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Smart Cooperatives: Adapting Smart Grid Concepts to Agricultural Cooperatives

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Abstract - This paper introduces a novel approach to creating cooperation-optimized farming groups called *Smart Cooperatives.* These groups leverage advancements in smart agricultural technologies to address critical challenges in the agricultural sector, including water scarcity, market access limitations, and the adverse impacts of climate change and geopolitical tensions. Through a detailed analysis of current farming practices and organizational methods, Smart Cooperatives are proposed as a transformative model that combines the principles of smart grids from the electrical sector with the unique needs of agriculture. This model aims to foster enhanced collaboration among farmers, equitable resource distribution, and stronger market presence by utilizing data-driven methodologies for grouping farmers based on both intrinsic and extrinsic characteristics. By examining potential counterarguments and challenges, the paper highlights the importance of accessibility, adaptability, and scalability in implementing Smart Cooperatives. Concluding with a call for further research and a pilot questionnaire aimed at refining the model and understanding farmer needs, this study presents Smart Cooperatives as a promising avenue towards sustainable, resilient, and cooperative farming futures, potentially reshaping the agricultural landscape in the face of global uncertainties.

***Keywords*:** smart agriculture, cooperatives, farming, smart cooperatives, farmer collaboration

1. Introduction

The agricultural sector faces severe hurdles: escalating water scarcity [1], inadequate market access [2], and insufficient governmental support. Droughts, intensified by climate change, threaten global crop yields [3], while fragmented market access limits farmers' profitability, especially smallholders. Coupled with these is the often lacking government support, which fails to provide necessary infrastructure, policies, and technological access.

Due to the war in Ukraine, the price of agricultural inputs has skyrocketed. Russia, the largest fertiliser producer, was hit with sanctions, which drove a further 50% increase in fertiliser prices from the increase felt during the COVID-19 crisis [4]. This showed a vulnerability in the global fertiliser market, which, while the prices have since dropped [5], and several countries have announced increases in production to fulfil demand [6], [7] farmers are still worried about potential decreases in production [8].

In recent years, worsening climate conditions have compounded these challenges [9]. Droughts have intensified globally, particularly affecting regions like Southern Europe, Northern Africa, and beyond. The adoption of Smart Agricultural technologies emerges as a beacon of hope, offering tools to mitigate the impacts of climate change. These innovations enable precise forecasting of field conditions and provide real-time insights into the needs of crops and soil [10]. By empowering farmers with the ability to make informed decisions swiftly, such technologies hold the potential to reduce the adverse effects of climate on agricultural productivity significantly.

A fragmented approach to farming exacerbates the challenges in agriculture. The landscape is divided among those who join cooperatives, those who enter into contractual agreements with farming organisations, or those who navigate the industry independently. This division often results in an uneven allocation of resources, leaving smallholder farmers particularly disadvantaged.

Our study proposes a transformative model, "Smart Cooperatives," a framework inspired by the "Smart Grids" concept from the electrical sector. These cooperatives aim to foster enhanced farmer collaboration, promoting equitable resource distribution, knowledge exchange, and a stronger market presence. By organising farmers into interconnected networks that consider their unique and shared characteristics and equipping them, these cooperatives aspire to revolutionise how farmers work together.

The paper unfolds systematically, beginning with a review of existing literature. It then delves into the Smart Cooperatives framework, outlining the methodology for grouping farmers, criteria for group stability, and strategies to boost cooperation. Following this, we outline an approach for implementation, proceed to analyse a case study involving a prototype of the model and explore both the advantages and hurdles of applying this innovative system. Our discussion extends to the influence of policy on the model's success and offers suggestions to increase farmer participation. The paper concludes with a summary of our findings and reflections on the potential of Smart Cooperatives to reshape the future of farming.

2. Related Work

Several studies have shown that when farmers collaborate, agricultural productivity increases, improving the local economy, communities, and the surrounding environment [8], [9]. However, due to differences in ideology and vision, farmers tend to disagree on their collaboration trajectory. When some farmers try to expand, others try to maintain. This disagreement leads to a natural breakdown in collaboration.

Generally, farmers organise themselves using one of three methods. First, they can be self-reliant. Farmers who choose this route operate independently, making all their own decisions about crop selection, cultivation practices, and sales strategies. This approach allows for maximum autonomy, enabling farmers to reap the benefits of their labor and market savvy directly. However, it also means they shoulder all the risk, from fluctuating market prices to unpredictable weather conditions. Independent farmers must be adept at business management, market analysis, and often rely on their own resources for investment in technology, seeds, and equipment.

