Piekutin et al., 2021). Therefore, it is important to understand the feedstock composition in terms of elemental nutrients such as C, H, N, S, N, P, and K. In agricultural waste, cellulose-rich lignins are difficult to digest because of complex cell walls in molecular structure (Himmel and Picataggio, 2009). Therefore, coupling anaerobic digestion with additional mechanical, chemical, thermal, or biological processes is often considered beneficial for the complete digestion of waste (Patinvoh et al., 2017). In an AD process, a pretreatment could be introduced, in which the wastes were mechanically pretreated (via grinding or milling) before enzymatic fermentation (i.e., biological process) to degrade recalcitrant ingredients before being anaerobically digested (Haosagul et al., 2019). The inclusion of the pretreatment step not only enhances the AD system treatability but also improves the energy value of the produced biogas. Meanwhile, the fermentation process may also produce hydrogen (Righetti et al., 2020) which increases the efficiency of the overall energy production. In a traditional AD process, biogas exhibits less energy efficiency because of its mixing content of methane and carbon dioxide (30–40%) (EESI, 2017). With the pretreatment, biogas with more energy (e.g., 10% hydrogen and 55% methane) along with volatile fatty acids (acetate and butyrate) as byproducts could be achieved, according to the study by Righetti et al. (2020).

Pyrolysis and hydrothermal liquefaction could be considered auxiliary processes in the traditional AD process to increase biogas production (Serrano et al., 2017; Chang and Huang, 2020; Chew et al., 2021; Tayibi et al., 2021). Pyrolysis may be included as the following treatment after AD, in which the digestate could be combusted to extract energy from syngas bio-oil and biochar. Being used as an alternative energy source, the biochar can be used as a soil amendment, as a sequestering agent for carbon dioxide (Kizito et al., 2019; Plaimart et al., 2021), and as animal feed as well (Romero et al., 2022). One of the main disadvantages of pyrolysis is the requirement for dry feedstock, hence biomass with high water content is not suitable. In contrast, hydrothermal liquefaction makes use of wet wastes to produce liquid fuels (Gollakota et al., 2018). The liquid fuels can be converted to methane via anaerobic digestion and coupling hydrothermal with anaerobic digestion can therefore generate a higher energy-rich end product by converting the feedstock into oil and methane (Posmanik et al., 2017). However, the requirement of high operating temperatures for both pyrolysis (400–800 °C) and hydrothermal liquefaction (250–350 °C) would make it challenging to utilize these processes on a larger scale (Posmanik et al., 2017; Prurapark et al., 2020).

4.2. Business model and material flow in the supply chain

A business model in the circular economy comprises institute/industry collaborations (e.g., Mishra et al., 2019), green innovations (e.g., Donner et al., 2021), business design (e.g., Ranta et al., 2021), waste re-utilization and management (e.g., Shevchenko et al., 2021), and policy frameworks (e.g., Milios, 2021). An efficient business model ensures waste utilization to keep the eventual high revenue and useful products flowing in the economy by continuous recycling, reusing, and remanufacturing of resources (Hina et al., 2022). The business model in the circular economy for agricultural sectors is important and remains a challenging issue that deserves further investigation (Franceschelli et al., 2018; Barth et al., 2017; Donner et al., 2021; Donner and de Vries, 2021; Babbitt et al., 2022). Many theoretical frameworks have been discussed as the prospective business models that lead to ameliorating the environmental, economic, and social dimensions of an organization, but their applications in the field are still missing. Other barriers include financial uncertainties and complex circular business models (in comparison to simpler linear business models) that lead to the inefficient implementation of the circular economy concept. One probable parameter not considered was the role of stakeholders involved in the organization, and the customer's inclination towards the final product which limits the sustainable flow of the supply chain (Evans et al., 2017). The absence of suitable infrastructure supporting the business model and lack of management expertise also restrict the material flow in the supply chain thus affecting the entire business model (Hina et al., 2022). To integrate a business model considering the circular economy strategy in an agricultural sector, an organization needs to identify the value expected from a CE project proposition, target customers, market demands, and potential competitors. Designing sustainable technologies for product manufacturing and supply chain and creating networking between different stakeholders are important as well (Nosratabadi et al., 2019). A successful business cannot be built in a day without R&D innovation on the scientific front and the business strategy needs to be designed in the first place.

Another challenge to be addressed is to ensure that the input of the raw materials (agricultural waste) and output of the (by)products are in synchronization with the supply and demand to maintain a sustainable supply chain. In other words, the unavailability of feedstock supply and digestate at the time of need may limit the practice of AD technology or circular economy business model. Therefore, continuous personal or institutional demands for the digestate are required, for instance, as a source of soil amendment or animal feed. Simultaneously, there should be enough agricultural waste supply to fulfill this demand, which would determine the treatment capacity of the AD-reacting units. Meanwhile, infrastructure and environmental parameters may impose further restrictions when applying the circular economy business model. Understanding the waste and byproduct flow in the supply chain is necessary. A sustainable supply chain needs to be established to maximize waste valorization and minimize byproduct wastage. While designing the business model, the organization needs to identify the key elements in the supply chain, resource distribution, and production/consumption phases (Dora et al., 2021). Efforts in research and development, business modeling, and framework establishment are needed to favor such integration and enable a sustainable supply chain. The conversion technology (for example, anaerobic digestion) needs to be upgraded so that it can be integrated into the existing infrastructure to partially or completely improve the existing technologies. Additionally, developing a sustainable supply chain also requires the continuous training of the labor forces, including the front-line workers in waste collection and treatment, waste valorization, product application, and project evaluation (Kharola et al., 2022).

4.3. Analytical tools for the circular economy

Another challenge for the circular economy application is the accurate assessment of the synchronization between various phases (e.g., from resource management to production) and drivers (i.e., stakeholders) for the successful implementation of a circular economy. The key challenge consists of the agricultural waste management strategies since there is a lack of estimation tools that can provide clear guidance to policy makers and stakeholders (e.g., farmers and industries) (Gava et al., 2020; Rocchi et al., 2021; Grippo et al., 2019). The adoption of analytical tools such as life cycle assessment (LCA) and economic evaluation is necessary when integrating agricultural waste into a circular economy model (Fig. 3). To optimize resource utilization and management, identifying the (1) prospective waste conversion method to mitigate negative environmental impacts along the production line and (2) various drivers and stakeholders' roles in an organization is important (Zhang et al., 2013). The LCA is an effective tool and its applications can be increased by considering a systematic accounting of byproduct loss along the supply chain and modeling byproduct handling and storage in the waste management system (Corrado et al., 2017).

