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How to Turn Poultry Manure into Valuable Resources: A Circular Business Model for Resilient and Sustainable Small and Medium-Sized Farms

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Abstract

This paper illustrates how small and medium-sized farmers can resolve the complex issue of poultry manure disposal by implementing an innovative technology with the aims of reducing emissions and waste and transforming manure into precious resources for the production of energy and fertilizers. After a literature review, a case study is analyzed to identify the main elements of a circular business model that can realize a strategic priority, such as defining production and consumption processes compatible with sustainability, circularity, and resilience. This paper identifies the main elements that constitute the "value proposition," "value creation and delivery," and "value captured," showing the potential benefits in terms of competitiveness and profitability. This good practice may be replicated by other breeding and agricultural companies that want to be sustainable and resilient. The analyzed topic is a key concern given the great quantity of energy and chemical substances used by farms and the challenges posed by current dramatic events, such as the Russia–Ukraine conflict and the COVID-19 pandemic, which have led to less availability of energy and fertilizers and unsustainable prices.

Keywords: business model, technological innovation, waste minimization, sustainability, resilience

1. Introduction

This research intends to investigate how companies can react to restrictions of resources and the waste issue by implementing a new business model that embeds circular economy principles, with the aim of decreasing emissions and waste, preserving natural capital, and reducing their vulnerability to sudden shocks in resource provision. These issues are a key concern given the great quantity of energy and chemical substances currently used (Shao et al., 2017) and the challenges posed by increasingly dramatic extreme events, such as the Russia–Ukraine conflict and the COVID-19 pandemic, which have accentuated the already growing interest in the concepts of resilience and sustainability. Despite their differences in spatial and temporal scales, both concepts refer to the ability of a system to continue to operate over time, meaning its persistence in operating and responding to critical events, which may require immediate solutions. Given this common emphasis on system survivability, in this paper, sustainability and resilience are analyzed using the same research methodologies and following a unified approach (Marchese et al., 2018).

The well-known Circular Economy Action Plan aims to promote Europe's transition toward a circular economy, increase global competitiveness, support sustainable economic growth, and generate new job opportunities (European Commission, 2015). Moreover, the United Nations has emphasized the role of the circular economy in achieving a significant part of its Sustainable Development Goals in the 2030 Agenda (UNIDO, 2019; D'Adamo et al., 2022).

A circular economy makes it possible to circulate resources for an extended period, thus contributing to saving raw materials and energy as well as increasing attention on cleaner production, biomaterials, and recovery processes (Haines-Gadd et al., 2021). It focuses on enhancing resources that can be recirculated not only through recovery, but also through the creation of innovative materials that can be used to replace other non-renewables (Mahabir et al., 2021).

As embedded in its original notion, the main focus of the circular economy has progressively been expanded from a more specific waste management concern to a wider issue regarding efficiency-oriented control in the closed-loop flows of resources at all stages of production and distribution processes. Hence, other questions are involved, such as the scarcity of natural resources, dependence on energy and raw material suppliers, and soil, water, and air pollution—all issues that make dematerialization and eco-innovation necessary (Geissdoerfer et al., 2018). It follows that the main aim of moving toward a circular economy is to slow the depletion of scarce natural resources, reduce environmental damage from the extraction and processing of virgin materials, and decrease pollution from the processing, use, and end-of-life of products. All these aspects are open to a broad range of options for corporate operativity and research.

The implementation of circular economy principles requires new strategies, an essential redesign of product and service concepts, and new processes. However, the use of new technologies in order to achieve greater cost efficiency, effectiveness, and competitive advantage, thus reducing the consumption of non-renewable resources, still appears to be rather limited. These new technologies not only assume sustainable product and process innovation but also new business models that combine competitiveness, sustainable growth, and eco-friendly supply chains (Manninen & Huiskonen, 2022; Ajmal et al., 2021).

The successful implementation of circular economy principles necessitates engagement at three levels: the micro, meso, and macro levels (Yuan et al., 2008). Production, consumption, waste management, and other supporting activities should all move toward sustainability through innovative practices that operate on ascending scale levels of complexity to realize various objectives, at the level of a single subject such as a company (micro), symbiosis association (meso), and population structure such as city, province, or state (macro). The majority of research concerning the circular economy has focused on the macro and meso levels, whereas research on the micro level has been limited (Barreiro-Gen & Lozano, 2020).

There is no universal approach for how to achieve a circular economy, and academic studies on circular business models that may promote an ecological transition are relatively few (Dwivedi, et al., 2022). Consequently, there has emerged an evident necessity for case studies that could corroborate the current theoretical literature (Rosa et al., 2020). In particular, the principles to follow need to be fleshed out to promote more sustainable resource consumption patterns and production processes through an empirical analysis that shows how the circular economy can be effectively employed by companies (Urbinati et al., 2020; Teece, 2018; Khan et al., 2021).

