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Challenges for Operational and Business Management of Rice Straw Extraction: An analysis Based on CIMO-Logic and System Thinking Process with Experts

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Abstract:

Purpose: This study examines the operational and business challenges associated with rice straw management, focusing on sustainable alternatives to traditional burning methods. The research identifies key barriers and potential solutions for effective rice straw utilisation within the Valencian agricultural context by applying the CIMO-logic framework.

Design/methodology/approach: The research utilises a qualitative methodology based on system thinking and expert interviews to assess rice straw management's operational and business dimensions. Interviews were conducted with stakeholders across the agri-food value chain, capturing diverse perspectives on the socio-technical, regulatory, and economic challenges of adopting sustainable rice straw practices.

Findings: The study reveals several significant barriers, including technological constraints, regulatory challenges, and economic disincentives favouring traditional burning. However, provided financial and regulatory support is established, experts also identified promising opportunities for rice straw use, such as bioenergy production, bio-construction, and sustainable packaging.

Research limitations/implications: The findings are contextual to the Albufera region, where environmental policies and agricultural practices may differ from those of other rice-producing areas. Further comparative studies in varied geographies would benefit from more comprehensive implementation.

Practical implications: The research suggests that targeted economic incentives and advancements in lightweight, efficient machinery could make sustainable rice straw management economically viable for farmers, especially in regions with strict environmental regulations.

Social implications: Sustainable rice straw management practices could improve air quality and public health, reduce social tensions from traditional burning, and promote rural employment by developing small industries based on straw-derived products.

Originality/value: This study provides a novel application of CIMO-logic to agricultural waste management, offering insights into sustainable rice straw practices' operational and business feasibility in a regulated European context.

Keywords: rice straw management, CIMO-logic, sustainability, agricultural waste, bioenergy, Albufera, system thinking, socio-technical challenges

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1. Introduction

Rice straw management poses significant environmental, economic, and operational challenges in rice-producing regions worldwide. Due to its high volume and complex logistical requirements, rice straw is frequently disposed of through traditional practices such as open-field burning. Although practical for farmers, these methods result in substantial greenhouse gas emissions, degrade soil and water quality, and negatively impact public health (Singh, Kaur, Singh, Arya & Krishania, 2024; Ribó, Albiach, Pomares & Canet, 2016). The urgency to adopt sustainable waste management solutions has intensified in recent years, driven by stricter environmental regulations, growing social demands, and international sustainability objectives (Bhattacharyya, Bisen, Bhaduri, Priyadarsini, Munda, Chakraborti et al., 2021; Maji, Dwivedi, Singh, Kishor & Gond, 2020).

Within this context, the Albufera region of Valencia, Spain, faces stringent regulatory constraints on rice straw burning due to its environmental sensitivity. This regulatory environment creates additional operational complexity, pushing stakeholders to explore alternative management approaches (Torregrosa, Giner & Velázquez-Martí, 2021). However, technological, economic, and socio-cultural barriers hinder transitioning to sustainable alternatives, requiring a comprehensive understanding of the multifaceted challenges involved.

This study addresses these challenges through a structured qualitative analysis, leveraging the CIMO-logic (Context–Intervention–Mechanism–Outcome) framework combined with systems thinking and expert interviews. The main objectives of the research are (1) to identify the operational and business barriers currently preventing widespread adoption of sustainable rice straw management practices, (2) to explore viable socio-technical alternatives that could overcome these barriers, and (3) to propose concrete, context-sensitive solutions for policymakers, agricultural practitioners, and other stakeholders.

By integrating expert perspectives across the agri-food value chain, this research applies the CIMO-logic framework and systems thinking approach to the complex challenge of rice straw management in the Albufera of Valencia. This combination provides a structured yet dynamic lens to analyse sustainability transitions in protected and regulated agroecosystems. It offers a novel and practical contribution to the academic debate on agricultural waste management and its real-world implementation.

The article comprises several sections. Section 2 presents the Theoretical Framework, focusing on rice straw and CIMO logic–section 3 details the methodology, using system thinking and expert interviews across the pentagonal dimensions. Section 4 discusses interview results within each dimension. Section 5 addresses implications for operations, business, and policy. Section 6 concludes, followed by references in Section 7.

2. Background

Agricultural waste management is critical for sustainable development (Morseletto, 2022). Agriculture produces large volumes of organic waste, including crop residues and animal waste (Bhattacharyya et al., 2021). Inadequate waste management harms the environment and local economies (Maji et al., 2020; Obi, Ugwuishiwu & Nwakaire, 2016). The Food and Agriculture Organization reports increased agricultural waste due to rising food demand (FAO, IFAD, UNICEF, WFP, & WHO, 2023).

Burning waste remains common, clearing fields but emitting greenhouse gases and depleting soil nutrients (Domínguez-Escribà & Porcar, 2010). Policies aim to reduce burning, but limited alternatives and infrastructure hinder progress, especially in India and China (Bhattacharyya et al., 2021).

Rice straw is particularly challenging due to its volume and geographic spread. Global rice production generates 700–800 million tonnes of straw annually, with China and India producing over 50% (Singh, Kaur et al., 2024; Palma-Guillén, Salicrú, Nadal, Serrat & Nogués, 2024). Rice straw's composition complicates its natural degradation (Van Hung, Maguyon-Detras, Migo, Quilloy, Balingbing, Chivenge et al., 2019).

Environmental restrictions affect rice straw management in sensitive areas like Spain's Albufera Natural Park (Ribó et al., 2016). Spanish rice-growing areas face strict regulations, affecting straw management options like in-field burning and mixing with soil (Palma-Guillén et al., 2024; Singh & Brar, 2021). Burning is now restricted due to impacts on biodiversity and air quality (Ribó et al., 2016). Leaving straw in fields also disrupts irrigation, produces methane, and harms water and soil quality (Quintana-Gallardo, Romero-Clausell, Guillén-Guillamón & Mendiguchia, 2021).

