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ANALYSIS OF THE ROLE OF SIMULTANEOUS SOCIAL ENTREPRENEURSHIP (SE) AND PENTA-HELIX COLLABORATION (PH) ON SUSTAINABLE FOOD CROP AGRICULTURE: CASE STUDY FROM WEST SUMATRA, INDONESIA

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Abstract
Multi-actor-based agricultural empowerment is one of the strategies to realize sustainable food crop agriculture. Social entrepreneurship (SE) and pentahelix collaboration (PH) are two parameters recognized for strengthening the connection between stakeholders, enhancing the people's economy, and contributing to agricultural empowerment. However, the role of SE and PH collaboration can differ between regions depending on various complex factors. The SE is represented by a combination of the Farmer's exchange rate (EFV), income, and the human development index (HDI). PH is represented by the regional agricultural gross domestic product (RGDPA). This study aims to analyze the relationship between SE and PH collaboration on sustainable food crop agriculture, using panel data from 11 districts in West Sumatra Province between 2013 and 2023. The results showed that the simultaneous implementation of SE and PH in food crop agriculture had a positive impact on sustainability. However, some of the variables used to define SE and PH still had a relatively weak correlation. The implementation of SE and PH in the research area still requires additional interventions. These findings can be used as a reference for policymakers to optimally promote sustainable food crop agriculture through a combination of SE and PH collaboration.
Keywords: Sustainable, agriculture, food crop, development area, social, economic, environment, technology, policy.

1. INTRODUCTION

A combination of social entrepreneurship (SE) and penta-helix collaboration (PH) is a promising approach, particularly in sustainable food crop agriculture. SE aims to create businesses that emphasize socio-economic impacts, while PH serves as a conceptual framework for innovation management. The synergy of both could potentially result in significant impacts. Before entering to the role of SE and PH in the agriculture context, let consider some of fundamental challenges; our literature study reveal that almost 70% of global water have been consumed for agricultural irrigation (Li et al., 2022), only 8–10 % of farmers worldwide have adopted conservation agriculture system to drive transformation in agricultural society (Valizadeh et al., 2024; Valizadeh & Hayati, 2021). Moreover, cultivated areas in developed countries grew by 8–140 %, while irrigated land expanded by approximately 112 % (Hashemi et al., 2024). The multi-objective cropping pattern led to 1% decrease in water consumption, a 14% reduction in global warming potential, and a 14% decrease in non-renewable energy usage (Karimi et al., 2024). These components can drive transformative changes in agricultural practices, making their integration a potent strategy for promoting sustainability in food crop systems.
Note that sustainability can be realized if and only if all actors play an effective role in their respective positions. Actors in the agricultural industry are key to realizing sustainable agriculture, which also encompasses local socio-economic welfare (Ferrari et al., 2023; Tiwari et al., 2023). They are required to understand effective strategies in running their farming industry. In addition, realizing sustainable food crop agriculture requires the implementation of strategies that address sustainability aspects (Zhu et al., 2024). Sustainability aspects include practices such as precision irrigation technology to minimize wastage (Auci & Pronti, 2023). These practices help reduce pest and disease risks and improve biodiversity, which contributes to long-term agricultural sustainability. Equally important is the proper allocation of resources, which involves optimizing the use of inputs to ensure cost-effectiveness. These strategies collectively support a more resilient and sustainable agricultural system capable of meeting growing food demands while preserving environmental integrity.
There are some challenges in actualizing sustainable food crop agriculture that are usually found in agricultural countries. In Indonesia, sustainable agriculture faces several key challenges, which vary by region or province and context. Among them are land resource allocation, supply chain resilience, and social welfare (Isnan et al., 2023;

Keefe et al., 2024; Moeis et al., 2020; Mulya & Hudalah, 2024; Nasikh et al., 2021; Sahara et al., 2024; Salam et al., 2024). Additionally, it is still possible to discover various other problems that do not yet have a definite solution. In general, these problems exhibit similar patterns because the climate is similar across territories, although certain areas have unique characteristics. Our literature study has more clearly identified the problems and scope in several agriculture-based areas in Indonesia. After a rigorous collection and selection process, we classified several problems that are currently of high priority. However, it is understandable that addressing these challenges requires a holistic approach that integrates community-based practices with supportive policies to ensure food security and environmental sustainability. This integrated approach not only addresses environmental challenges but also strengthens social cohesion and economic stability, forming a resilient foundation for sustainable agriculture.