In this paper, a case study is analyzed with the aim of identifying and interpreting the main elements of a circular business model based on a technological innovation that seeks to create production and consumption processes compatible with sustainability and resilience. More precisely, an Italian high-tech small and medium enterprise (SME) proposes an innovative technology to farm and breeding firms, reformulating their business model with the aim of developing circular and sustainable flows of resources and reducing the risk of raw material and energy supply dependence. This study analyzes the influence of an innovative solution on the strategic planning of companies that choose to be more circular, sustainable, and autonomous, thus reconceptualizing the role of waste as a valuable resource capable of contributing to the realization of new products and energy. The proposed new business model attempts to verify the implementation of the main circular economy principles, overcoming a restrictive description that, as often happens in the existing literature, does not incorporate concrete managerial aspects of competitiveness and profitability (De Angelis, 2021). It is assumed that the application of the principles of the regeneration of resources and the adoption of sustainable production practices positively influence the resilience of the supply chain, as the companies involved will have greater autonomy in finding materials (Bag et al., 2019). This study attempts to fill a literature gap by examining a good practice that may be replicated by other farms that want to design and implement a circular business model to generate sustainability and resilience.

The remainder of this paper is organized as follows. Section 2 includes the literature review on sustainability, circular economy, resilience, and circular business models as well as the theoretical approach used in the research. Section 3 introduces the methodology and data used. Section 4 provides a discussion of the main findings. Section 5 shows the main theoretical contribution and practical implications of the study, and Section 6 provides some conclusions by highlighting future challenges and research developments.

2. Literature Review

2.1 Sustainability, Circularity, and Resilience

The focus of sustainability concerns the maintenance of environmental, social, and economic well-being over time, while resilience is the ability of a system to adapt and positively transform itself after a critical event, which can create instability but also an opportunity to improve (Bansal & DesJardine, 2014). Marchese et al.

(2018) stated that a system becomes more resilient when its sustainability increases. According to Ahern (2013), resilience makes a system more sustainable, and this sustainability is the priority. Masnavi et al. (2019) affirmed that the positive transformation that makes a system resilient refers to a new, more suitable, and sustainable system.

The analysis of the differences between the circular economy and sustainable development and the relationship with resilience can be ambiguous and remain unclear. Nevertheless, the three concepts require a systemic analysis, considering the role of companies in the wider system of stakeholders and the environment and the ability to change, thus enhancing a socially fair development that preserves the ecosystem (Murray et al., 2017).

Some authors propose an integration of these main concepts, such as Fabbricatti & Biancamano (2019), who tried to assimilate circularity, productivity, and resilience, and Fan et al. (2019) who suggested managing some environmental concerns, including waste, energy, and pollution, into a smart, resilient, sustainable, and circular economy.

The theoretical concept embedded in this analysis considers the idea that a circular economy necessarily requires the integration of sustainability and resilience to ensure that production and consumption processes over time are able to adapt and transform positively in case of perturbations.

2.2 Business Model and the Concept of Value

A business model is the architecture of the product, service, and information flows that depict the various business actors, their roles, and the potential benefits for them; it is also a description of the sources of revenues (Timmers, 1998). It takes technological characteristics and potentials as inputs and converts them through customers and markets into economic outputs (Chesbrough & Rosenbloom, 2002). A business model defines how a firm creates and delivers value to customers and the mechanisms employed to capture a share of it (Teece, 2018). The role of value is crucial in most definitions of a business model (Biloslavo et al., 2020), such as value proposition (product/service offering), value creation and delivery (how value is provided), and value capture (how the firm makes money and captures other forms of value) (Richardson, 2008).

Value proposition is the basis of the business model conceptualization and implementation, as it represents what the value is, in other words, the reasons for the company's existence that influence the value created and delivered through products and services offered over time (Osterwalder & Pigneur, 2010; Bansal & DesJardine, 2014). Value creation indicates the processes through which the value is created and how companies use the available resources and capabilities and manage the relationship with partners (Richardson, 2008) consistent with the value proposition; it includes many aspects, such as eco-design, operations, and processes, management, and strategy, organizational systems, procurement, marketing, assessment, and communication (Lozano, 2018). Value capture describes the mechanisms that allow the creator of a value to capture it and how this value is obtained by stakeholders (Schaltegger et al., 2016). However, these concepts are most often proposed for a traditional approach rather than for one that focuses on sustainability and circularity dimensions (Bocken & Short, 2016). To address this gap, this paper primary concentrates on the literature that has attempted to analyze an inclusive concept of business model that incorporates sustainability, circularity, and resilience.

2.3 Sustainable Business Model

Scholars have studied the effects of the ecological transition of companies that realize sustainable business models with the aim of exploiting available resources, mitigating risks, realizing a competitive advantage, and improving resilience (Porter & Kramer, 2011). A sustainable business model has to consider every opportunity to maximize material and energy efficiency, substitute natural resources with renewables, and create value from waste that, if abandoned or not properly reclaimed, can be dangerous for the environment and society.