Traditional rice straw management is increasingly unsustainable (Ribó et al., 2016; Singh, Kaur et al., 2024). Sustainable alternatives should emphasise circular economy principles, promoting off-field straw-use options (Van Hung et al., 2019; Singh & Brar, 2021) such as:

a) Agricultural Supplement:

Rice straw has several sustainable agricultural applications, most notably composting, which improves soil fertility and reduces greenhouse gas emissions (Muliarta, 2019). However, to achieve efficient composting, it is crucial to balance the carbon-nitrogen ratio by mixing the straw with animal waste due to its high carbon content (Rathour, Devi, Dahiya, Sharma, Kaushik, Kumari et al., 2023; Van Hung et al., 2019). It is also used in mushroom cultivation as a substrate, where the straw is used after treatment, adding value by converting the waste into commercially viable food (Singh & Brar, 2021; Singh, Sharma, Kumar, Sihag, Balvan, Singh et al., 2024). In addition, straw serves as animal bedding material due to its absorption capacity, although its high silica content may affect its effectiveness in this application (Rathour et al., 2023; Torregrosa et al., 2021).

b) Energy Production:

Rice straw has excellent potential as a feedstock for energy production, especially in the generation of bioethanol and biogas. Anaerobic digestion transforms it into biogas, which can be used as an energy source, while the resulting by-products can be used as fertilisers (Rathour et al., 2023). This technology has been widely explored as a sustainable option to reduce greenhouse gas emissions and generate added value (Harun, Hanafiah & Noor, 2022). Another alternative is the conversion of rice straw into bioethanol through fermentation processes. This approach not only helps reduce dependence on fossil fuels but also takes advantage of a low-value agricultural residue, contributing to the sustainability of the energy sector (Kumar, Nayak, Sharma, Senapati, Mitra, Mohanty et al., 2023; Singh, Gupta, Chaurasiya, Sharma & Pimenov, 2021). In addition, rice straw, alone or mixed with other agricultural residues, can be transformed into pellets for use as solid biofuel. This provides an alternative to conventional fuels for producing electricity and heat. These alternatives reduce the dependence on fossil fuels and provide a new source of income for farmers (Satlewal, Agrawal, Bhagia, Das & Ragauskas, 2018).

c) In Manufacturing as Raw Material:

Rice straw is a versatile raw material for various products, reducing non-renewable materials and environmental impact (Ishii & Furuichi, 2014). Applications include construction materials, offering thermal and acoustic insulation with lower CO_2 emissions than bricks (Torregrosa et al., 2021). It substitutes wood fibres in biocomposites, packaging, paper, and cardboard, supporting sustainability and reducing deforestation (Ribó et al., 2016). Rice straw is also used in nanomaterial production, with applications in advanced technology (Rathour et al., 2023) and recent footwear research (Straw4Footwear project).

These alternatives provide sustainable alternatives to burning or burying straw, polluting and releasing methane (Singh et al., 2021). However, sustainable straw management faces barriers, including high volumes, geographic spread, and logistical costs, especially in remote areas (Kaur & Singh, 2024; Singh, Kaur et al., 2024). Inadequate infrastructure and short harvest windows further complicate collection and transport (Bhattacharyya et al., 2021; Satlewal et al., 2018).

Traditional practices like burning are quicker and eliminate pests, appealing to farmers (Ribó et al., 2016). The low profitability of alternatives, such as biofuel production, poses a significant challenge due to high costs and limited scalability (Ma, Shen & Liu, 2020; Singh et al., 2021; Singh & Brar, 2021). Additional obstacles include cultural resistance to change and insufficient policies promoting sustainable management (Harun et al., 2022; Kaur & Singh, 2024).

Advancing sustainable rice straw management requires overcoming structural and economic barriers. Energy production, manufacturing, and agriculture solutions hold potential but need government and private investment to ensure infrastructure and incentives. Further research on sustainable management practices is essential, applying CIMO logic to analyse interventions and outcomes (Denyer, Tranfield & van Aken, 2008).

Each component of the CIMO model is described as follows:

- Context (C): Refers to the environment or situation where the intervention is implemented. This includes external and internal factors that may influence the success or failure of the intervention. The context can be organisational, social, economic, and cultural.
- Interventions (I) are actions, strategies, or programs implemented to generate change or achieve a specific objective. They can vary in nature, intensity, and duration, among other aspects.
- Mechanisms (M) are the processes or pathways through which interventions produce their effects. They explain how and why interventions work (or do not) in specific contexts.
- Outcomes (O) are the effects or consequences of the interventions. They can be intended or not, positive or negative, and measured in the short, medium, or long term.

The CIMO model is beneficial for designing and evaluating complex interventions. It allows for a deeper understanding of the dynamics between context, interventions, mechanisms, and outcomes. Its focus on mechanisms offers clues on how to adapt interventions to different contexts to improve their effectiveness. This model is relevant in practice-oriented research and evidence-based decision-making, as it promotes a detailed analysis of interventions and their effects.

To adapt the CIMO model for the management of rice straw, a structured approach can be followed to identify how and why specific interventions may be effective in handling this type of waste in this context. Below, an adaptation of the CIMO model for this purpose in the Valencian Community is presented:

- Context: The Albufera de Valencia is an environmentally sensitive area where rice production generates approximately 75,000 to 90,000 tons of straw annually. However, only 3% to 5% of this straw is collected annually due to regulatory restrictions on its burning and the need for adequate infrastructure for its management.
- Interventions: There are two types of interventions for managing rice straw. Conventional interventions focus on leaving the straw in the same field or burning it in the open air. New interventions concentrate on removing the straw from the field and using it as raw material for producing new products.
- Mechanisms: The mechanisms driving rice straw management in Albufera include economic incentives for sustainable practices, environmental regulations that limit conventional practices, technological advances that facilitate the valorisation of straw in derived products, and awareness campaigns on the benefits of proper management.
- Outcomes: The expected results include a positive impact on the environment, the generation of additional income for farmers, and an improvement in field productivity and efficiency. In addition, using straw in sustainable products contributes to a circular economy model with environmental, economic, and social benefits.

Applying the CIMO model to rice straw management in the Albufera de Valencia highlights the problem's complexity and multidimensionality. However, the region has specific characteristics that require environmentally responsible management and sustainable alternatives to straw burning to face significant barriers. Lack of infrastructure, technological limitations, and cultural resistance to adopting new practices are some of the main challenges that must be overcome.