LCA has been widely used in quantifying the environmental impact of agricultural waste and its conversion into value-added byproducts (Vaneeckhaute et al., 2018; Ahmad et al., 2019; Aleisa et al., 2021; Huang et al., 2022; Ncube et al., 2022). It is a computation procedure compiling an inventory of feedstock inputs (energy and raw materials) and environmental outputs (energy loss and byproduct output), using a built-in algorithm to quantify the prospective impacts of byproducts on the environment (Colley et al., 2021). One of the main challenges of the LCA application is the inventory database that is only available for specific criteria (EPLCA, 2022). When conducting an LCA analysis for a given process at a specific location (especially for developing countries or local communities), using a generic database frequently leads to inaccurate assessment. It would be misleading to stereotype a particular LCA study of a specific circular economy model for the entire agricultural waste sector. This concern deserves more attention because of the different feedstock being generated from different agricultural facilities, including the cropping systems and the livestock sectors, in which variation in raw material property significantly impacts the valorization processes as well as the environmental sustainability. An appropriate LCA methodology should be able to account for feedstock characteristics while inputting the parameters and observed data (Castillo-Villar et al., 2016; Beggio et al., 2019). Also, there is a lack of inclusion of agricultural waste supply and byproduct production along the supply chain (Cerutti et al., 2014; Corrado et al., 2017), which limits the accuracy and overall effectiveness of LCA as an analytical tool, posing a challenge to make decisions at the economic level. For instance, Vaneeckhaute et al. (2018) conducted an assessment of organic waste management through the AD process and pointed out that digestate handling, storage, end-user application, the effect of digestate on soil organic carbon, and other environmental parameters should be included in the future LCA studies.

Another analytical tool for a circular economy is the economic evaluation which is the main driver for the success of a business. While LCA predicts the energy, cost, and environmental benefits of production, cost-benefit analysis and net present value (NPV) of the product decide the market worth. However, only limited literature is available that discusses the economic evaluation of the circular economy concept in the area of agricultural waste management (Chaparro et al., 2021; Barros et al., 2020; Montoro et al., 2019; Vaskalis et al., 2019). Prediction of the future cash flow requires proper communication and collaboration among the stakeholders to ensure that scientists and analyzers have complete knowledge of the business model. All the important aspects of a supply chain (waste type, feedstock characteristics, conversation technology, experimental conditions, storage, and handling of the final product) should be considered in the cost-benefit analysis (Vaneeckhaute et al., 2018). To achieve economic sustainability, agricultural industries should increase product yields (biogas as well as digestate), enhance feed conversion efficiency, and reduce production costs while fulfilling market demands for high-quality and safe produce. As suggested previously regarding the inclusion of pretreatment steps along with the AD process, the economic evaluation process would be further complicated, and more evaluation techniques should be considered in the cost-benefit analysis process.

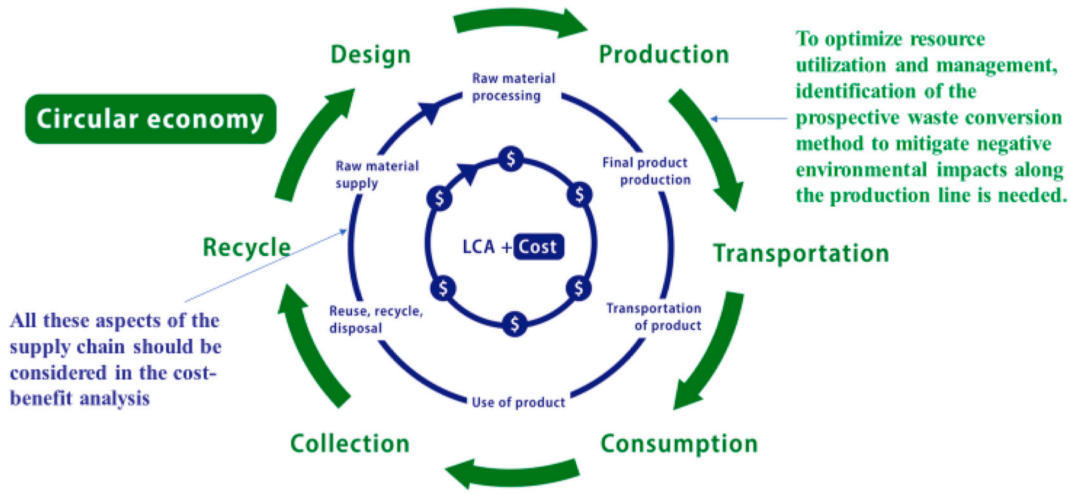

Fig. 3. The adoption of analytical tools such as life cycle assessment (LCA) and economic evaluation is necessary when integrating agricultural waste into a circular economy model. Along with the assessment of the life cycle of the raw material in the circular economy model, cost analysis also needs to be considered to understand the economic benefit. (Figure adapted from Mannan and Al-Ghamdi, 2022).

4.4. Stakeholder involvement

Collaboration and communication among stakeholders are one of the main challenges that influence the sustainability of an agricultural waste-based circular economy. By considering sustainability as a goal in the circular business model, the contributions of the key drivers towards the circular vision are important (Winn and Kirchgeorg, 2005). Along with the innovative sciences and technologies, competent key drivers play an important role to bridge the gap among agricultural waste conversion technology, business model, and sustainable supply chain. In this context, the role of government (policy makers), farmers, and consumers have been discussed herein.

Government: A timely and effective policy can affect the stakeholders' behaviors through incentives, regulation, tax credits, public awareness, and education (Evans et al., 2017; Abad-Segura et al., 2020). To encourage the use of products generated from waste by industries and agricultural sectors, such as the use of biogas and byproducts (digestate and bioactive compounds), the government may introduce energy and land policies to incentivize its use. Doing so will instill confidence in the industrial and agricultural sector users who are taking a risk and offering to use products generated from waste. Therefore, effective government policies are needed that provide essential protections to these sectors to advance circular solutions.

Farmers: The major utilization of the digestate from the waste conversion is to apply as a soil amendment or as animal feed. The farmer's willingness needs to be accessed; however, a small number of studies acknowledged the role of farmers in the circular economy model. The challenge is to comprehend the farmer's perspective to use and/or purchase the upcycled products. The farmers' intentions would further depend on the location, legislative rules, and available incentives (Atinkut et al., 2020). Encouragement from the local authorities and the implementation of environmental policies can drive the farmers to possess a positive perception of agro-waste recycling towards the circular economy. An example is the case of a composting study conducted in Morocco where 80% of the farmers were willing to use composted organic waste instead of chemical fertilizers (Majbar et al., 2021). Hence, farmers need to adapt conversion technologies to manage their agricultural wastes. In Ecuador (Amazon), farmers used pyrolysis to produce biochar in line with the encouragement of the government. However, what is missing is a standardized procedure for pyrolysis operation (Heredia Salgado et al., 2021). In the absence of organized management, the circular model approach might not be as sustainable as expected in the future.