Secondly, farmers can be signed to contract farming agreements with agribusiness companies, processors, or retailers. In contract farming, the terms of production and sale are predefined, specifying the produce's quantity, quality, and sometimes price. This arrangement offers farmers a more predictable income by mitigating some market risks and securing a guaranteed buyer for their crops or livestock [11]. However, it can also limit their operational flexibility and decision-making autonomy, as they must adhere to the contract specifications. Additionally, while contract farming can provide access to better technology, inputs, and farming practices through the contracting company, farmers may find their profit margins constrained by the terms of the agreement.

Finally, farmers can join an agricultural cooperative. Joining an agricultural cooperative requires buying a stake and making farmers co-owners. This democratic structure means profits are equitably distributed, and decisions are made collectively, often requiring a majority vote. This fosters a community of mutual support, where resources and knowledge are shared, benefiting especially small-scale farmers [12]. However, adherence to cooperative rules on production and quality standards can limit individual operational flexibility. The initial financial contribution can also be a barrier for those with limited capital. Despite these benefits, a significant drawback is that cooperatives can suffer from inefficient management due to their democratic nature, potentially leading to slower decision-making processes and conflicts among members with differing opinions.

Many of the world’s farmers currently belong to a farming cooperative. It has been shown that while cooperatives are effective [13], especially in the developing world, a large number of farmers fall out of favor with the cooperative, discouraged by unfavorable decisions agreed upon by the cooperative members [14]. In modern cooperative movements, particularly those involving larger, more commercially oriented operations, there might be provisions for different classes of membership or investment that can impact the control dynamics [12]. In these cases, some members yield more power and can therefore make decisions in their favor.

Despite significant advancements in technologies enhancing individual farming practices, such as smart agriculture and decision support systems, technological progress for collective farming endeavors, like cooperatives and other agricultural collectives, remains limited [15], [16]. To date, there have been no breakthrough developments in this area, largely due to a lack of research into technologies akin to *Smart Cooperatives* or any supportive technologies tailored for such collaborative agricultural models.

3. Conceptual Framework for Smart Cooperatives

Several parallels can be drawn between electrical production and agriculture. Like the electrical market, agriculture is composed of producers and consumers, with the goal of delivering a product to the end consumer - the citizen. To improve efficiency, *Smart Grids* were developed to dynamically match supply with fluctuating demand, enhancing responsiveness and reducing waste [17]. Similarly, in agriculture, inefficiencies in the supply chain, from farm to table, mirror the pre-Smart Grid electrical challenges, with produce often wasted before reaching consumers [18]. Moreover, agriculture has its own logistical chain analogous to the electrical grid, encompassing all the steps involved in getting food from farms to consumers. This chain's complexity and inefficiency can lead to shortages and surpluses, harming producers and consumers. This realization—the need to better match agricultural supply with demand and streamline the logistical chain—has led to the creation of *Smart Cooperatives*.

Smart Agriculture aims to enhance sustainability through two primary mechanisms. Firstly, it leverages advanced technologies to improve farmers' ability to react quickly to changing conditions on their farms. This rapid responsiveness is achieved through the use of IoT (Internet of Things) sensors, AI-based predictive analytics, and other real-time data-gathering tools. Secondly, Smart Agriculture increases the accuracy of applying water, fertilizer, and pesticides. By utilizing precision agriculture techniques, such as drone and satellite imagery, it ensures that these vital resources are applied in the right amounts and locations, minimizing waste and environmental impact [19].

Consider each farm as a node within a broader system similar to a micro-grid. In the context of a micro-grid, nodes typically encompass a mix of energy producers and consumers interconnected to optimize resource distribution and consumption. In agriculture, farms operate as nodes within a network, each functioning as a producer of agricultural products. Additionally, these nodes act as consumers of essential resources, such as water, fertilizers, and energy. They connect through a sophisticated network that facilitates data exchange and resource management.

This network, akin to a micro-grid, simplifies the efficient flow and use of resources among the interconnected farms. By linking together in this manner, they form what could be likened to an agricultural *'Smart Grid*.' From this advanced network of collaborative and technologically empowered farms, the concept of *Smart Cooperatives* is born. These cooperatives aim to leverage the synergy of the network to enhance sustainability, improve efficiency, and boost productivity across the agricultural sector, mirroring the benefits seen in electrical micro-grids.