Despite the increased straw collection in recent years, the managed sustainably straw percentage remains low, between 3% and 5% (Pla de gestió de la palla de l'arròs, 2022). This highlights the need to investigate the obstacles and opportunities in implementing more effective straw management, which considers the challenges of extraction intervention from an operational and business management perspective. This review raises the central research question: What are the main challenges and opportunities facing the rice straw extraction intervention in the Albufera de Valencia? From an operational and business management perspective, this research aims to identify the barriers and strategies that could improve the adoption of sustainable straw management practices among local farmers, thus promoting a circular and sustainable economy in the region.

To deepen the theoretical foundation and guide the empirical analysis, this study adopts the CIMO-logic framework as a conceptual model and an analytical lens for structuring the data collected from expert interviews. The framework enables a systematic examination of how context-specific conditions, selected interventions, and enabling mechanisms are expected to lead to desired outcomes in the rice straw management system. Rather than being treated as separate elements, these four components are integrated to explore barriers, opportunities, and systemic interrelations. This approach strengthens the explanatory potential of the study and reinforces the usefulness of CIMO-logic in designing effective, context-sensitive strategies for sustainable agricultural waste management.

3. Methodology

To understand the determinants that allow us to know why rice straw collection is not the dominant solution, a justified selection of informants was made and a qualitative methodology was followed based on the conduct of semi-structured interviews based on the pentagonal model proposed by De Vicente and Matti (2016) for the implementation of system thinking protocols. This methodology has been used extensively in international studies (Nisiforou, Shakou, Magou & Charalambides, 2022; Betta, Nikologianni, Berg, Ciolli, Ternell & Gretter, 2022; Koundouri, Papadaki, Guittard, Demian & Akinsete, 2021; Chibambo, Popokostova & Carry, 2019).

The selection of informants allowed the different links in the industry's value chain to be heard, collecting assessments from stakeholders involved in co-creating solutions to social and environmental problems (Castelló-Sirvent, Farran-Teixidó & Peris-Ortiz, 2024). The system thinking process (Espejo, 1994; Mononen, 2017) was developed through design thinking (Rowe, 1991; Brown, 2008; Plattner, Meinel & Weinberg, 2009).

The purpose of the empirical process was based on fieldwork consisting of identifying the vectors that contribute to defining the widespread use of the rice straw collection technique, addressing a global reflection from the worldview offered by the different stakeholders to understand the barriers from dominant solutions (generalised alternatives based on burning rice straw and not collecting it, leaving it to rot in the field), the socio-technical alternatives existing at present, the visible consequences of applying collection as a common technique in the agri-food industry, the set of social challenges that must be faced to improve the widespread adoption and consolidation of this practice with a lower environmental impact and the long-term drivers that could positively impact this emerging practice.

The methodology allowed us to focus on participating stakeholders and address multiple challenges (Brown, 2008). Design thinking is aligned with the use of non-linear, iterative and overlapping approaches (Platter et al., 2009), being applied in multiple fields of study (Brown, 2008) and facilitating the generation of ideas and combining divergent thinking with convergent thinking through a subsequent phase of concretion and selection of the best solutions (Kimbell, 2011; Black, Gardner, Pierce & Steers, 2019). The following process promoted interdisciplinary collaboration, combining and refining ideas (Meinel & Leifer, 2011). Informants characterised by a wide heterogeneity represented the interests of the stakeholders involved in the value chain were selected. The emphasis was placed on avoiding excessive simplification of complex problems to consider the specific experience of the domain (Vinsel, 2018). The sample size of informants used in this study follows the recommendations of authors of previous research (Almanasreh, Moles & Chen, 2019; Young & Casey, 2018). On the one hand, Almanasreh et al. (2019) emphasise that there is no consensus regarding the number of experts needed to review an instrument; they suggest a threshold close to 10 experts, given that a more significant number of experts or informants would decrease the likelihood of casual agreement, making it difficult to achieve agreement and consensus, and negatively impacting the development of the instrument. On the other hand, Young and Casey (2018) confirm that small, homogeneous samples effectively identify codes and themes, achieving meaningful representation with 6-9 cases, while 7-10 participants are adequate to address complex topics. This finding is relevant, suggesting that researchers can achieve significant results without large samples.

Systemic reflection allows for defining and redefining the perimeter of the issue under study. It is widely used in little-studied contexts or in those where the defining elements of a problem still need to be evident and agreed upon (Watanabe, Tomita, Ishibashi, Ioki & Shirasaka, 2017; Buchanan, 2019).

The different interviews were recorded in audio, obtaining the participants' informed consent for this research and preserving their anonymity in attributing ideas, assessments, and ideas. Thus, it was guaranteed that the participants would not find a causal identification of their ideas with each other but that in this study, the general lines of opinion would be raised, describing the blind profiles of the informants.

The various interviews were then transcribed, and a content analysis was carried out. The content analysis allowed us to identify critical ideas linked to the dimensions of the pentagonal model. At this stage, each key idea was categorised (social-technological, economic-technological, technological, social, climatic, normative, economic, ecological), and its non-repetition was guaranteed, as well as the preservation of the synthesis of ideas without losing essential elements.

Finally, an analysis of coinciding discourses was carried out through the study of the main consensuses, as well as divergent points of view characterised by the most relevant dissents, to understand the contingent elements that allow defining the problem under study, as well as to carry out its discussion, the identification of implications and the formulation of specific recommendations of this research. This process was repeated for each of the five vectors of the pentagonal model proposed by De Vicente and Matti (2016): (1) Barriers from dominant solutions; (2) Socio-Technical alternatives; (3) Visible consequences; (4) Social challenges; (5) Long-term drivers.

4. Results and Discussion

As reported in the methodology section, this study conducted qualitative interviews with seven key informants involved in rice straw management. The profiles of the interviewees are presented in Table 1 below, blinded to protect their identities while providing an overview of their backgrounds and professional roles.

The information gathered from these interviews has been organised around the dimensions of the pentagonal problem: barriers to dominant solutions, socio-technical alternatives, visible consequences, societal challenges and long-term drivers. Below, the different sizes are presented, and the results are extracted after the interviews.

4.1. Barriers from Dominant Solutions

Table 2 summarises the main ideas identified regarding barriers to dominant solutions. It highlights the socio-technological, economic, technological, climatic, regulatory, and ecological dimensions influencing current practices and the informants who highlight these ideas in their interviews.