Consumers: There are limited studies that investigate the mindset of consumers if they accept the byproducts manufactured from waste (Bhatt et al., 2018; Aschemann-Witzel and Peschel, 2019; Perito et al., 2019). Coderoni and Perito (2021) assessed the willingness of Italian consumers to purchase upcycled products from agricultural waste. The survey from more than 300 customers showed that approximately 60% of the respondents were aware of the products produced from agricultural waste, whereas only 50% of them were ready to use such products. Based on these studies, the major challenge is that consumers are not informed about the environmental benefits of using these products. Thus, awareness of their environmental benefits is a key limitation of circular economy promotion (Vega-Zamora et al., 2019). If the consumers are not willing to buy the high-value products generated from waste, the products will end up becoming waste in the supply chain and the whole purpose of converting waste will be marred. Therefore, the market demands and interests of the consumers to ensure the sustainability of the supply chain are important and remain very challenging.

As recommended, a circular-based model should aim to (a) understand the trade-offs of multiple stakeholders in different networks under the operation of an agricultural circular economy, (b) establish the relationship between the degree of influence and the weight of multiple stakeholders in the agricultural circular economy, and (c) assess the role of multiple stakeholders in the application of agricultural circular economy and the strategies and directions for future operations.

5. Conclusion and outlook on future considerations

Converting agricultural waste to high-value byproducts is an effective approach to waste management and using a circular economy model to promote the concept is a promising route. Several strategies and research activities have been conducted, but more effort should be expended to ensure the implementation of a circular economy with more economic viability or sustainability. A viewpoint on the key challenges in the route of integrating agricultural waste into a circular economy model was presented in this study. These challenges are interlinked and the limitations of one area (technology, business model and supply chain, analytical tools, and stakeholder) impact one another directly/indirectly. Anaerobic digestion of agricultural wastes is the most widely used technology at a commercial scale, but the limitations on the use of various feedstock (e.g. lignocellulosic-rich waste) or improving the energy value of the byproduct require the integration of other waste valorization techniques into the AD process such as fermentation, pyrolysis, or hydrothermal liquefaction to pretreat the feedstock. The upgrade at the technological/scientific level drives the business model to include economical prediction tools such as LCA and techno-economic cost evaluation. The success of integrating agricultural waste into the circular economy also depends on the availability of robust technologies that minimize environmental impact and maximize economic benefit. Spatial analytical tools and databases on agriculture wastes are required as well. For example, big data analysis of waste valorization in agriculture can be achieved by using artificial intelligence (AI), machine learning (ML), and the internet of things (IoT) (Li D., 2021; Liu Y, 2021; Belaud et al., 2022). These approaches integrate various parameters of running an agricultural-based economy model including manufacturing, feedstock, energy, and transportation (Benos et al., 2021; Farooq and Akram, 2021). Meanwhile, sensing apparatuses or monitoring technologies are useful to measure environmental parameters such as rainfall, temperature, and spatial analysis (waste streams, soil types, and water quality) (Venter et al., 2020; Tang J., 2021). These scientific tools can be included while designing a circular economy model for agricultural waste by using environmental assessment and decision-making processes to minimize future challenges.

The circular business model should consider resource recycling, that is, the byproduct of one circular economy model can be the raw material for another one, hence preventing a waste of resources and enabling optimum resource utilization. For example, anaerobic digestion of agricultural waste (supposing this is the circular economy model 1) generates digestate as the byproduct, this nutrient-rich byproduct can be used to supplement the hydroponic solutions to grow crops such as tomato and muskmelon (this is the circular economy model 2). The products from circular economy model 2 are the antioxidants and anti-inflammatory-rich bioactives and these products can be circulated to another circular economy model to extract high functional molecules (circular economy model 3). Hence, the flow of the resources between circular economy model 1 (anaerobic digestion of agricultural wastes) to circular economy model 2 (hydroponic crop cultivation), and circular economy model 3 (extraction of high functional molecules from fruits) will result in optimum utilization of resources. For the efficient utilization of agricultural wastes and resource/byproducts among different circular economy models, a common database should be available with information on the waste materials as well as the resources being produced, which would make it easier for waste and resource identification, resulting in the efficient matching of supply and demand of products.

Achieving valorization of agricultural waste along with a sustainable business model and supply chain needs strong cooperation between various stakeholders. While scientists play an important role in the research and development to propose innovative solutions to convert waste to high-value products and design a sustainable supply chain, the government and policy makers should incentivize the use of the byproducts created from waste. The farmers should be given incentives to use digestate as soil amendments and animal feed. High-value functional products created from the wastes should become a part of the industrial manufacturing and supply chain, and the consumer's behavior toward purchasing such products would determine the willingness of the industries to include such products in their business models. Government can set up frameworks to make it compulsory to turn waste into secondary products and encourage the utilization of the generated secondary products by various individuals and institutions.

While the level of adoption varies from country to country, many nations have taken significant steps to promote circular economy principles. For example, the EU has been at the forefront of promoting the circular economy. In 2015, the EU adopted an ambitious Circular Economy Action Plan, setting out measures to enhance recycling, promote eco-design, and reduce waste. The plan includes targets for recycling rates, landfill diversion, and performance assessment. Many EU countries implemented legislation and initiatives to support the transition to a circular economy, such as extended producer responsibility schemes and incentives for recycling and reuse (Ellen MacArthur Foundation, 2015). The Netherlands has established a Circular Dutch Economy Program which includes measures such as promoting sustainable procurement, supporting circular startups, and facilitating resource exchanges between companies (Circular Dutch economy plan, 2023). Tax reduction incentives have been introduced for businesses adopting circular practices. Meanwhile, China is investing heavily in renewable energy, electric vehicles, and waste management infrastructure and the initiatives such as the Circular Economy Promotion Law and the National Pilot Eco-Industrial Park Program have been launched to support the circular economy (Bleischwitz et al., 2022). Overall, while progress has been made in many regions, the political support for the circular economy is not consistent worldwide. Countries with strong policies and regulations tend to have more advanced circular economy practices, while others are still in the process of developing the framework. Collaboration between governments, businesses, and civil sectors is crucial for advancing the circular economy agenda globally.