The interdisciplinary framework underpinning a sustainable business model offers good prospects for improving production and consumption models, which often appear inadequate because of their environmental impact and social inequity. These are evident forms of inefficiency, which is currently no longer focused only on the economic perspective (Elkington, 1998; Fabietti & Trovarelli, 2016).

In a sustainable business model, three main elements have to be satisfied: sustainable value creation, long-life solutions, and proactive involvement of companies' different stakeholders (Bocken et al., 2016). These elements are in line with a broader spatio-temporal view of the corporate strategic solutions' impacts, which include a revision of the role of suppliers and other partners as well as a value chain that is projected on long-term efficiency in order to consider the needs of current and future generations (Bansal & DesJardine, 2014).

The traditional model is transformed or, rather, supplemented by social and environmental priorities (Stubbs & Cocklin, 2008). In other words, the value concept absorbs social and environmental sustainability notions influencing the definition of corporate goals (Rosa et al., 2020), which are oriented toward providing value to customers, the natural environment, and society. According to Boons and Lüdeke-Freund (2013), in a sustainable business model, the conventional value proposition includes ecological and social values in concert with economic values. In particular, the suppliers and consumers are responsible to their stakeholders and the stakeholders of the focal company.

2.4 Circular Business Model

The introduction of a new business model that enables companies to generate value by adopting circular economy principles should improve sustainability. Bocken et al. (2016) developed a framework of strategies to guide designers and business strategists, focusing the study on the three main conditions of closing, narrowing, and slowing resource loops. More precisely, the three conditions are described as follows:

- *closing resource loop (recycling)* concerns the closing of a loop between post-use and production phases, recycling the waste that should be treated or disposed of, and therefore reducing the corresponding environmental impact (circular flow) (Govindan & Soleimani, 2017),
- *narrowing resource flow (reduction)* regards the adoption of new processes that employ fewer natural resources, such as primary energy and raw materials, thus minimizing waste (eco-efficiency) (Kazancoglu et al., 2018), and
- *slowing resource loop (redesign)* concerns the design of long-life goods and product life extension to prolong the use and reuse over time (product life extension) (Blomsma & Brennan, 2017; European Parliament, 2016).

According to Merli et al. (2018), researchers mainly focus on analyzing the closing resource loop strategy, whereas slowing the loop, which requires a radical change of consumption and production patterns, is only examined marginally. For this reason, proposing an empirical solution capable of offering an exemplification of "slowing the loop" is important.

Lastly, Geissdoerfer et al. (2018) emphasized the importance of two other terms: *intensifying*, which means to realize a more intense use of resources, and *dematerializing*, which consists of the substitution of product utility by service and software solutions.

A circular business model satisfies the conditions of sustainability and resilience, thereby ensuring the transformation of production–consumption processes to make them more sustainable and less vulnerable to critical events. Nonetheless, innovation and key relationships with suppliers, partners, and customers over time are crucial pillars for realizing the ambitious circular economy principles (Lieder & Rashid, 2016).

2.5 Circular Business Model and Innovation

The introduction of innovation in business models for a circular economy strengthens the orientation toward the traditional business model innovation perspective, hence improving the research stream on sustainable business model innovation (Teece, 2018). This integration of values improves the capacity of companies to capture opportunities and counteract environmental risks by exploiting resources through the design and implementation of new materials, products, and processes.

A circular business model that incorporates innovation should lead to the adoption of new strategies that can be successful throughout sustainable start-ups, acquisitions, diversifications, or transformations. The result is often a new business model that consists of competitive solutions capable of radically reducing negative or enhancing positive external effects for the environment and society (Schaltegger et al., 2016), especially when it involves a new product or process that is different from those offered by competitors (Porter & Kramer, 2011).

The improvement of social, economic, and environmental performance as a result of sustainability and circularity for a broader range of stakeholders should be one of the main objectives of all economic activities (Frey & Stutzer, 2010). Introducing innovation, circularity, and sustainability allows the preservation of biological nutrients to rebuild natural capital, thus reducing negative externalities and enhancing the resilience of economic systems. This also offers benefits such as cost savings and revenue, new sources of innovation, and improved relationships between customers and other stakeholders (Moshood et al., 2022).

2.6 Industrial Symbiosis

A circular economy cannot be implemented without activating an industrial symbiosis, which Chertow (2000, p. 313) described as the activity that engages traditionally separate industries in a collective approach to gaining a competitive advantage that involves the physical exchange of materials, energy, water, and/or by‐products.

The literature has promoted the analysis of the collaborative eco-industrial initiatives related to circular business model implementation by considering that, in the same supply chain, initiatives that would improve the sustainability of one firm should not damage the position of others (Hazen et al., 2021). Furthermore, circular economy initiatives should facilitate the lean management, eco-efficiency, and profit position of multiple firms (Martınez-Jurado & Moyano-Fuentes, 2014).