In the analysis of the interviews, several significant consensuses emerge that reveal the intersection of perspectives around straw management and associated barriers. From a gender perspective, although there is a male predominance in the interviews, the only woman interviewed (D), with a background in environmental sciences, brings a clear focus on sustainability and ecological impact, suggesting that solutions more focused on ecosystem conservation have more excellent support among those with an environmental background.

Informant Code	Gender	Age Range	Education	Profession - Entity	Observations
A	Male	42-52	Economics - Business	Director - Rice Cooperative	Economic and organizational perspective on straw management
B	Male	35-45	Chemical Engineering and Energy Technology	Project Director - Biogas Marketing Company	Technical view on energy alternatives for straw
C	Male	55-65	Agricultural Engineering	Technician - Federation of Agri-food Cooperatives	Focus on sustainable agricultural practices and inter-entity cooperation
D	Female	40-50	Technical Forestry Engineering and Environmental Sciences	Active Member - Environmental Organization	Environmentalist perspective on sustainable management
E	Male	45-55	Biology	Biologist - Natural Park	Ecosystem conservation focus and environmental impact
F	Male	44-54	Secondary Education	Independent Agricultural Machinery Operator	Operational perspective on daily challenges in straw handling
G	Male	45-55	Vocational Training	Farmer - Irrigation Community	Practical knowledge of rice cultivation and water and agricultural needs

Table 1. Blind profile of informants

Summary Idea	Category	A	B	C	D	E	F	G
Wind aids both smoke dispersion after controlled burning and the viability of straw collection, especially with west winds that reduce the likelihood of rain.	Climatic							X
Rain hinders straw collection, favouring burning, as machinery cannot operate in wet fields.	Climatic	X	X	X	X	X	X	X
Wet straw rots in water, impacting the ecosystem and becoming ineffective for other uses, so burning is preferred, even though the smoke is bothersome, as it prevents greater environmental harm.	Ecological	X					X	
High silicon content in rice straw and reduced demand due to a decline in livestock and other traditional uses hinder current utilisation.	Economic					X	X	
High cost and technological difficulties make collecting wet straw inefficient.	Economic-Technological			X	X		X	
Heavy machinery damages fields, raising costs and prompting farmer demands for fields to be returned in good condition after straw removal.	Economic-Technological		X					
Limited availability and adaptation of machinery hinder efficient straw collection in Albufera, especially due to wet conditions, crop timing, and equipment usage in other regions.	Economic-Technological	X		X	X			
Lack of consolidated regulations.	Regulatory		X		X			
Farmers prefer to burn straw quickly to facilitate field flooding for hunting.	Social				X			
Farmers, especially in protected areas, resist changing traditional burning practices for straw removal.	Social		X					
Burning straw is preferred as it is faster and less dependent.	Social-Technological				X			
Wet straw poses self-combustion and fermentation risks, requiring special storage techniques.	Technological	X	X					
Furrows left by harvesters in muddy fields complicate straw extraction, except in stable areas accessible to tractors.	Technological					X		

Table 2. Key ideas on barriers from dominant solutions

Regarding profession and experience, directors and technicians of agricultural entities and cooperatives (A, C, G) tend to focus on technological and economic barriers. For example, the high cost of machinery to collect straw and the preference for burning due to its simplicity and speed are recurring perceptions. These arguments underline a strong dependence on immediate solutions, such as burning, which minimises the cost and operational effort. However, this approach also reflects a resistance to change, especially when investment in machinery or modification of established practices is required. On the other hand, actors with more technical expertise (B and F), such as engineers and machine operators, highlight operational challenges, such as the risks of self-combustion of wet straw or damage caused by the use of heavy machinery in the fields. This group provides a more detailed analysis of the risks and limitations inherent in using current technologies, suggesting that technological innovation could mitigate some of these problems if economic barriers are overcome.

In summary, the barriers shared in the interviews suggest a consensus on the need for more sustainable solutions. However, deep-rooted scepticism regarding their practical and economic viability remains, which poses a multidimensional challenge for future interventions.

The following figure (Figure 1) summarises the main barriers identified by the interviewed experts, highlighting climatic, technological, and economic-technological factors as the most significant. The graph displays the number of experts who mentioned each barrier, facilitating rapid understanding of key obstacles hindering the widespread adoption of sustainable rice straw management practices.

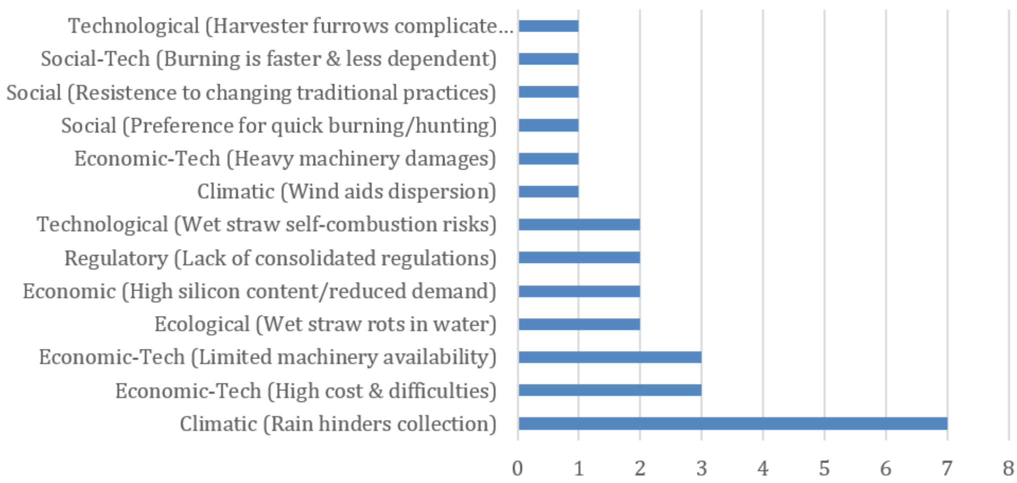

Figure 1. Main barriers identified by experts for rice straw collection

4.2. Socio-Technical Alternatives

Table 3 summarises the main ideas and categories identified in the study on socio-technical alternatives for using rice straw. It highlights the economic-financial, technological-business, socio-technological, and engineering dimensions that influence the viability and development of sustainable options for managing this agricultural residue. It also indicates the interviewees who have shown their preference for each alternative.