The circular economy presents various economic implications that make it an appealing approach for adoption. Although transitioning to a circular economy necessitates initial investments and alterations to business models, the long-term economic benefits may outweigh the associated costs. The circular economy focuses on maximizing the value derived from resources by prolonged utilization, resulting in reduced resource consumption and decreased expenses related to extracting and producing raw materials. Through waste reduction and optimization of resource utilization, businesses can enhance operational efficiency and minimize production costs. Rather than purchasing raw materials, businesses can obtain materials from recycled sources, which are often more cost-effective. Moreover, circular economy strategies such as product life extension and repair services can diminish the need for frequent replacements, ultimately reducing costs for both businesses and consumers. The circular economy also creates fresh business prospects and markets. Companies can develop innovative products and services based on circular principles, such as remanufacturing, sharing platforms, and resource recovery. These principles foster entrepreneurship, job creation, and economic growth in sectors associated with circular economy activities. Embracing circular economy principles can enhance a company's competitiveness by elevating its reputation, and meeting consumer demands for sustainable products and services. As consumers increasingly prioritize environmentally friendly practices, circular economy practices can result in heightened sales and customer loyalty. While the economic appeal of the circular economy is evident, it's crucial to acknowledge that a successful transition necessitates supportive policies, collaborations, and investments. Governments, businesses, and stakeholders should collaborate to establish an enabling environment that incentivizes and facilitates the adoption of circular practices.

Author contributions

Fatima Haque: Formal analysis, Investigation, Writing- Original Draft, Writing-Review & Editing, Visualization. **Chihhao Fan**: Conceptualization, Project administration, Writing-Original Draft, Writing-Review & Editing. **You-Yi Lee**: Methodology, Formal analysis, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgments

This work is supported by the National Science and Technology Council, Taiwan under the grant number of NSTC 110-2621-M-002-015-MY3.