2.7 Inertia and Uncertainties

For many companies, it may be essential to innovate their business models to preserve their market position and prevent the fall into a negative conjuncture from which it would be difficult to get out of (Biloslavo et al., 2020). To adopt an innovative circular business model in a company, inertia to change is a substantial barrier that should be overcome. Nevertheless, many companies find it hard to implement a technological innovation that modifies products and processes because of difficulties in identifying an appropriate business model for new technologies or solutions (Chesbrough, 2010). According to Teece (2018), innovation by itself cannot assure business success, since every new technology development effort should determine an innovative business model, which defines how to "go to market" and "capture value" strategies.

Numerous boundaries and uncertainties can thwart the environmental advantages of a circular economy approach, which may have a socio-political, economic, and environmental nature (Kumar et al., 2019). This is primarily true for bureaucracy and normative heterogeneity, since European, national, and regional regulations are not always congruent and do not identify clear institutional interlocutors for companies that need to be efficaciously guided toward innovation, sustainability, and circularity. Furthermore, it is important to highlight that increasing the amount of recycled materials does not automatically lead to superior environmental performance (Haupt et al., 2017). Recycling practices could also result in more greenhouse gas emissions of production due, for example, to the recovery and transformation processes of materials or to the additional transport needed to collect products from the consumer and bring them back to the producer for recycling/reusing processes.

These issues further emphasize how crucial it is to define a systematic and strategic coordination of instruments and operational functions on the basis of a clear regulation and a correct evaluation of the different impacts that innovative and circular business models may generate for all interdependent partners (Estampe et al., 2013) who work closely to fulfill a common aim, such as improving the performance of each company, the whole chain, and any stakeholders (Biloslavo et al., 2020). However, as indicated in the introduction, there is no clear evidence of how these circular and innovative business models might be implemented within companies, as the literature has not offered numerous empirical studies describing good practices that can be understood and replied to by other firms.

3. Method

This research applies a qualitative methodology based on a single case study, which is a particularly suitable approach in exploring the meanings, individuals, or groups involved in social issues (Creswell, 2013). A case study is also useful because the subject under investigation is evolving and has not yet been analyzed in depth (Yin, 2014). Moreover, by creating a connection between scientific research and corporate operativity, case studies allow for a broad and widespread understanding and, thus, a replicability of best practices (Dal Mas et al., 2022). In fact, this case study is intended as an attempt to fill the literature gap and produce a good practice that can be adopted also by other companies.

In order to develop the analysis, a research protocol was rigorously adopted. Multiple sources of evidence were collected, as suggested by Yin (2014). First, articles from newspapers, specialized sector magazines, and conference papers were collected by the academic author with the aim of identifying an appropriate case study and defining its relevance in relation to the research purpose. As Eisenhardt (1989) asserted, the subjects should be polar types, in which the process of interest is transparently observable and must be chosen, and random selection is neither necessary nor even preferable.

A literature review was also conducted to identify an integrated concept of the business model that can assure circularity, sustainability, and resilience, thereby defining its founding elements. The main conceptual contribution based on operational experience was directly provided by the chief executive officer and the founding partner of the 3P Engineering Company. They shared the company's strategic plan which included the main technology initiatives, strategic objectives, and actions designed to achieve their aims.

Significant information was gathered through semi-structured interviews to evaluate how a circular business model that entails innovation can be defined according to the needs of farm and breeding companies to sustain their growing processes. The interviewees were company members and collaborators involved in the development of the technology in terms of their different technical-administrative expertise; they included two technical engineers, an electronics engineer, a project engineer, and a marketing and communication manager. Utilizing multiple sources of data, researchers can realize triangulation and, thus, increase the internal and construct validity of research (Eisenhardt, 1989). In addition to enabling triangulation, various sources of data, due to their distinct nature, can generate different insights and, thus, can be understood as a strategy to add rigor, breadth, complexity, richness, and depth to the study (Rashid et al., 2019).

According to Qu and Dumay (2011, p. 246), the semi-structured interview involves prepared questioning guided by identified themes in a consistent and systematic manner interposed with probes designed to elicit more elaborate responses. The questions mainly focused on the company's strategic objectives and their impacts on internal and external stakeholders (Secundo et al., 2018). More precisely, the issues analyzed concerned the key features of a particular technology, considering its possible implementation in the poultry sector: industry economic trends, social impacts, and environmental issues; farm and breeding companies' needs and constraints; and strategic objectives. Furthermore, the questions aimed to identify the elements of a circular business model that can be proposed to farm and breeding companies together with new technology to make the companies more circular, sustainable, and resilient. Compliance with circular economy principles in the new products and processes realized according to the new business model was also verified. Additionally, all the collected data were manually systematized and discussed with the chief executive officer and the founding partner to conduct a deeper investigation.