In analysing the socio-technical alternatives collected from the interviews, a series of significant consensuses can be seen that can be interpreted from the different training, professional experiences and, to a lesser extent, from the gender perspective.

Expert voices with experience in management and direction (such as informants A, C and D) repeatedly point to the need for economic incentives and regulatory policies as a critical driver for adopting more sustainable alternatives. This trend reflects a pragmatic concern for the cost of implementing new technologies and solutions, especially in sectors where current practices are economically advantageous, such as straw burning. For these actors, any cultural or technical change must be accompanied by policies that mitigate the financial impact, and this is articulated as a sine qua non-condition for accepting these alternatives.

Summary Idea	Category	A	B	C	D	E	F	G
Economic incentives and energy policies could enhance the viability of using straw for bioenergy, but economic barriers persist, even with studies on its potential for biogas.	Economic-Financial			X	X			
A cultural and technological shift is essential to make the industrial utilization of rice straw viable, overcoming current economic and technical barriers.	Social-Technological			X				
Rice straw holds great potential in sectors such as bioconstruction, agro-industry, biodegradable packaging, biogas production, fertilizers, bioethanol, and cosmetics. However, costs remain challenging, and many technological solutions are still experimental or lack conclusive results.	Technological-Business	X	X	X	X	X		
Specific technologies, such as lightweight machinery, specialized storage, and satellite tools, can optimize straw collection and storage, especially in challenging terrains, though they still require improvements to be fully efficient in adverse conditions.	Technological-Engineering	X	X	X	X		X	X
Improving water pumping in flooded areas would facilitate straw collection, increasing its profitability.	Technological-Engineering				X			

Table 3. Key ideas on socio-technical alternatives

On the other hand, the perspectives of those with a more technical background (B, F, and G) focus on more specific solutions, such as light and efficient machinery or improved water pumping technologies, mainly on agricultural land. This group has an optimistic view regarding technology's capacity to solve current operational challenges, stressing that, with the right machinery, the physical and logistical barriers that currently hinder the adoption of greener practices could be significantly reduced.

Regarding the gender perspective, although only one woman is interviewed, her emphasis on the importance of cultural change reflects a more holistic and long-term vision that transcends immediate technical solutions. She highlights the importance of integrating sustainability into the collective consciousness and in the training of future generations.

In summary, the consensus indicates that, although there is divergence regarding the means–economic, technical, or cultural–to implement the alternatives, there is agreement that a multifaceted approach is essential to addressing the challenges associated with straw management.

The following figure (Figure 2) summarises the socio-technical alternatives identified by the interviewed experts. It highlights technological engineering solutions and the multiple potential uses of rice straw as the most supported alternatives. The graph shows the number of experts mentioning each alternative, providing insight into the most promising sustainable rice straw management solutions.

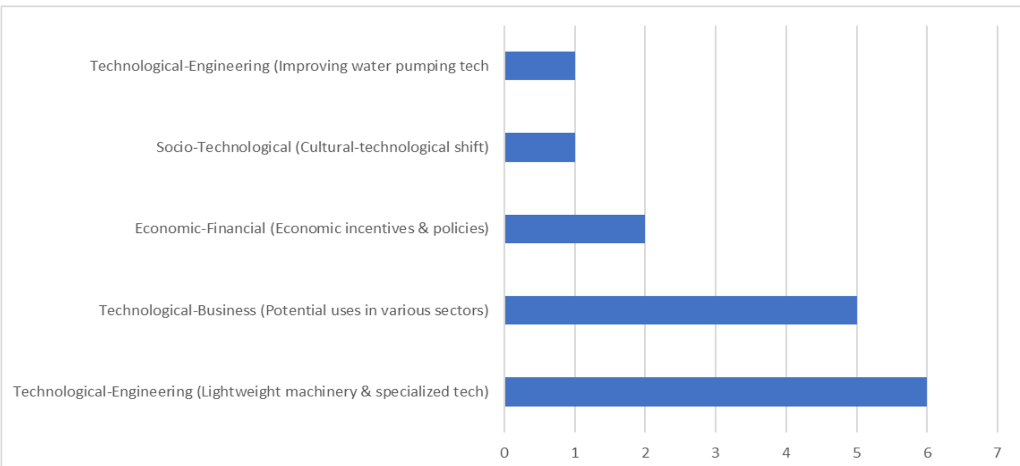

Figure 2. Socio-technical alternatives identified by experts for rice straw collection

4.3. Visible Consequences

In this section, Table 4 summarises the main visible consequences identified in the study on different rice straw management practices. The impacts and benefits of leaving straw in the field, removing or burning it are compared, and environmental, economic, agricultural, and public health aspects are addressed. This information provides a comprehensive view of the implications of each management method.

Summary Idea	Category	A	B	C	D	E	F	G
Burning straw produces emissions harmful to public health and the environment, affecting air quality with silica particles and CO_2 and damaging canal vegetation; wind is relied upon to minimise its impact on urban areas.	Burning		X	X	X		X	
Burning straw simplifies the process, eliminating weeks of additional work.	Burning	X					X	
Burning straw removes seeds, fungi, spores, and insects, improving soil health and reducing pesticide needs, although it releases CO_2.	Burning	X	X		X	X	X	X
Straw removal interrupts the nutrient cycle, like silica, but anaerobic digestion digestate returns these nutrients to the field, restoring the cycle.	Extraction		X					
Extracting straw provides an economic benefit to farmers by avoiding burning costs and allowing them to receive compensation for collection.	Extraction		X				X	
Extracted straw has multiple uses, such as in livestock, bioconstruction, soil erosion protection, and as a plastic substitute in eco-friendly packaging.	Extraction				X			
Straw extraction reduces CO_2 emissions by avoiding burning, converting it into biomethane, and preventing decomposition that pollutes water after rain.	Extraction	X	X					
Removing straw eliminates unwanted seeds, reduces the incorporation of spores and CO_2, and enhances soil health, decreasing pesticide needs.	Extraction	X	X		X	X		
Straw decomposition in water produces methane and anoxia, negatively impacting soil, water quality, crops, and aquatic life; therefore, it is crucial to remove or burn it in time to prevent these environmental issues.	Leaving	X		X		X	X	X

Table 4. Key ideas on visible consequences

The analysis of the visible consequences of straw management reveals a series of consensuses that can be read through the professional experiences, training and, in some cases, the cultural context of the informants. The main dimensions addressed include the burning, extraction and decomposition of straw, with different socio-environmental and economic implications.