References

Abad-Segura, E., Fuente, A.B., González-Zamar, M.D., Belmonte-Ureña, L.J., 2020. Effects of circular economy policies on the environment and sustainable growth: worldwide research. Sustainability 12 (14), 5792.
Ahmad, S., Wong, K.Y., Ahmad, R., 2019. Life cycle assessment for food production and manufacturing: recent trends, global applications and future prospects. Procedia Manuf. 34, 49–57.
Ahmed, M., Ali, A., Sarfraz, A., Hong, Q., Boran, H., 2022. Effect of freeze-drying on apple pomace and pomegranate peel powders used as a source of bioactive ingredients for the development of functional yogurt. J. Food Qual. 2022.
Aleisa, E., Alsulaili, A., Almuzaini, Y., 2021. Recirculating treated sewage sludge for agricultural use: life cycle assessment for a circular economy. Waste Manag. 135, 79–89.
Aschemann-Witzel, J., Peschel, A.O., 2019. How circular will you eat? The sustainability challenge in food and consumer reaction to either waste-to-value or yet underused novel ingredients in food. Food Qual. Prefer. 77, 15–20.
Aso, S.N., 2022. Mitigation of external costs of inorganic fertilizers with liquid fraction digestate. Biomass Conversion and Biorefinery 1–7.
Atinkut, H.B., Yan, T., Arega, Y., Raza, M.H., 2020. Farmers' willingness-to-pay for eco-friendly agricultural waste management in Ethiopia: a contingent valuation. J. Clean. Prod. 261, 121211.
Awogbemi, O., Kallon, D.V.V., 2022. Valorization of agricultural wastes for biofuel applications. Heliyon 8 (10), e11117.
Babbitt, C.W., Neff, R.A., Roe, B.E., Siddiqui, S., Chavis, C., Trabold, T.A., 2022. Transforming wasted food will require systemic and sustainable infrastructure innovations. Curr. Opin. Environ. Sustain. 54, 101151.
Bakan, B., Bernet, N., Bouchez, T., Boutrou, R., Choubert, J.M., Dabert, P., Duquennoi, C., Ferraro, V., Garcia-Bernet, D., Gillot, S., Méry, J., 2022. Circular economy applied to organic residues and wastewater: research challenges. Waste and Biomass Valorization 13 (2), 1267–1276.
Barros, M.V., Salvador, R., de Francisco, A.C., Piekarski, C.M., 2020. Mapping of research lines on circular economy practices in agriculture: from waste to energy. Renew. Sustain. Energy Rev. 131, 109958.
Barth, H., Ulvenblad, P.O., Ulvenblad, P., 2017. Towards a conceptual framework of sustainable business model innovation in the agri-food sector: a systematic literature review. Sustainability 9 (9), 1620.
Bas-Bellver, C., Barrera, C., Betoret, N., Seguí, L., 2020. Turning agri-food cooperative vegetable residues into functional powdered ingredients for the food industry. Sustainability 12 (4), 1284.
Beggio, G., Schievano, A., Bonato, T., Hennebert, P., Pivato, A., 2019. Statistical analysis for the quality assessment of digestates from separately collected organic fraction of municipal solid waste (OFMSW) and agro-industrial feedstock. Should input feedstock to anaerobic digestion determine the legal status of digestate? Waste Manag. 87, 546–558.
Belaud, J.P., Prioux, N., Vialle, C., Buche, P., Destercke, S., Barakat, A., Sablayrolles, C., 2022. Intensive data and knowledge-driven approach for sustainability analysis: application to lignocellulosic waste valorization processes. Waste and Biomass Valorization 13 (1), 583–598.
Belmonte-Ureña, L.J., Plaza-Úbeda, J.A., Vazquez-Brust, D., Yakovleva, N., 2021. Circular economy, degrowth and green growth as pathways for research on sustainable development goals: a global analysis and future agenda. Ecol. Econ. 185, 107050.
Benos, L., Tagarakis, A.C., Dolias, G., Berruto, R., Kateris, D., Bochtis, D., 2021. Machine learning in agriculture: a comprehensive updated review. Sensors 21 (11), 3758.
Bertoldi, F.C., Sant'Anna, E., Barcelos-Oliveira, J.L., 2008. Chlorella vulgaris cultivated in hydroponic wastewater. InInternational Symposium on Soilless Culture and Hydroponics 843, 203–210.
Bhatt, S., Lee, J., Deutsch, J., Ayaz, H., Fulton, B., Suri, R., 2018. From food waste to value-added surplus products (VASP): consumer acceptance of a novel food product category. J. Consum. Behav. 17 (1), 57–63.
Bleischwitz, R., Yang, M., Huang, B., Xiaozhen, X.U., Zhou, J., McDowall, W., Andrews-Speed, P., Liu, Z., Yong, G., 2022. The circular economy in China: achievements, challenges and potential implications for decarbonisation. Resour. Conserv. Recycl. 183, 106350.
Blomsma, F., Brennan, G., 2017. The emergence of circular economy: a new framing around prolonging resource productivity. J. Ind. Ecol. 21 (3), 603–614.
Boulding, K.E., 1966. The Economics of the Coming Spaceship Earth, pp. 1–7. New York.
Budzianowski, W.M., Postawa, K., 2017. Renewable energy from biogas with reduced carbon dioxide footprint: implications of applying different plant configurations and operating pressures. Renew. Sustain. Energy Rev. 68, 852–868.
Castillo-Villar, K.K., Minor-Popocatl, H., Webb, E., 2016. Quantifying the impact of feedstock quality on the design of bioenergy supply chain networks. Energies 9 (3), 203.
Cerutti, A.K., Beccaro, G.L., Bruun, S., Bosco, S., Donno, D., Notarnicola, B., Bounous, G., 2014. Life cycle assessment application in the fruit sector: state of the art and recommendations for environmental declarations of fruit products. J. Clean. Prod. 73, 125–135.
Chang, M.Y., Huang, W.J., 2020. A practical case report on the node point of a butterfly model circular economy: synthesis of a new hybrid mineral–hydrothermal fertilizer for rice cropping. Sustainability 12 (3), 1245.
Chaparro, M.L., Sanabria, P.J., Jiménez, A.M., Gómez, M.I., Bautista, E.J., Mesa, L., 2021. A circular economy approach for producing a fungal-based biopesticide employing pearl millet as a substrate and its economic evaluation. Bioresource Technology Reports 16, 100869.
Chebbi, A., Franzetti, A., Duarte Castro, F., Gomez Tovar, F.H., Tazzari, M., Sbaffoni, S., Vaccari, M., 2021. Potentials of winery and olive oil residues for the production of rhamnolipids and other biosurfactants: a step towards achieving a circular economy model. Waste and Biomass Valorization 12 (8), 4733–4743.
Chew, K.W., Chia, S.R., Chia, W.Y., Cheah, W.Y., Munawaroh, H.S., Ong, W.J., 2021. Abatement of hazardous materials and biomass waste via pyrolysis and co-pyrolysis for environmental sustainability and circular economy. Environ. Pollut. 278, 116836.
Chiarelotto, M., Restrepo, J.C., Lorin, H.E., Damaceno, F.M., 2021. Composting organic waste from the broiler production chain: a perspective for the circular economy. J. Clean. Prod. 329, 129717.
Chinnasamy, S., Ramakrishnan, B., Bhatnagar, A., Das, K.C., 2009. Biomass production potential of a wastewater alga Chlorella vulgaris ARC 1 under elevated levels of CO2 and temperature. Int. J. Mol. Sci. 10 (2), 518–532.
Chodkowska-Miszczuk, J., Martinát, S., Van Der Horst, D., 2021. Changes in feedstocks of rural anaerobic digestion plants: external drivers towards a circular bioeconomy. Renewable Sustainable Energy Rev. 148, 111344.
Chorolque, A., Pellejero, G., Sosa, M.C., Palacios, J., Aschkar, G., García-Delgado, C., Jiménez-Ballesta, R., 2021. Biological control of soil-borne phytopathogenic fungi through onion waste composting: implications for circular economy perspective. Int. J. Environ. Sci. Technol. 1-0.
Circular Dutch economy plan, 2023. https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050. (Accessed 22 May 2023).
Coderoni, S., Perito, M.A., 2021. Approaches for reducing wastes in the agricultural sector. An analysis of Millennials' willingness to buy food with upcycled ingredients. Waste Manag. 126, 283–290.
Colley, T.A., Valerian, J., Hauschild, M.Z., Olsen, S.I., Birkved, M., 2021. Addressing nutrient depletion in Tanzanian sisal fiber production using life cycle assessment and circular economy principles, with bioenergy co-production. Sustainability 13 (16), 8881.
Corrado, S., Ardente, F., Sala, S., Saouter, E., 2017. Modelling of food loss within life cycle assessment: from current practice towards a systematisation. J. Clean. Prod. 140, 847–859.
Czekała, W., Lewicki, A., Pochwatka, P., Czekała, A., Wojcieszak, D., Jóźwiakowski, K., Waliszewska, H., 2020. Digestate management in polish farms as an element of the nutrient cycle. J. Clean. Prod. 242, 118454.
Dahlin, J., Nelles, M., Herbes, C., 2017. Biogas digestate management: evaluating the attitudes and perceptions of German gardeners towards digestate-based soil amendments. Resour. Conserv. Recycl. 118, 27–38.
Demirbas, A., 2011. Waste management, waste resource facilities and waste conversion processes. Energy Convers. Manag. 52 (2), 1280–1287.
Donner, M., de Vries, H., 2021. How to innovate business models for a circular bio-economy? Bus. Strat. Environ. 30 (4), 1932–1947.
Donner, M., Gohier, R., de Vries, H., 2020. A new circular business model typology for creating value from agro-waste. Sci. Total Environ. 716, 137065.
Donner, M., Verniquet, A., Broeze, J., Kayser, K., De Vries, H., 2021. Critical success and risk factors for circular business models valorising agricultural waste and by-products. Resour. Conserv. Recycl. 165, 105236.
Dora, M., Biswas, S., Choudhary, S., Nayak, R., Irani, Z., 2021. A system-wide interdisciplinary conceptual framework for food loss and waste mitigation strategies in the supply chain. Ind. Market. Manag. 93, 492–508.
Duque-Acevedo, M., Belmonte-Ureña, L.J., Yakovleva, N., Camacho-Ferre, F., 2020. Analysis of the circular economic production models and their approach in agriculture and agricultural waste biomass management. Int. J. Environ. Res. Publ. Health 17 (24), 9549.
Economy, C., 2021. Circle Economy. *The Circularity Gap Report*. Circularity Gap Report. Circle Economy: Ruparo, Amsterdam, 2020.
EESI, 2017. Fact Sheet | Biogas: Converting Waste to Energy. https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy. (Accessed 10 June 2022), 6.
Ellen MacArthur Foundation, 2015. Towards a Circular Economy: Business Rationale for an Accelerated Transition; EMF: Cowes. Island of Wight, UK.
ElMekawy, A., Diels, L., De Wever, H., Pant, D., 2013. Valorization of cereal based biorefinery byproducts: reality and expectations. Environ. Sci. Technol. 47 (16), 9014–9027.
ElMekawy, A., Diels, L., Bertin, L., De Wever, H., Pant, D., 2014. Potential biovalorization techniques for olive mill biorefinery wastewater. Biofuels, Bioproducts and Biorefining 8 (2), 283–293.
EPLCA, 2022. https://data.jrc.ec.europa.eu/collection/EPLCA. (Accessed 10 June 2022), 6.
European Parliament, 2015. Circular Economy: Definition, Importance and Benefits. European Parliament, Brussels, Belgium.
Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E.A., Barlow, C. Y., 2017. Business model innovation for sustainability: towards a unified perspective for creation of sustainable business models. Bus. Strat. Environ. 26 (5), 597–608.
Farooq, M.S., Akram, S., 2021. IoT in agriculture: challenges and opportunities. J. Agric. Res. 59 (1), 63–87.
Franceschelli, M.V., Santoro, G., Candelo, E., 2018. Business model innovation for sustainability: a food start-up case study. Br. Food J.