4. Summary of the Case Study Results

4.1 Industry Context

The European Union (EU) is one of the largest poultry meat producers in the world. In 2018, it was a net exporter of poultry products with an annual production of around 15.2 million tons, which represents a cumulative increase of about one-quarter, or 3.2 million tons, since 2010 (Eurostat, 2019). Poultry meat is the second most produced and consumed meat in the EU, after pig meat, and this is destined to increase (Augère-Granier, 2019). According to poultry meat market projections for the EU for 2016–2030 (Avec, 2021), the gross indigenous production, consumption, and relevant export of poultry meat are gradually growing, unlike other kinds of meat, such as beef, veal, and pork. As result of the increased production in response to the growing demand for poultry meat and egg products, poultry litter has become one of the most abundant animal wastes. Accordingly, it has given rise to sustainability concerns due to the environmental, social, and economic impacts related to toxic and polluting compounds released into the air, water, and land.

Poultry manure may be classified as an animal by-product and can thus be valorized in different ways: as biomass "as is" or—since it is rich with nitrogen (N), phosphorus (P), and potassium (K)—dried for manuring the farm fields (Jeswani et al., 2019). In the latter case, poultry manure may produce several environmental and health impacts if managed improperly, as it can lead to an increased concentration of greenhouse gas emissions and pathogen contaminations that are harmful to the environment and humans as well (Billen et al., 2015).

According to the EU Nitrate Directive (https://environment.ec.europa.eu/topics/water/nitrates_en), farmers may not spread more than 170 kilograms of N per hectare per year. With the aim of increasing the environmental sustainability of the livestock sector, this EU Directive fixes a limit to contain the organic imbalance due to manure chemical overloads. It is a legal restriction that may jeopardize farm growth since the availability of land where the manure can be disposed of influences the number of breeder heads on which the production of manure depends. This situation could generate a stalemate for smaller poultry breeders who cannot develop their businesses due to the limited availability of fields and the high disposal costs of manure.

The sustainable use of organic waste material in agriculture reduces the need for mineral-based fertilizers, the production of which has negative environmental impacts and depends on imports of phosphate rock, a limited resource. The EU's Circular Economy Action Plan identified the fertilizer regulation revision as a key legislative proposal to boost the market for secondary raw materials, and the revised waste framework directive established ambitious targets for recycling. In this context, poultry manure shows considerable potential to provide safe sources of N, K, and P, with the latter constituting an alternative to the primary raw material, phosphate rock. Both P and phosphate rock have been identified by the European Commission as critical raw materials because of their economic importance, especially for EU operators. However, a few of the biggest players operate their own mines and factories, controlling a significant share of the global fertilizer market as monopolists (Agrifood Atlas, 2017). The depletion of N, K, and P resources may, in the long run, be negative for the sustainability and resilience of agriculture firms, given the expected impact on availability and supply costs.

The use of new technologies to recover materials by making high-quality fertilizing products as well as energy power, thus achieving cost-effectiveness and competitive advantage, is crucial. However, as highlighted in the introduction and the literature review section, sustainable product and process innovation is not sufficient. Companies also need a new business model with the aim of developing circular and sustainable flows of resources and reducing the risk of raw material and energy dependence. Creating new products and energy contributes to resilience and sustainability by preserving natural capital (Marchese et al., 2018) and decreasing emissions and waste.

4.2 Technological Innovation for a Circular Business Model

4.2.1 The Technology and Possible Users

There are many alternative processes available to treat poultry manure, such as composting, anaerobic digestion, energy recovery by combustion, pyrolysis, and gasification. Jeswani et al. (2019) have argue that these approaches have been shown to be viable, but each has advantages and disadvantages that should be better investigated. Furthermore, these technologies are often employed by large poultry farms that do not have to respond to the same economic and technical constraints of small-scale breeders, a phenomenon that cannot be ignored since it is rather widespread (Augère-Granier, 2019).

The company 3P Engineering Srl is an Italian high-tech SME that developed Chimera (CHIckens Manure Exploitation and RevAluation)—GA n. LIFE15 ENV/IT/000631. Chimera is an innovative process of thermo-valorization based on two registered patents that allow the value embedded in chicken manure to be exploited: an opportunity for recovering and recycling all the nutrients derived from the feeding of broiler and laying hens through fertilizer production in addition to heat and electrical energy (through an organic Rankine cycle). It is a process that overcomes the main problems related to traditional manure management solutions, in which sustainability and circularity are the central issues, because it assures minimum environmental impact (Garcia et al., 2019).

The potential main users who could gain the most advantages can be classified into two groups: smaller poultry breeders and farmers. They are normally excluded from the current treatment processes proposed by other companies that offer plants with high production capacities in terms of volume, but are rather inefficient for smaller-size firms. As shown in Table 1, thermo-valorization can generate advantages compared with other technological solutions currently available in the same industry and can be considered one of the most innovative and representative technologies. Technology offers the means to respond to the rising need for sustainability and competitiveness in the agriculture sector, which is a critical issue, especially for small and medium-sized farms and breeders who need to become more sustainable. In the table, some crucial features of the different technologies are shown according to the comparative analysis conducted with 3P Engineering concerning the alternative solutions applied in Italy, Germany, and the UK.