To achieve *Smart Cooperatives'* goal of sustainable farming groups, farmers are joined together into network of farmers, a micro-grid equivalent called Micro-Collectives. Each Micro-Collective can be composed of as many farms as needed to achieve stability - a point where collaboration in the group is sustained over a significant period of time. Collaboration is the cornerstone of Micro-Collectives. Farmers need to collaborate and share resources to reduce inequalities in resource-restricted environments. The core idea of a Micro-Collective is mutual growth. Farmers can share resources and knowledge, make collective purchases of farm inputs, and sell their products to the market together. This collective action aims to enhance their negotiating power.

Traditional cooperatives often face challenges in fostering collaboration among farmers, primarily due to cultural differences, perception of risk, future plans, and willingness to expand. These barriers are largely rooted in intrinsic characteristics—personal attributes and preferences that are not readily observable from the outside. Smart Cooperatives depart from traditional models by adopting an innovative approach. They emphasize the importance of both intrinsic and extrinsic characteristics of each farmer and farm. This focus is key to forming effective collaborative groups.

Smart Cooperatives leverage automated methods to analyze the mentioned characteristics, recognizing that intrinsic factors such as values, beliefs, and personal goals, and extrinsic factors such as geographical location, farm size and crop type play a crucial role in the potential for successful cooperation. This comprehensive analysis aims to identify farmers with compatible characteristics, thus increasing the likelihood of forming cohesive and synergistic groups.

After conducting a detailed assessment of intrinsic and extrinsic characteristics, Smart Cooperatives employ advanced grouping methods. These methods are used to assemble farmers into cooperatives. Currently, the methodology for grouping is envisioned to fall into one of two categories: Clustering, with algorithms such as k-means, DBSCAN, or Density-based clustering, and Matchmaking, which draws inspiration from systems used in gaming or dating apps, focusing on pairing or grouping individuals based on complementary characteristics.

The success of Smart Cooperatives hinges on the development of a comprehensive metric designed to quantify the level of collaboration within a group. This metric is predicated on the assumption that a group with a higher degree of collaboration correlates with greater success and sustainability of its members, while a lower degree of collaboration indicates the need for adjustments to the group. The metric can be constructed using several dimensions, such as communication frequency and quality, resource sharing, economic performance, and others.

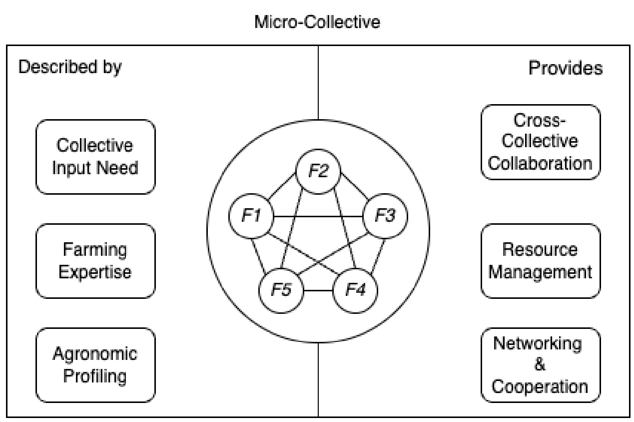

Fig 1: Diagram of Single Micro-Collective

As Figure 1 shows, each Micro-Collective can be described by their overall input needs (current and future), the overall expertise of the farmers (crop expertise, machinery and technology expertise; pest and disease management; etc) and an agronomic profile of the farms and farmers within the group. This profile could include the geographical centre of the group of farms, the average size of the farms, and, for example, the type of terrain, as well as other characteristics, both extrinsic and intrinsic. The use of these descriptions can be useful for interaction with the wider agricultural value chain, other Micro-Collectives, and other possible stakeholders, from the final customer to credit unions and more.

Predicting the input needs of each Micro-Collective is essential for optimizing resource use, enhancing environmental sustainability by reducing waste, and improving economic efficiency through precise resource allocation. Accurate forecasting enables farmers to adapt swiftly to environmental changes and market demands, ensuring crop health and maximizing yields. This approach also facilitates better planning and resource sharing within *Micro-Collectives*, embodying Smart Agriculture's goal of leveraging technology for more sustainable and efficient farming practices.