Fu, X., Zheng, Z., Sha, Z., Cao, H., Yuan, Q., Yu, H., Li, Q., 2022. Biorefining waste into nanobiotechnologies can revolutionize sustainable agriculture. Trends Biotechnol. 40 (12), 1503–1518.

Fuentes-Grünewald, C., Gayo-Peláez, J.I., Ndovela, V., Wood, E., Kapoore, R.V., Llewellyn, C.A., 2021. Towards a circular economy: a novel microalgal two-step growth approach to treat excess nutrients from digestate and to produce biomass for animal feed. Bioresour. Technol. 320, 124349.

García-Rodríguez, J., Ranilla, M.J., France, J., Alaiz-Moretón, H., Carro, M.D., López, S., 2019. Chemical composition, in vitro digestibility and rumen fermentation kinetics of agro-industrial by-products. Animals 9 (11), 861.

Gava, O., Bartolini, F., Venturi, F., Brunori, G., Pardossi, A., 2020. Improving policy evidence base for agricultural sustainability and food security: a content analysis of life cycle assessment research. Sustainability 12 (3), 1033.

Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J., 2017. The Circular Economy–A new sustainability paradigm? J. Clean. Prod. 143, 757–768.

Gemar, G., Soler, I.P., Sánchez-Teba, E.M., 2021. Waste management: valorisation is the way. Foods 10 (10), 2373.

Girotto, F., Alibardi, L., Cossu, R., 2015. Food waste generation and industrial uses: a review. Waste Manag. 45, 32–41.

Gollakota, A.R., Kishore, N., Gu, S., 2018. A review on hydrothermal liquefaction of biomass. Renew. Sustain. Energy Rev. 81, 1378–1392.

Grippo, V., Romano, S., Vastola, A., 2019. Multi-criteria evaluation of bran use to promote circularity in the cereal production chain. Nat. Resour. Res. 28 (1), 125–137.

Gupta, S., Pawar, S.B., Pandey, R.A., 2019. Current practices and challenges in using microalgae for treatment of nutrient rich wastewater from agro-based industries. Sci. Total Environ. 687, 1107–1126.

Hadj Saadoun, J., Bertani, G., Levante, A., Vezzosi, F., Ricci, A., Bernini, V., Lazzi, C., 2021. Fermentation of agri-food waste: a promising route for the production of aroma compounds. Foods 10 (4), 707.

Haosagul, S., Boonyawanich, S., Pisutpaisal, N., 2019. Biomethane Production from co-fermentation of agricultural wastes. Int. J. Hydrogen Energy 44 (11), 5355–5364.

Haque, F., Dutta, A., Thimmanagari, M., Chiang, Y.W., 2016. Intensified green production of astaxanthin from Haematococcus pluvialis. Food Bioprod. Process. 99, 1-1.

Haque, F., Dutta, A., Thimmanagari, M., Chiang, Y.W., 2017. Integrated Haematococcus pluvialis biomass production and nutrient removal using bioethanol plant waste effluent. Process Saf. Environ. Protect. 111, 128–137.

Hashim, S., Waqas, M., Rudra, R.P., Khan, A.A., Mirani, A.A., Sultan, T., Ehsan, F., Abid, M., Saifullah, M., 2022. On-farm composting of agricultural waste materials for sustainable agriculture in Pakistan. Sci. Tech. Rep. 2022.

Heredia Salgado, M.A., Säumel, I., Cianferoni, A., Tarelho, L.A., 2021. Potential for farmers' cooperatives to convert coffee husks into biochar and promote the bioeconomy in the north Ecuadorian amazon. Appl. Sci. 11 (11), 4747.

Himmel, M.E., Picataggio, S.K., 2009. Our challenge is to acquire deeper understanding of biomass recalcitrance and conversion. In: Biomass Recalcitrance: Deconstructing the Plant Cell Wall for Bioenergy, pp. 1–6.

Hina, M., Chauhan, C., Kaur, P., Kraus, S., Dhir, A., 2022. Drivers and barriers of circular economy business models: where we are now, and where we are heading. J. Clean. Prod. 333, 130049.

Huang, Y., Shafiee, M., Charnley, F., Encinas-Oropesa, A., 2022. Designing a framework for materials flow by integrating circular economy principles with end-of-life management strategies. Sustainability 14 (7), 4244.

Igoni, A.H., Ayotamuno, M.J., Eze, C.L., Ogaji, S.O., Probert, S.D., 2008. Designs of anaerobic digesters for producing biogas from municipal solid-waste. Appl. Energy 85 (6), 430–438.

Jimenez-Lopez, C., Fraga-Corral, M., Carpena, M., García-Oliveira, P., Echave, J., Pereira, A.G., Lourenço-Lopes, C., Prieto, M.A., Simal-Gandara, J., 2020. Agriculture waste valorisation as a source of antioxidant phenolic compounds within a circular and sustainable bioeconomy. Food Funct. 11 (6), 4853–4877.

Jingura, R.M., Matengaifa, R., 2009. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe. Renew. Sustain. Energy Rev. 13 (5), 1116–1120.

Kharola, S., Ram, M., Mangla, S.K., Goyal, N., Nautiyal, O.P., Pant, D., Kazancoglu, Y., 2022. Exploring the green waste management problem in food supply chains: a circular economy context. J. Clean. Prod. 351, 131355.

Kizito, S., Luo, H., Lu, J., Bah, H., Dong, R., Wu, S., 2019. Role of nutrient-enriched biochar as a soil amendment during maize growth: exploring practical alternatives to recycle agricultural residuals and to reduce chemical fertilizer demand. Sustainability 11 (11), 3211.

Lee, S.Y., Sankaran, R., Chew, K.W., Tan, C.H., Krishnamoorthy, R., Chu, D.-T., Show, P.-L., 2019. Waste to bioenergy: a review on the recent conversion technologies. BMC Energy 1 (1), 4.

Leipold, S., Petit-Boix, A., Luo, A., Helander, H., Simoens, M., Ashton, W.S., Babbitt, C. W., Bala, A., Bening, C.R., Birkved, M., Blomsma, F., 2023. Lessons, narratives, and research directions for a sustainable circular economy. J. Ind. Ecol. 27 (1), 6–18.

Li, D., 2021. Application of artificial intelligence and machine learning based on big data analysis in sustainable agriculture. Acta Agric. Scand. Sect. B Soil Plant Sci 71 (9), 956–969.

Liu, Y., 2021. Intelligent analysis platform of agricultural sustainable development based on the Internet of Things and machine learning. Acta Agric. Scand. Sect. B Soil Plant Sci 71 (8), 718–731.