Table 1. Comparison of technologies

Technology	Chimera thermo-valorization	Fluidized bed combustion	HiCHP™ combustion	Gasification	Moving grate combustion	EcoDCM® combustion	Fluidized bed combustion
Poultry manure valorization	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
No drying required	Satisfied	Satisfied				Satisfied	
Small-scale CHP	Satisfied		Satisfied		Satisfied	Satisfied	Satisfied
No de-NO_x required	Satisfied			Satisfied			Satisfied
Recovering in ashes	Satisfied			Satisfied			
NPK fertilizer production	Satisfied						
Low treated cost/ton	Satisfied			Satisfied	Satisfied		

Note. CHP=Combined Heat and Power; de-NO_x=Denitrification; NPK=Nitrogen, Phosphorus, Potassium.

Source: developed by the authors.

4.2.2 Features and Impacts of Technology

From the technological point of view, poultry manure is processed “as is” with no pre-treatment required (no drying and no homogenization), and it is suitable in small-scale combined heat and power (CHP) systems. Air with a large excess of oxygen is injected to provide the heat required to the gasification and pyrolysis zones. The combustion process develops in the absence of flames (combustion zone 800°C–1200°C), generating a very small amount of nitrogen oxide (NOx) and ensuring the complete elimination of pathogens. The recovery of most of poultry manure’s N content from ashes is one of the basic advantages of the Chimera solution, allowing its utilization as a raw material for the production of a liquid and ready for use NPK fertilizer.

A comparison of the proposed thermo-valorization solution with other technologies showed that it satisfies all the conditions analyzed in terms of poultry manure valorization: no drying required, small-scale biomass CHP, recoverable in ashes, no de-NOx required, low treatment cost per ton, and production of an NPK fertilizer. The latter can be the strategic innovation of the proposed process, in addition to the recovery of energy, which, however, often occurs in other technological systems. In light of its characteristics, the technology can approach a market segment in which others are not yet operating; in fact, it competes with other dominant technologies only available for large farmers.

Farmers can improve their environmental, social, and economic sustainability performance by employing an innovative solution that can generate the following benefits (as synthesized in Figure 1):

- eliminating the storage, transport, and disposal of manure and related spreading activities in agricultural fields,
- producing thermal and electrical energy, and
- transforming end-line ashes into rich NPK fertilizer.

Traditional method

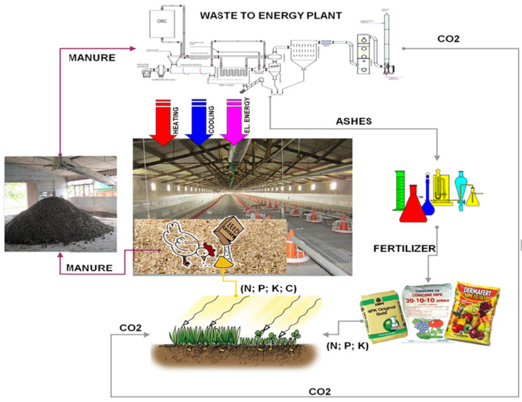
Stock within the farm

High transport cost

Waste treatment

- Direct disposal
- Incinerator/biogas

Treatment of animal by-product



Chimera technology

No stock

No transport cost

No disposal

No pre-treatment

“In farm” valorization

Production of energy and fertilizer

Figure 1. Chimera technology versus traditional methods

Source: developed by the authors.

Farmers may solve an environmental conundrum: growing use of fertilizers originated from non-renewable—and often non-available—resources on the one hand, and overload production of animal manure from breeders on the other hand. Concerning the former, it is important to highlight that traditional fertilizer production requires raw materials that are available in a few macro-areas in the world, that is, those that have nitrate and sulfate quarries, such as the Far East, North America, Eastern Europe, and Central Asia. Thus, producing fertilizers using alternative elements that are normally present in poultry litter makes farmers less vulnerable to sudden supply shocks, since they have the opportunity to exploit their own available resources autonomously.

Manure storage can also be identified as a cause of nuisance odor, which may create air and soil pollution and odor emissions for residents in nearby areas (Billen et al., 2015). In fact, these emissions are often a source of complaints as they affect the quality of life of humans and animals, especially when they are harmful to the environment and society. The disposal process also generates other emissions and costs, such as those related to transport and collecting activities in disposal centers. The reduction of greenhouse gas and other releases achieved by using the new technology proposed, considering the current chicken manure management solutions, improves sanitary safety for the surrounding community and farm employees and enhances food security as well (Prado et al., 2022).

4.2.3 The Adoption of Circular Economy Principles

A circular business model has been presented with the aim of showing how the use of an innovative technology in a farm and breeding firm can create sustainable value in the long-term perspective based on the proactive involvement of the supplier of the innovation itself; in fact, the technology provider can be considered the main stakeholder, as suggested by Bocken et al. (2016). Furthermore, through the adoption of circular economy principles, the in-house production of fertilizer and energy is guaranteed, thus improving farm resilience.