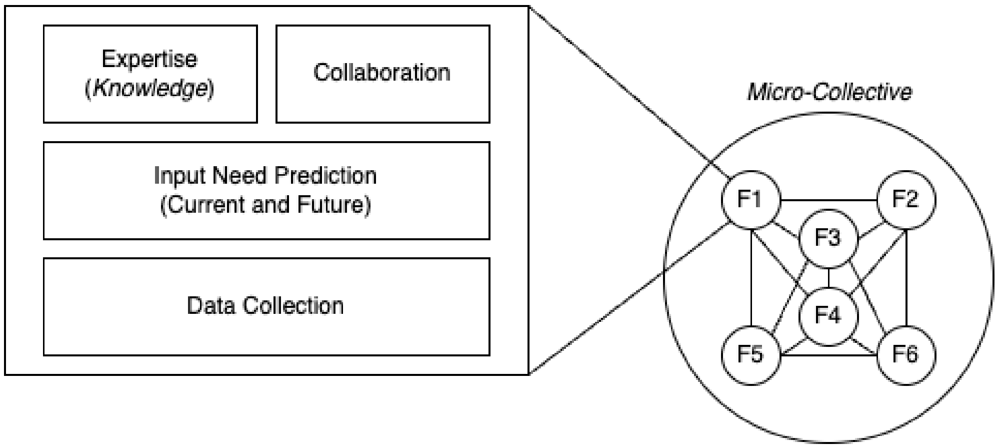

Fig 2: Farmer's Software Stack

In a Micro-Collective, the collaboration among farmers is orchestrated through a suite of networking tools that lay the groundwork for effective communication, collaborative decision-making, and knowledge sharing. Central to this cooperative engagement is the management and sharing of resources—farm inputs, machinery, and services are collectively managed, promoting efficient use and reducing waste. This collaboration is underpinned by a software stack designed to secure and streamline these interactions, ensuring data governance and safeguarding information privacy.

Figure 2 illustrates the software architecture facilitating this cooperation. At its base, *Data Collection* feeds into an *Input Need Prediction* agent, which analyzes and predicts resource requirements, essential for planning and managing the collective's assets. Tied into this is the *Collaboration* agent, which utilizes these predictions to enhance joint operations among farmers. Additionally, an *Expertise* agent integrates specialized knowledge into the system, enabling a responsive and informed collaborative network that adapts to both current and future agricultural demands.