From the point of view of those informants with a technical and environmentalist approach (B and D), an apparent concern is perceived about the negative consequences of straw burning, particularly regarding gas emissions and their impact on public health and the environment. This position suggests a deeper awareness of the long-term effects of this practice, consistent with their training in energy technology and ecosystem conservation fields. In this sense, the professionalisation and experience of these actors tend to focus on the need to reduce burning, favouring more sustainable practices.

On the other hand, informants involved in daily straw management, such as agricultural machinery operators (G) and farmers (E), offer a more pragmatic perspective. In their discourse, straw extraction is seen as a viable solution for its environmental benefits, such as avoiding the impact of straw decomposition in water and the economic opportunities it generates, such as its use in livestock farming. This more practical view reflects a consensus about balancing economic demands and environmental sustainability.

From a gender perspective, although there is only one woman in the interviews, her environmentalist approach highlights an inclination towards preventing long-term consequences, such as methane emissions or the interruption of the soil nutrient cycle, reflecting her technical training and role within an environmental organisation.

In summary, the consensus leans towards adopting mixed solutions, where burning is recognised as a problematic practice. Still, straw extraction and its alternative use emerge as a favourable solution from both an economic and environmental point of view.

The following figure (Figure 3) presents the visible consequences associated with different rice straw management practices, as reported by the experts. It illustrates both the environmental and operational impacts of burning and extraction. The graph shows how many experts referred to each consequence, offering a concise view of perceived benefits and drawbacks.

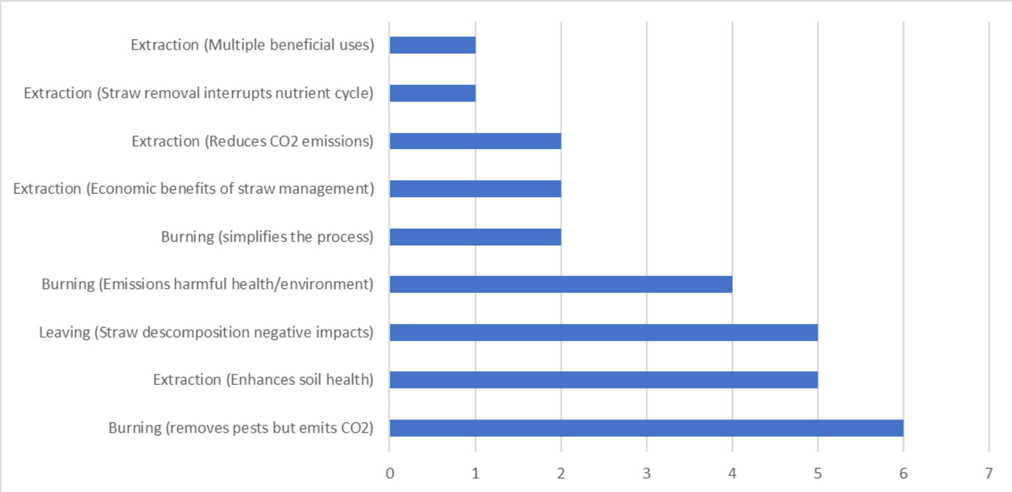

Figure 3. Visible consequences identified by experts for rice straw collection

4.4. Social Challenges

Table 5 summarises the main ideas and categories identified in the study on the social challenges of different rice straw management practices. The perspectives of farmers and society are addressed, highlighting the tensions, opportunities and challenges associated with traditional burning, straw extraction and its potential utilisation. This information provides a comprehensive view of the social and economic implications of the different management strategies.

Summary Idea	Category	A	B	C	D	E	F	G
It is challenging to convince farmers to abandon the traditional practice of burning straw.	Farmers	X						
Promoting straw collection encourages responsible waste use, enhancing rural sustainability.	Farmers				X		X	X
Burning rice straw creates social tensions due to its proximity to urban areas and sporting events, complicating public acceptance.	Society	X		X	X		X	
Burning straw negatively impacts public health in urban areas like Valencia, emitting particles equivalent to those from all vehicles in a year. In contrast, straw fermentation in fields releases methane and harms local fauna.	Society		X		X			
Establishing small local industries around straw management could generate rural employment, impacting sectors such as engineering, cosmetics, and sustainable construction.	Society		X		X		X	X
Extracting straw and subsequent uses could boost sustainable tourism in rural areas, promoting sustainability awareness and leveraging the rice cycle to create educational tourism experiences that benefit the local economy.	Society				X	X	X	X

Table 5. Key ideas on social challenges

As captured in the interviews, the social challenges surrounding rice straw management reveal several complex tensions that need to be resolved without addressing the economic and cultural perspectives of the actors involved. One of the key challenges lies in the difficulty in convincing farmers about the benefits of burning alternatives, which is mainly reflected in the voices of those with experience in direct agricultural management (A, G). This group tends to perceive traditional practices as more efficient and simpler in the short term, which generates resistance to changes that involve more excellent investment or operational complexity.

From the perspective of informants working in organisations or entities more connected to environmental impact and public health (B, D, F), the importance of creating a deeper awareness about the negative consequences of burning is underlined, not only at the environmental level but also in terms of the health of nearby communities. Here, a marked difference is seen in conceiving the problems, where the long-term impact is valued more by those with a technical or environmental background. Regarding gender, the only woman interviewed, with a strong background in environmental sciences, offers a more holistic view, promoting the idea of developing small local industries using straw, which would reduce emissions, create employment, and encourage local innovation. This resonates with informants who perceive economic and technological solutions as complementary to the agricultural sector's needs, especially among those with experience in broader and more strategic projects (B, F).

In summary, the consensus points to solutions that must be adapted to the agricultural environment's social and economic conditions. While resistance to change persists among more traditional actors, social challenges could be mitigated through financial incentives and awareness-raising programmes that highlight both economic benefits and long-term impacts.

The following figure (Figure 4) summarises the main social challenges identified by the interviewed experts. It emphasises the social tensions linked to traditional straw burning and highlights opportunities such as promoting rural employment and sustainable tourism. The graph indicates the number of experts mentioning each challenge, clearly illustrating key social issues influencing straw management practices.