Farmers ***close*** resource loops by using poultry manure, which is transformed into energy and fertilizers. The former can be used to maintain the farm, whereas the latter can enrich cereal fields, which are the basis of poultry feeding (circular flow) (Sauve et al., 2016). Technology thus solves a burdensome disposal problem as it eliminates special waste, even reducing the corresponding environmental, social, and economic impacts (Govindan & Soleimani, 2017). In addition to closing the carbon cycle like other technologies, it allows the N, P, and K cycles to be closed as well by recovering all the nutrients that would otherwise be lost with other treatment processes such as biogas, incineration, and pyro-gasification. The recovered nutrients are returned to the soil through fertilizers, which can be stored and used over time according to the farmers' requirements.

Slowing a resource loop concerns the employment of long-time technology in the substitution of other short-term raw materials (Blomsma & Brennan, 2017), thus assuring the extension of the life of three fundamental resources for agriculture: N, K, and P. This technology prevents the depletion of virgin materials that otherwise continue to be extracted from quarries present in a few countries in the world, the availability of which is destined to drop. Furthermore, their importation generates a condition of dependence on the few countries that have these virgin resources. It follows that the analyzed technology permits verification of a condition (slowing the loop) that has only marginally been taken into consideration in other case studies, demonstrating that its implementation involves a radical change in the design of production and consumption patterns.

Narrowing a resource flow (reduction) regards the production of new energy and fertilizers, avoiding the employment of resources that are scarce, such as energy sources, but also the essential resources for producing fertilizers (eco-efficiency) (Kazancoglu et al., 2018). Even in this case, the elements that should be purchased are produced in-house. In the current process, fertilizer represents an input, while chicken, eggs, and dejections represent the output. The latter is a special waste that must be disposed of, but with thermo-valorization, the cereals used as feed are returned to the environment in the form of fertilizer.

The technology allows a deeper and more intense use of resources (***intensifying***) through the replacement of pre-existent logistic, treatment, and purchasing processes with an innovative internal solution (***dematerializing***) (Geissdoerfer et al., 2018). According to the paradigm of Industrial 4.0 and the Internet of Things the plant can be managed remotely, and updating can also be conducted by the technology producer, thus improving proper functioning and extending the useful life of the system.

4.2.4 The Main Elements of the Circular Business Model

The entire resource recovery process takes place within the company, the latter becomes autonomous and more capable of dealing with critical events, such as the unavailability of energy and fertilizers and the related virgin materials that only a few multinational corporations can supply. This capability is crucial to create a condition of resilience that is a priority for the governance of food and agricultural systems (FAO, 2018; Kliem & Sievers-Glotzbach, 2022).

The proposed innovation encourages the development of a competitive business model (Diaz Lopez et al., 2019) focused on circularity principles and based on the implementation of a new plant that can foster farm and breeding sustainability, therefore creating opportunities of growth. Table 2 shows the main elements of the circular business model:

- value proposition, that responds to "What creates value?"
- value creation and delivery, in this case, "How to create value?"
- value captured or "How to capture value?"

Table 2. Main terms of the circular business model

Value proposition *What creates value?*
NPK fertilizer
Electric and thermal energy
Minimization of waste
Minimization of greenhouse gas emissions
Minimization of odor emission
Reduction of virgin material consumption
Minimization of fertilizers and energy purchases

Value creation and delivery *How to create value?*
Patented technology
Product and process innovation
New operational capabilities
Collaboration with high-tech companies
Collaboration with other farm and breeder companies and fertilizer distributors

Value captured *How to capture value?*
Increasing farm/breeding profit: less costs and new revenues
Farm/breeding energy and fertilizers' procurement independence
Farm/breeding growth
Value for stakeholders

Source: developed by the authors.

Value proposition corresponds to the value created and delivered through products and services offered over time, as highlighted by Osterwalder and Pigneur (2010) and Bansal and DesJardine (2014). In this case study, value proposition depends on NPK fertilizer and energy that the breeding firms can obtain and use first of all at the farm, while the surplus can be sold in the markets as local products, replacing other imported ones, made with non-renewable resources. A rich N, K, and P fertilizer can represent an important source of revenue, both in the case of utilization in the farm fields and market exploitation. The combined production of energy represents an opportunity for breeders because it can be used to warm up the farm factory, chicks' nurseries, or nearby greenhouses, sold for district heating, or used for air refrigeration. Other important results create further value, such as minimization of waste, minimization of greenhouse gas and odor emissions, reduction of virgin material consumption, and minimization of fertilizer and energy purchases. Increasingly, the latter impact is of particular relevance to companies, given the current uncontrolled growth in fertilizer and energy prices and supply difficulties.

Value creation indicates the processes by which the value is created and how companies use the available resources and capabilities through, in this case, collaboration with innovation suppliers, new patented technology implementation, product and process innovation, eco-efficiency production and distribution, new operational capabilities, and collaboration with other farm and breeder companies and fertilizer distributors, in agreement with Lozano (2018). Hence, these are conditions that create new opportunities to increase corporate productivity and efficiency while ensuring environmental and social sustainability.