In this study, we focus on agricultural problems related to the collaboration of socio-economic, environmental, and multi-element factors. The research areas are in 11 districts in West Sumatra, Indonesia. Using standard agricultural assessment theories, we identified various parameters and variables to investigate existing agricultural conditions. In addition, using official data from the Central Statistics Agency of the Republic of Indonesia, we analyzed the linear relationship between SE, PH, and sustainable agriculture. However, research related to SE in sustainable agriculture and the PH framework has been widely reported, but studies that simultaneously address SE and PH in agriculture remain rare. Based on this condition, we developed a conceptual model to investigate how SE and PH work in agriculture-based regions in Indonesia. Indeed, the index of SE and PH implementation might vary and depend on other variables. However, this concept can be beneficial for investigating agricultural conditions in other agriculture-focused countries.

2. THEORETICAL BACKGROUND

2.1 Social Entrepreneurship (SE) in crop agriculture

First, let us briefly explore the fundamental theory of entrepreneurship and social entrepreneurship. There are several definitions of entrepreneurship, one of which defines it as an attempt to create business profits through innovation. Ratten et al. collected at least 34 definitions of entrepreneurship based on the types and dimensions (Ratten, 2023). The literature exploration found that entrepreneurship can be interpreted as an effort to combine resources to explore existing opportunities, aiming to catalyze social change by sustainably addressing basic human needs (Mair & Marti, 2009). Entrepreneurship can also be interpreted as a field of study that consists of various dimensions, with a more important aspect being its positive impact on society (Jones et al., 2020). Social entrepreneurship is defined as an effort to create financial and social benefits to overcome poverty, create jobs, gender equality, and conserve natural resources(Diaz-Sarachaga & Ariza-Montes, 2022). Furthermore, 567 scientific articles concerning social entrepreneurship highlight overlaps across different levels of analysis, including micro-to-macro levels (Canestrino et al., 2020). At least 37 definitions of SE and Social Entrepreneur exist, none of which show apparent conceptual convergence in terms of meaning (Torres & Augusto, 2020). Due to the lack of uniformity in existing definitions and the varying perspectives on this issue, defining SE is complex enough. Regardless of these controversies, in simple terms, SE relates to individuals or organizations that engage in entrepreneurial activities with social goals. Actors in the non-profit business sector apply their expertise to become independent of grants and subsidies.

Meanwhile, for-profit businesses usually offer solutions for social and economic problems using market-based models. The combination of both emphasizes achieving social impact while maintaining a sustainable business model. Finally, our understanding of SE in crop agriculture involves building entrepreneurship by utilizing various local resources to create broader and more comprehensive societal impacts.

To simplify these many definitions, we are going to focus on the concept that is related to socio-economic issues. There are key aspects related to socio-economic issues in sustainable agriculture, such as profit, social impacts, and barriers. In order to realize social impacts, social entrepreneurs need to identify and optimize profit resources (Kremsa, 2021; Neumeyer et al., 2020). Several resources can be developed, but of course, the development will depend on local conditions and whether they can facilitate it or not. Several socio-economic problems that are most likely to be resolved should be prioritized for focused attention. As is known, the scope of the socio-economic dimension is comprehensive, and a region may have specific problems that are considered to be significant obstacles (Siebrecht, 2020). Priority attention should also be directed to smallholder farmers, who are the producers of the most vital agricultural commodities.

In many cases, smallholder farmers, who form the backbone of agriculture in many regions, often face challenges (Gyapong, 2020; Smit et al., 2015). In addition, inequities in land ownership further hinder efforts to improve agricultural sustainability (Griffin et al., 2002), as farmers may lack the motivation to invest in land they do not own. Low wages and poor working conditions also affect the viability of sustainable agriculture by limiting workforce availability and productivity. These socio-economic disparities result in unequal access (Shabaya & Konadu-Agyemang, 2004), with low-income consumers often unable to afford them. Addressing these issues requires integrated solutions that combine policy interventions and financial inclusion (Adegbite & Machethe, 2020). These barriers limit their capacity to adopt sustainable practices that require upfront investment (Deng et al., 2022; Grande et al., 2011). Thus, social entrepreneurs in sustainable agriculture can be defined based on predetermined priority points.