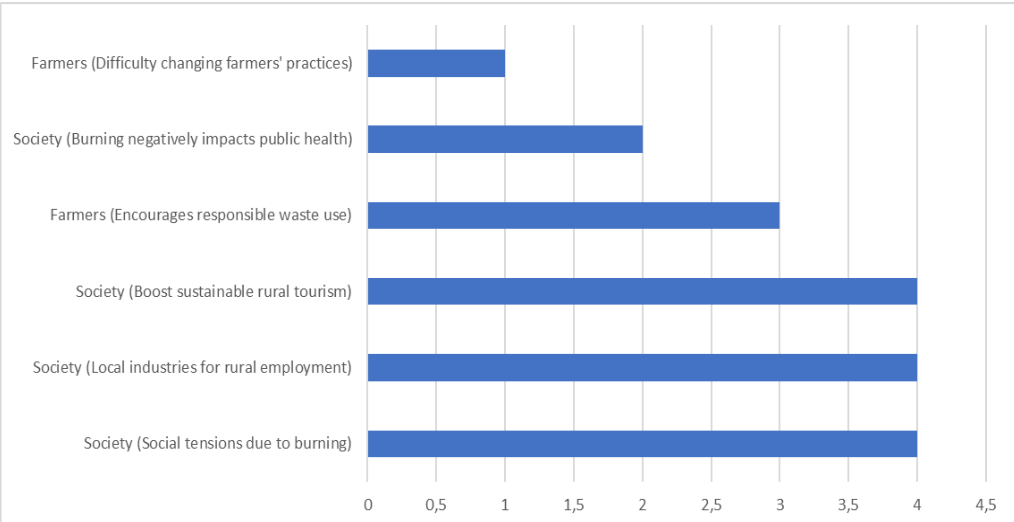

Figure 4. Social challenges identified by experts for rice straw collection

4.5. Long-Term Drivers

Table 6 summarises the long-term drivers related to sustainable rice straw management. The importance of economic incentives, social and regulatory considerations, and climatic and technological challenges are highlighted.

From the analysis of the long-term drivers collected in the interviews, several key consensuses emerge that reflect the interconnection between economic, regulatory and social factors. The primary trend observed is the centrality of financial incentives and aid as catalysts for change, a recurring theme among interviewees with experience in agricultural management (A, C, E). For this group, economic aid facilitates the adoption of new technologies and generates a more tangible path towards the transition to sustainable practices. The relationship between the agricultural sector and public policies is a determining factor, as informants underline the importance of European regulations and public tenders in promoting straw collection.

Summary Idea	Category	A	B	C	D	E	F	G
Straw collection is hindered by soil moisture in rainy years, as climatic factors complicate planning and machinery access after initial harvests. Improved climate forecasting could benefit the process and planning.	Climatic	X				X		X
Financial support and incentives are key to enhancing the profitability of straw extraction, facilitating sustainable management, reducing associated costs, and promoting a shift towards more efficient and sustainable practices.	Economic	X	X	X	X	X	X	X
Increasing and improving opportunities for rice straw utilisation.	Economic			X	X	X		
Public policies and European regulations, such as burning bans and straw collection tenders, help reduce CO_2 emissions and costs for farmers. In contrast, waste management consolidation and emissions certification are key tools for promoting sustainability.	Regulatory		X		X	X		
Straw collection requires the field owner's authorisation, and companies must have permission to operate on their land.	Social							X
Raising awareness of environmental improvement through straw collection would reduce CO_2 emissions, eliminate weeds and pests, and enhance the sustainability of rice cultivation.	Social	X					X	
Technical challenges with heavy machinery limit the straw collection; therefore, advancing agricultural technology is essential for operating on wet terrain and making straw removal more viable.	Technological	X		X		X	X	X

Table 6. Key ideas on long-term drivers

From a social perspective, informants such as G highlight the need to generate agreements with landowners to ensure effective straw management. This approach suggests that social dynamics and landowner permissions can be either a brake or a facilitator in implementing sustainable solutions, especially in contexts where community agreements highly regulate agricultural practices.

The normative approach is also a central aspect of the interviews. Informants linked to broader projects (B and D) advocate for strengthening public policies that promote straw collection, suggesting that European regulations play a crucial role in promoting good practices. However, climatic challenges persist, especially in rainy years, which affect the operational capacity to collect straw, as mentioned by those with practical experience in the field (A, E, G).

In summary, the consensus indicates that combining economic incentives, effective public regulations and robust social agreements is fundamental to promoting a sustainable transition in straw management. However, climatic and logistical factors continue to represent challenges that must be addressed to ensure long-term success.

The figure below (Figure 5) outlines the long-term drivers identified by the experts as key to enabling sustainable rice straw management. It highlights financial support, technological improvements, and favourable policies as the most frequently cited factors. The graph shows the number of experts who mentioned each driver, providing insight into future enablers of change.