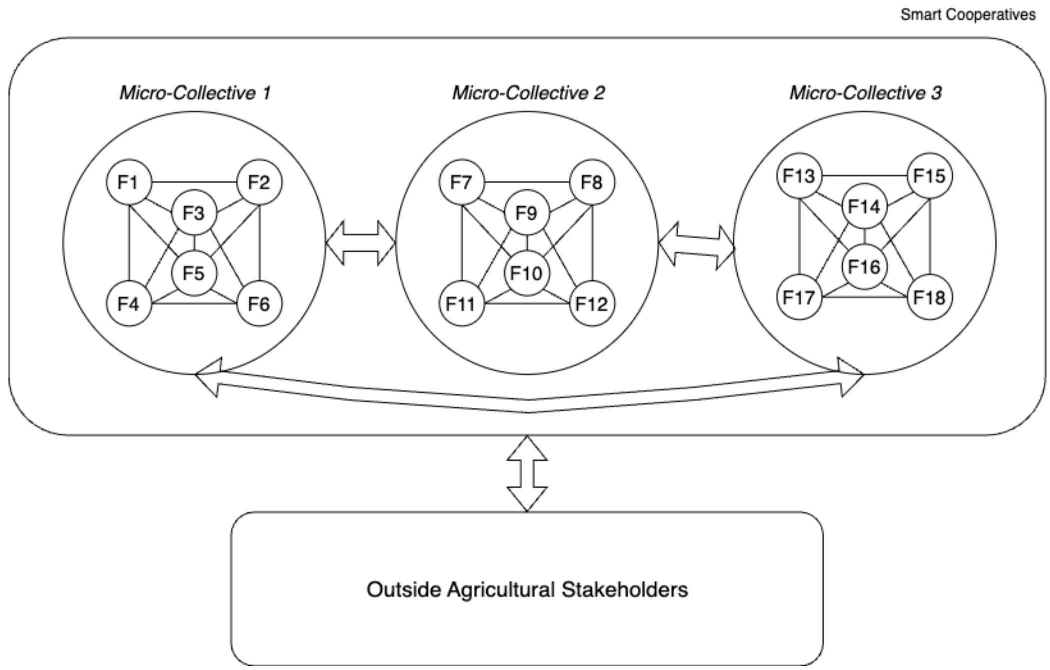

Fig 3: Smart Cooperatives - Collaboration between several Micro-Collectives

Micro-Collectives should be able to cooperate with one another, allowing for higher levels of cooperation. Cross-collective collaboration can be leveraged to increase cooperative independence by enabling the exchange of the same products and services within the cooperative. This can be used to foster a circular economy between farmers. To permit this, as seen in Figure 1, each Micro-Collective will have an interface that can be used to interact with other Micro-Collectives. As an equative mechanism, group decisions should be taken by leveraging consensus-building tools and democratic voting systems embedded within the Micro-Collective. This creates a wider network of collectives, known as a Smart Cooperative.

These systems will ensure that each farmer in the Micro-Collective has a voice in the decision-making processes, promoting transparency and equality. The same system can be used for larger decisions affecting the wider collective network. This approach not only strengthens the bonds between the farmers within one collective and between different collectives but also ensures that the strategies and policies adopted reflect the collective will and best interests of the community as a whole. By facilitating this level of collaborative governance, *Smart Cooperatives* can achieve a sustainable and inclusive model that empowers farmers and enhances the resilience and productivity of the agricultural sector.

Each *Micro-Collective* will interact with a backend *Infrastructure,* which will provide data governance, data storage, and the possibility to interact with the rest of the agricultural stakeholders. This interaction can be facilitated using an API. The backend infrastructure can also be used to offer extra services to the farmers, such as data analytics, which can be enriched with remote sensing data to provide a larger spatial resolution to the data they are currently collecting. Figure 4 provides a macro overview of the full architecture of the platform.

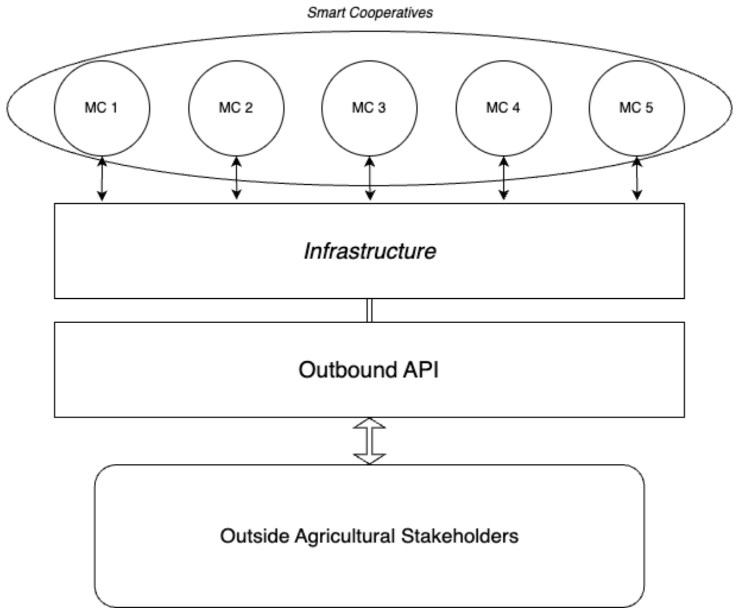

Fig 4: Example of the Full Architecture

Moving forward, implementing the *Smart Cooperatives* concept requires a strategic approach that encompasses several key areas. First, the economic viability of these cooperatives must be thoroughly assessed, ensuring they offer a sustainable and profitable model for the farmers involved. This process involves several steps. First, analyze cost structures. Next, assess potential revenue streams. Finally, evaluate the impact of shared resources on both individual and collective profitability. Integration with existing agricultural systems and practices is crucial, allowing Smart Cooperatives to seamlessly enhance current operations without requiring extensive overhauls. The technology and frameworks used must be compatible with existing agricultural infrastructures to encourage adoption and minimize disruption.

Scalability and adaptability are also vital components of the implementation strategy. The model should be designed to scale easily, accommodate varying sizes and types of farming operations, and be adaptable to different agricultural contexts and climates. This flexibility ensures that Smart Cooperatives can be applied globally, addressing the unique challenges and leveraging the specific opportunities present in diverse farming communities.