Innovation and collaboration with the producer of technology and with other farm and breeder companies and fertilizer distributors to enhance the production and distribution processes will be crucial (Richardson, 2008). In particular, the producer can ensure efficient use of the plant through correct set-up and maintenance until the further technological needs of the users are satisfied. The best expertise will be involved in ensuring a skilled work team and adopting the best solutions available. Also, the production and distribution of energy and fertilizer should inspire other relationships in value-chain symbiosis to improve the circularity, sustainability, and resilience of all supply chain members.

Value capture describes the mechanism that allows the creator of value to capture it and how this value is in turn captured by stakeholders (Schaltegger et al., 2016; Bocken & Short, 2016). It represents the results according to the obtained positive impact in terms of increasing farm/breeding profit and managerial autonomy: less costs and new revenues, energy and fertilizer procurement independence, and, consequently, economic growth and stakeholder value.

5. Discussion

Small and medium-sized farms can produce thermal and electric energy and fertilizer and, at the same time, eliminate the issues related to stocking and treatment of a special waste that may be dangerous by employing a technological innovation whose implementation is supported by a circular business model (Teece, 2018). On one hand, there are all the benefits derived from the production in loco of new energy and products, avoiding the consumption of other resources, and on the other, those benefits related to the minimization of a waste rich in chemical compounds as well as the resulting reduction of pollution and odor emissions. The availability of new energy and fertilizer, through poultry manure valorization, makes farms more resilient as they reduce the dependence on external sources that can be risky in the case of critical events (Fabbricatti & Biancamano, 2019; Fan et al., 2019) such as the recent unfavorable trends in the availability of energy and raw materials and prices due to economic instability, COVID-19 pandemic, and the Russia–Ukraine conflict.

The evidences based on our analysis of this innovative technology are also consistent with the idea that the agri-food sector must move toward zero waste generation, or at least minimize its environmental impacts by creating value in manufacturing and supply chains and recovering resources from by-products if techno-economically viable. Through product and process innovation, a growing quantity of special waste, the disposal of which is normally economically, socially, and environmentally onerous, is transformed into valuable energy and fertilizers that can generate new profit opportunities. This case shows that there are clear interconnections between the food, energy, and waste management systems, which will require further research and long-term sustainable solutions, as shown by Garcia et al. (2019). This is likewise in line with the concept of Industry 5.0, which the European Commission refers to as a complement to the current Industry 4.0 approach, as it specifically places research and innovation at the service of the transition to a sustainable, human-centered, and resilient European industry.

The holistic approach of circular production models and supporting technologies pursues not only the solution of technical problems but also the opportunity to move to a more efficient use of the available resources through valorization processes. Nevertheless, farms need to be involved in the implementation of ecological innovations in order to improve their operation capabilities and overcome initial inertia and lack of confidence (Kumar et al., 2019). To achieve this aim, collaborations among farms and also with high-tech companies should allow an effective and efficient use of technological innovation and related know-how over time (Bocken et al., 2016; Bansal & DesJardine, 2014). In this sense, geographically closed and similar farms can share the use of the plant to fulfill a common aim, such as improving the performance of each company, the whole chain, and any stakeholders (Biloslavo et al., 2020; Moshood et al., 2022). It follows that product and process innovation, new capabilities, and collaboration along the supply chain should generate procurement independence and new growth opportunities for all the companies involved (Manninen & Huiskonen, 2022).

This topic sheds light on the important role that policymakers play in relation to the implementation of eco-innovation and collaborations between small and medium-sized farms and high-tech firms to create an economic context favoring the development of a stable and equitable agri-food production, suited to the growing demand for meat and chicken products. In this context, local and national governments, complying with the EU directive and indications, can inspire current and future farmers at the crossroads of ecological renewal to connect with new technological tools whose use should be encouraged by concrete incentivation instruments. In fact, these tools can promote the diffusion of good practices in the poultry industries even beyond European boundaries.

6. Conclusion

A circular business model can be employed to turn an environmental, social, and economic burden (manure disposal) into valuable resources through a technology that can support sustainability of small and medium-sized farms, making them more resilient and thus less exposed to the risk of suffering from the consequences of critical events. In fact, they can overcome the hurdles related to their small size and attempt to realize growth processes over time, which may make them stronger and more competitive. The resulting opportunity to strengthen non-intensive farming is a crucial aspect, considering the high environmental and social impacts of this type of farming.

One of the main challenges of implementing the proposed circular business model is related to the difficulties of making potential farmers and breeders aware of the benefits, in terms of value created and captured, generated by a new approach. For this reason, it is important to verify the environmental, social, and economic impact that may be derived for all the stakeholders, not only farmers and breeders, but also fertilizer companies, distributors, communities, and even public institutions, so as to highlight the validity and replicability of the business model and support the strategic planning process of the companies involved. The performance assessment should consider different characteristics of farms, such as breeding size, poultry manure type (from broilers or laying hens), and manure from other animal species. In the future, accurate scientific research will concentrate on developing assessment methods and parameters specifically focused on companies that are involved in the adoption of innovative and circular business models.

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