Majbar, Z., El Madani, F.Z., Khalis, M., Lahlou, K., Ben Abbou, M., Majbar, E.B., Bourhia, M., Al-Huqail, A.A., El Askary, A., Khalifa, A.S., Ouahmane, L., 2021. Farmers' perceptions and willingness of compost production and use to contribute to environmental sustainability. Sustainability 13 (23), 13335.

Mannan, M., Al-Ghamdi, S.G., 2022. Complementing circular economy with life cycle assessment: deeper understanding of economic, social, and environmental sustainability. InCircular Economy and Sustainability 145–160 (Elsevier).

Merlin, G., Boileau, H., 2013. Anaerobic Digestion of Agricultural Waste: State of the Art and Future Trends. Anaerobic Digestion: Types, Processes and Environmental Impact. Nova Science Publishers, Inc., New York.

Mieldažys, R., Jotautienė, E., Pocius, A., Jasinskas, A., 2016. Analysis of organic agricultural waste usage for fertilizer production. Agron. Res. 14 (1), 143–149.

Milios, L., 2021. Overarching policy framework for product life extension in a circular economy—a bottom-up business perspective. Environmental Policy and Governance 31 (4), 330–346.

Mishra, J.L., Chiwenga, K.D., Ali, K., 2019. Collaboration as an enabler for circular economy: a case study of a developing country. Manag. Decis.

Monlau, F., Sambusiti, C., Ficara, E., Aboulkas, A., Barakat, A., Carrère, H., 2015. New opportunities for agricultural digestate valorization: current situation and perspectives. Energy Environ. Sci. 8 (9), 2600–2621.

Montoro, S.B., Lucas Jr., J., Santos, D.F., Costa, M.S., 2019. Anaerobic co-digestion of sweet potato and dairy cattle manure: a technical and economic evaluation for energy and biofertilizer production. J. Clean. Prod. 226, 1082–1091.

Ncube, A., Fiorentino, G., Panfilo, C., De Falco, M., Ulgiati, S., 2022. Circular economy paths in the olive oil industry: a Life Cycle Assessment look into environmental performance and benefits. Int. J. Life Cycle Assess. 1–21.

Ness, D., 2008. Sustainable urban infrastructure in China: towards a Factor 10 improvement in resource productivity through integrated infrastructure systems. Int. J. Sustain. Dev. World Ecol. 15 (4), 288–301.

Nosratabadi, S., Mosavi, A., Shamshirband, S., Kazimieras Zavadskas, E., Rakotonirainy, A., Chau, K.W., 2019. Sustainable business models: a review. Sustainability 11 (6), 1663.

Pan, S.Y., Tsai, C.Y., Liu, C.W., Wang, S.W., Kim, H., Fan, C., 2021. Anaerobic co-digestion of agricultural wastes toward circular bioeconomy. iScience 24 (7), 102704.

Patinvoh, R.J., Osadolor, O.A., Chandolias, K., Horváth, I.S., Taherzadeh, M.J., 2017. Innovative pretreatment strategies for biogas production. Bioresour. Technol. 224, 13–24.

Pelayo Lind, O., Hultberg, M., Bergstrand, K.J., Larsson-Jönsson, H., Caspersen, S., Asp, H., 2021. Biogas digestate in vegetable hydroponic production: pH dynamics and pH management by controlled nitrification. Waste and Biomass Valorization 12 (1), 123–133.

Perito, M.A., Di Fonzo, A., Sansone, M., Russo, C., 2019. Consumer acceptance of food obtained from olive by-products: a survey of Italian consumers. Br. Food J.

Piekutin, J., Puchlik, M., Haczykowski, M., Dyczewska, K., 2021. The efficiency of the biogas plant operation depending on the substrate used. Energies 14 (11), 3157.

Plaimart, J., Acharya, K., Mrozik, W., Davenport, R.J., Vinitnantharat, S., Werner, D., 2021. Coconut husk biochar amendment enhances nutrient retention by suppressing nitrification in agricultural soil following anaerobic digestate application. Environ. Pollut. 268, 115684.

Posmanik, R., Labatut, R.A., Kim, A.H., Usack, J.G., Tester, J.W., Angenent, L.T., 2017. Coupling hydrothermal liquefaction and anaerobic digestion for energy valorization from model biomass feedstocks. Bioresour. Technol. 233, 134–143.

Pragati, A., Smriti, S., Kharkwal, A.C., Ajit, V., 2015. Biofuel from agricultural waste: a review. International Journal of Current Microbiology and Applied Sciences 4 (1), 470–477.

Preston F, Lehne J. A wider circle? The circular economy in developing countries. Chatham, J.L. House Briefing A Wider Circle? The Circular Economy in Developing Countries. Available online: https://reader.chathamhouse.org/wider-circle-circular-economy-developing-countries#thecircular-economy (accessed on 17 April 2019).

Prurapark, R., Owjaraen, K., Saengphrom, B., Limthongtip, I., Tongam, N., 2020. Effect of temperature on pyrolysis oil using high-density polyethylene and polyethylene terephthalate sources from mobile pyrolysis plant. Front. Energy Res. 8, 541535.

Rahimi, Z., Anand, A., Gautam, S., 2022. An overview on thermochemical conversion and potential evaluation of biofuels derived from agricultural wastes. Energy Nexus 7, 100125.

Ranta, V., Aarikka-Stenroos, L., Väisänen, J.M., 2021. Digital technologies catalyzing business model innovation for circular economy—multiple case study. Resour. Conserv. Recycl. 164, 105155.

Rao, P., Rathod, V., 2019. Valorization of food and agricultural waste: a step towards greener future. Chem. Rec. 19 (9), 1858–1871.

Rekleitis, G., Haralambous, K.J., Loizidou, M., Aravossis, K., 2020. Utilization of agricultural and livestock waste in anaerobic digestion (AD): applying the biorefinery concept in a circular economy. Energies 13 (17), 4428.

Righetti, E., Nortilli, S., Fatone, F., Frison, N., Bolzonella, D., 2020. A multiproduct biorefinery approach for the production of hydrogen, methane and volatile fatty acids from agricultural waste. Waste and Biomass Valorization 11 (10), 5239–5246.

Rocchi, L., Paolotti, L., Cortina, C., Fagioli, F.F., Boggia, A., 2021. Measuring circularity: an application of modified Material Circularity Indicator to agricultural systems. Agricultural and Food Economics 9 (1), 1–3.

Romero, C.M., Redman, A.A., Owens, J., Terry, S.A., Ribeiro, G.O., Gorzelak, M.A., Oldenburg, T.B., Hazendonk, P., Larney, F.J., Hao, X., Okine, E., 2022. Effects of feeding a pine-based biochar to beef cattle on subsequent manure nutrients, organic matter composition and greenhouse gas emissions. Sci. Total Environ. 812, 152267.