Finally, the development of robust, user-friendly platforms and tools that facilitate communication, knowledge exchange, and efficient data management is essential. These tools must prioritize data governance and security, ensuring farmers' information is protected and used ethically. By addressing these aspects—economic viability, integration, scalability, adaptability, and technology development—Smart Cooperatives can move from concept to reality, offering a promising path toward sustainable and collaborative farming futures.

4. Discussion

While *Smart Cooperatives* presents a novel approach to enhancing agricultural practices through collaboration and the integration of technology to improve collaboration, several challenges need close examination to ensure the model's effectiveness and reach. Addressing these challenges head-on not only strengthens the case for *Smart Cooperatives* but also paves the way for more inclusive and adaptable solutions.

A foundational aspect of Smart Cooperatives is data collection at the farm level, utilizing sensors and edge devices. However, this requirement potentially limits the model's applicability, particularly in regions where farmers may lack the necessary infrastructure for such technology deployment. To overcome this obstacle, the development and integration of mobile applications, already prevalent in agricultural contexts in developing countries, alongside remote sensing technologies, offer a viable solution. While acknowledging that this adaptation may affect the temporal resolution and precision of data for individual farms, it represents a crucial step towards inclusivity, ensuring that the benefits of Smart Cooperatives can reach a broader range of farmers worldwide.

The success of Smart Cooperatives hinges on the accurate prediction of current and future input needs and the effective formation of cooperatives based on comprehensive data. This poses a significant challenge, as acquiring, installing, and managing new sensors may financially burden some farmers. Moreover, the reliance on direct data collection from farmers, either through written submissions or structured questionnaires to extract intrinsic characteristics, introduces complexities related to the formulation of questions and the interpretation of responses, particularly in detailing farmers' expertise. Encouraging openness among farmers to share their expertise is vital, yet it requires careful consideration of privacy concerns and the value proposition offered to participants.

Furthermore, the methodology for defining stability within Smart Cooperatives is critical. An inaccurate definition could lead to the formation of unstable groups, undermining collaboration and diminishing trust in the technology. Furthermore, the design of collaboration tools must account for the diverse backgrounds of farmers, ensuring ease of use and accessibility to facilitate seamless cooperation. This necessitates a user-centric approach in tool development, emphasizing intuitive design and language inclusivity.

Additionally, for Smart Cooperatives to thrive, adherence to country-specific regulations, particularly concerning data privacy and agricultural standards, is essential. The European context, with its unique regulatory landscape, serves as an initial framework for this project. However, expanding beyond Europe introduces complexities related to varying legal and cultural environments. The platform must be inherently adaptable and capable of accommodating diverse agricultural practices, languages, and cultural nuances. This includes recognizing the subtle yet significant differences within and between European countries, as well as preparing for the broader challenges of international expansion.

Finally, the metric used to calculate the stability or success of a Smart Cooperative needs to be able to distinguish between lack of collaboration due to bad grouping and lack of collaboration due to bad tooling. This point is extremely important, as farmers will interact with each other using the tools provided. There needs to be a method to analyse the efficiency of the tools created to motivate cooperation.

5. Conclusion

With this position paper, we introduce a transformative approach to agriculture aimed at bolstering cooperation among farmers through advanced, cooperative tools, ultimately enhancing both environmental and financial sustainability. This approach recognizes agriculture as the backbone of rural communities, where a decline in sustainable practices risks the vitality and productivity of these regions. The emergence of desertification, reduced food production, and growing dependence underscores the urgency for resilient agricultural models.

*Smart C*ooperatives not only attempt to improve collaboration between farmers but could also be used by farmers to improve their negotiating stand regarding buying and selling. As a discovery tool, input sellers, buyers, processing entities, and other stakeholders could also use its outbound API. This can be leveraged to find the most sustainable matches between farmers and stakeholders.

The initiative commences with a comprehensive questionnaire distributed to farmers across Europe and the Mediterranean, the results of which will refine our understanding of farmer needs and the dynamics of cooperative interactions within Smart Cooperatives. The insights gathered will not only inform the development of groupings and collaborative strategies but will also shape the metrics used to gauge the stability and impact of these cooperatives.

This paper ultimately lays the groundwork for a future where Smart Cooperatives can significantly impact the agricultural sector, marking a shift towards more connected, efficient, and sustainable farming practices. The anticipated impact spans economic improvement, environmental protection, and strengthened rural communities, aligning with broader goals for sustainable development and food security.

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