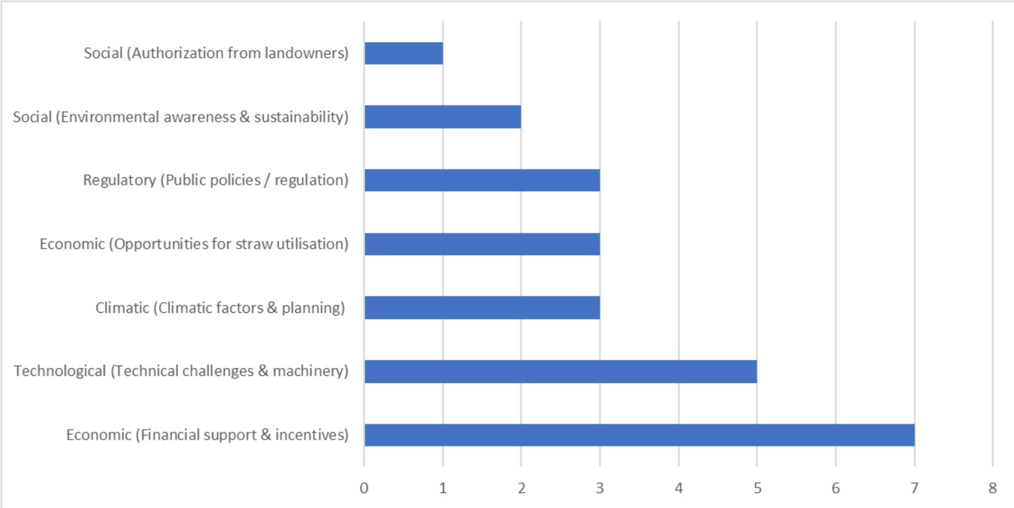

Figure 5. Long-term drivers identified by experts for rice straw collection

5. Implications

Several key implications regarding rice straw management can be identified based on the results obtained from the analysis of the qualitative interviews. These implications cover technological-operational, business and governance dimensions, which must be considered to develop viable and sustainable solutions in this context. This section analyses the most notable repercussions in these dimensions, allowing for a more complete view of the challenges and opportunities facing the transition towards more efficient and environmentally friendly management. This study systematically applies the CIMO logical framework to identify and understand practical mechanisms for overcoming operational, economic, and regulatory barriers. By clearly delineating short-, medium--, and long-term implications for diverse stakeholders, including policymakers, farmers, and agri-food industries, the study effectively provides a structured pathway to foster sustainable rice straw management practices. In this sense, one implication of this study is to establish a preliminary knowledge base that aids public policy analysis, leading to the establishment of mechanisms that contribute to promoting sustainable practices with a positive social impact. A good recommendation for future lines of research derived from the findings of this research is that authorities establish regulatory frameworks conducive to the creation of a sandbox in which the different components of the rice straw value chain can test new business models for the agri-food industries, preserving the experimental conditions that allow understanding the necessary implications for the business and social success of these new circular economy business models based on the utilisation of agricultural waste.

5.1. Technological, Operational and Engineering Implications

Rice straw management requires significant advances in agricultural technology to overcome the challenges inherent to the terrain and climatic conditions. The current machinery is limited in operating efficiently in wet or muddy terrain, favouring burning as a quicker solution. However, adopting lighter machinery and specific storage technologies could optimise straw collection, storage and transport, minimising damage to fields and improving operational efficiency. Implementing satellite technologies for weather planning and prediction could also increase the viability of harvesting in adverse conditions. This study recommends specific investment in innovative lightweight machinery prototypes enhanced with geospatial and remote sensing technologies to address the technical limitations identified, including heavy machinery used on wet terrains. These solutions could significantly improve operational efficiency, minimise field damage, and facilitate straw collection even in challenging climatic conditions. It is recommended to introduce integrated logistic systems that combine real-time meteorological data and machine learning algorithms. Such systems can optimise straw harvesting schedules, thus reducing uncertainties linked to weather variations and enhancing overall straw management feasibility.

5.2. Business Implications

Economic barriers remain a critical obstacle to implementing business models based on sustainable straw management. Straw collection and treatment will only be viable if business models are developed that incorporate economic incentives, such as subsidies or public aid, and promote new commercial uses for straw, such as its application in green construction, fertilisers or biofuels. Technology and agricultural companies could benefit from developing new markets for straw-derived products, encouraging investment in innovation and optimising collection and processing processes. The findings support the design of new business models emphasising circular economy principles. Specifically, establishing value chains linking rice producers directly to bioenergy, construction, and biodegradable packaging industries should be encouraged. These linkages could incentivise sustainable straw extraction economically and environmentally. We propose targeted financial mechanisms to overcome current economic barriers, including tax incentives, public subsidies, and performance-based grants. Such measures can lower initial investment risks, foster industry collaboration, and enhance the market competitiveness of sustainable straw-derived products.

5.3. Administrative, Regulatory and Governmental Implications

The role of public administrations is key to catalysing the shift towards more sustainable straw management. European regulations, such as the ban on burning and public tenders for waste collection, have proven effective in reducing emissions. However, a more consolidated regulatory framework is needed to encourage investment in technology and offer support to farmers. Governments must work on creating integrated policies that promote sustainability and can balance economic, social and environmental aspects. The study suggests reinforcing existing regulations with clear, enforceable guidelines for straw management. Policymakers should consider introducing mandatory certification processes for sustainable practices, complemented by transparent monitoring systems that enhance compliance and accountability among farmers and businesses. Another approach to future development involves reviewing investment and tax incentives that can bring about behavioural changes among the ecosystem's economic agents. The introduction of specific governmental pilot projects is recommended to demonstrate the viability and benefits of sustainable straw management practices. Successful pilots could inform wider policy implementation, encourage stakeholder engagement, and facilitate a cultural shift among producers toward sustainability.

6. Conclusions

Rice straw management presents a critical issue highlighting the urgent need to develop innovative approaches to address this agricultural waste's logistical, economic and environmental challenges. Traditional practices, such as open burning, generate significant greenhouse gas emissions and represent a loss of valuable resources that could be reused in bioenergy production or as feedstock in various industries.

The implementation of sustainable technologies, such as anaerobic digestion for biogas production and the conversion of straw into bioethanol, together with the promotion of practices such as composting or the use of straw as a feedstock to make new products, could significantly contribute to a more efficient and sustainable model for rice straw management. However, for these solutions to be viable on a large scale, it is essential to overcome structural barriers such as the lack of adequate infrastructure and economic constraints that currently hinder their adoption in many rice-producing regions.

It is essential to simultaneously promote the creation of industries that develop alternative and economically attractive uses for straw, which would make it possible to offset the costs of collection and storage. Straw reuse must be driven by an integrated approach that considers both economic and logistical aspects as well as social and environmental ones, thus promoting sustainability in the agricultural sector.

Future research should focus on developing more efficient and economically viable technologies for using rice straws and implementing policies that incentivise sustainable practices and discourage traditional practices. It is essential to foster collaboration between farmers, industries, and governments to create sustainable value chains and investigate the long-term impacts of various straw management strategies on different ecosystems.

The transformation towards more sustainable management of rice straw not only addresses current environmental challenges but also opens up new economic opportunities and contributes to sustainable development goals at a global level. A collaborative and multidimensional approach is key to ensuring that the proposed solutions are practical and widely adopted in rice-producing communities.

In doing so, the study addresses an urgent local environmental challenge and contributes to the broader academic debate on sustainable agricultural waste management. Integrating the CIMO-logic with contemporary systems thinking opens new avenues for research into complex socio-technical transitions in agriculture, particularly in environmentally sensitive and heavily regulated contexts like Albufera.

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