Rufí-Salís, M., Calvo, M.J., Petit-Boix, A., Villalba, G., Gabarrell, X., 2020. Exploring nutrient recovery from hydroponics in urban agriculture: An environmental assessment. Resourc. Conserv. Recycl. 155, 104683.

Sagar, N.A., Pareek, S., Sharma, S., Yahia, E.M., Lobo, M.G., 2018. Fruit and vegetable waste: bioactive compounds, their extraction, and possible utilization. Compr. Rev. Food Sci. Food Saf. 17 (3), 512–531.

Sakai, S.I., Yoshida, H., Hirai, Y., Asari, M., Takigami, H., Takahashi, S., Tomoda, K., Peeler, M.V., Wejchert, J., Schmid-Unterseh, T., Douvan, A.R., 2011. International comparative study of 3R and waste management policy developments. J. Mater. Cycles Waste Manag. 13 (2), 86–102.
Santolini, E., Bovo, M., Barbaresi, A., Torreggiani, D., Tassinari, P., 2021. Turning agricultural wastes into biomaterials: assessing the sustainability of scenarios of circular valorization of corn cob in a life-cycle perspective. Appl. Sci. 11 (14), 6281.
Serrano, A., Fermoso, F.G., Alonso-Fariñas, B., Rodríguez-Gutierrez, G., Fernandez-Bolaños, J., Borja, R., 2017. Olive mill solid waste biorefinery: high-temperature thermal pre-treatment for phenol recovery and biomethanization. J. Clean. Prod. 148, 314–323.
Sheldon, R.A., 2020. Biocatalysis and biomass conversion: enabling a circular economy. Philosophical Transactions of the Royal Society A 378 (2176), 20190274.
Shevchenko, T., Saidani, M., Danko, Y., Golysheva, I., Chovancová, J., Vavrek, R., 2021. Towards a smart E-waste system utilizing supply chain participants and interactive online maps. Recycling 6 (1), 8.
Shilev, S., Naydenov, M., Vancheva, V., Aladjadjiyan, A., 2007. Composting of food and agricultural wastes. In: InUtilization of By-Products and Treatment of Waste in the Food Industry. Springer, Boston, MA, pp. 283–301.
Taifouris, M., Martin, M., 2021. Toward a circular economy approach for integrated intensive livestock and cropping systems. ACS Sustain. Chem. Eng. 9 (40), 13471–13479.
Takolpuckdee, P., 2014. Transformation of agricultural market waste disposal to biochar soil amendments. Procedia Environmental Sciences 20, 64–70.
Tang, J., 2021. GIS Fundamentals for Agriculture. InAgro-Geoinformatics. Springer, Cham, pp. 25–39.
Tayibi, S., Monlau, F., Marias, F., Cazaudehore, G., Fayoud, N.E., Oukarroum, A., Zeroual, Y., Barakat, A., 2021. Coupling anaerobic digestion and pyrolysis processes for maximizing energy recovery and soil preservation according to the circular economy concept. J. Environ. Manag. 279, 111632.
Thornton, P.K., 2010. Livestock production: recent trends, future prospects. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 365, 2853–2867. https://doi.org/10.1098/rstb.2010.0134.
Truzzi, E., Chaouch, M.A., Rossi, G., Tagliazucchi, L., Bertelli, D., Benvenuti, S., 2022. Characterization and valorization of the agricultural waste obtained from Lavandula steam distillation for its reuse in the food and pharmaceutical fields. Molecules 27 (5), 1613.
Tuomela, M., Vikman, M., Hatakka, A., Itävaara, M., 2000. Biodegradation of lignin in a compost environment: a review. Bioresour. Technol. 72 (2), 169–183.
United Nations, 2015. https://sdgs.un.org/goals. (Accessed 4 June 2022), 4.
United Nations, 2022. Department of economic and social affairs. https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100. (Accessed 4 June 2022), 4.
Van Nguyen, T.T., Phan, A.N., Nguyen, T.-A., Nguyen, T.K., Nguyen, S.T., Pugazhendhi, A., Ky Phuong, H.H., 2022. Valorization of agriculture waste biomass as biochar: as first-rate biosorbent for remediation of contaminated soil. Chemosphere 307, 135834.
Vaneeckhaute, C., Styles, D., Prade, T., Adams, P., Thelin, G., Rodhe, L., Gunnarsson, I., D'Hertefeldt, T., 2018. Closing nutrient loops through decentralized anaerobic digestion of organic residues in agricultural regions: a multi-dimensional sustainability assessment. Resour. Conserv. Recycl. 136, 110–117.
Vaskalis, I., Skoulou, V., Stavropoulos, G., Zabaniotou, A., 2019. Towards circular economy solutions for the management of rice processing residues to bioenergy via gasification. Sustainability 11 (22), 6433.
Vega-Zamora, M., Torres-Ruiz, F.J., Parras-Rosa, M., 2019. Towards sustainable consumption: keys to communication for improving trust in organic foods. J. Clean. Prod. 216, 511–519.
Velasco-Muñoz, J.F., Mendoza, J.M., Aznar-Sánchez, J.A., Gallego-Schmid, A., 2021. Circular economy implementation in the agricultural sector: definition, strategies and indicators. Resour. Conserv. Recycl. 170, 105618.
Venter, Z.S., Brousse, O., Esau, I., Meier, F., 2020. Hyperlocal mapping of urban air temperature using remote sensing and crowdsourced weather data. Remote Sens. Environ. 242, 111791.
Wang, X., Li, C., Lam, C.H., Subramanian, K., Qin, Z.H., Mou, J.H., Jin, M., Chopra, S.S., Singh, V., Ok, Y.S., Yan, J., 2022. Emerging waste valorisation techniques to moderate the hazardous impacts, and their path towards sustainability. J. Hazard Mater. 423, 127023.
Winn, M.I., Kirchgeorg, M., 2005. 11. The siesta is over: a rude awakening from sustainability myopia. Environmental Strategy and Competitive Advantage 232.
Yaqot, M., Menezes, B.C., Al-Ansari, T., 2022. Roadmap to precision agriculture under circular economy constraints. J. Inf. Knowl. Manag., 2250092
Zannini, D., Dal Poggetto, G., Malinconico, M., Santagata, G., Immirzi, B., 2021. Citrus pomace biomass as a source of pectin and lignocellulose fibers: from waste to upgraded biocomposites for mulching applications. Polymers 13 (8), 1280.
Zhang, X.X., Ma, F., Wang, L., 2013. Application of life cycle assessment in agricultural circular economy. InApplied Mechanics and Materials 260, 1086–1091 (Trans Tech Publications Ltd).