After simplifying the concept of SE in sustainable agriculture, we can see clearly that the primary key is inclusivity. Inclusivity can translate into equitable access, ensuring that smallholder farmers have sufficient resources to carry out sustainable agricultural practices. Equitable access concepts in the agricultural industry can enhance economic sustainability while addressing food security concerns (Krishna, 1982). It ensures that benefits from the resources are fairly distributed among all smallholder farmers, laborers, and marginalized communities. This concept addresses disparities in access to critical resources, which are often concentrated among larger or wealthier agricultural entities. By implementing policies that secure land tenure for small-scale farmers and promote affordable credit systems, equitable access is fostered, inclusion is achieved, and underserved groups are empowered. Apart from the various potential agricultural equitability patterns, their effectiveness always depends on resource availability and environmental conditions. For an agriculture-based rural area, the most suitable equitability pattern is community-supported agriculture (CSA) (Medici et al., 2021; Tay et al., 2024). Kinship relations between elements of society are still relatively strong compared to urban areas. Therefore, building SE in crop agriculture requires not only developing an agriculture-based business model but also fostering a community-based social system. Combining these models with local needs can help create more resilient and sustainable agricultural systems.

2.2 Penta-helix (PH) collaboration in the agriculture industry

Penta-helix (PH) collaboration is an effective technique to overcome socio-economic problems in the agricultural industry. It mobilizes diverse elements and resources to solve specific cases constructively. Penta-helix or multi-helix framework is a development of the triple-helix (TH), i.e., a framework that includes collaboration between three elements (academics, government, and industry) (Leydesdorff, 2000). Over time, the TH model transformed into a quadruple-helix (QH) (Cai & Lattu, 2022) and then into a penta-helix (PH) equipped with societal and media dimensions (Capetillo et al., 2021). Within the scope of this study, we will apply these five elements to address several complex problems in the socio-economic dimension of the agricultural industry.

Academia plays a foundational role in sustainable agriculture by serving as the primary source of knowledge and innovation (Zilahy & Huisingh, 2009). Academic institutions conduct scientific research to develop advanced farming practices and technologies that enhance productivity while preserving natural resources. For example, studies on precision agriculture provide insights into water optimization that can increase crop yields (Davijani et al., 2016). Through various training programs, academia equips agricultural stakeholders with the skills and knowledge needed to adopt sustainable practices. Universities and research institutions collaborate with agricultural extension services to translate scientific findings into practical techniques that farmers can implement (Wiggins et al., 2010). Moreover, academia plays a crucial role in assessing the socio-economic and environmental impacts of agricultural practices, offering data-driven recommendations for policymakers and industry leaders (Fischer et al., 2005). In the broader context of innovation, academia fosters partnerships with industry and government, driving the co-development of technologies like drought-resistant crops or systems for converting agricultural waste into usable resources. These collaborations amplify the impact of academic research, ensuring its application at scale.

The industry plays a pivotal role in sustainable agriculture by acting as the primary driver of commercialization and large-scale implementation of sustainable practices and technologies. By leveraging research insights from academia, industry develops and manufactures tools and products designed to enhance agricultural productivity while minimizing environmental impacts. Examples include precision farming technology systems (Belal et al., 2021). These innovations empower farmers to adopt more efficient practices that conserve resources while reducing greenhouse gas emissions. In addition to developing solutions, the industry facilitates the integration of sustainability into the agricultural supply chain. Companies are increasingly adopting circular economy principles [58], where they provide strategies for saving relevant resources and reducing negative environmental impacts while improving economic performance. Companies are increasingly adopting circular economy principles (Velasco-Muñoz et al., 2021), which offer strategies for conserving essential resources, reducing negative environmental impacts, and enhancing economic performance. For this purpose, waste products may be reused as inputs (Capanoglu et al., 2022). The industry also creates economic incentives by promoting and marketing sustainably produced goods, encouraging farmers to prioritize eco-friendly practices to meet market demands(de Janvry & Sadoulet, 2020).

Furthermore, the industry supports capacity building by providing farmers with access to resources and advisory services. Through partnerships with academia and government, industrial actors ensure that innovations are accessible to smallholder farmers and adapted to the specific needs of diverse local conditions. By acting as a bridge between research and real-world application, the industry accelerates the transition toward agricultural systems that are environmentally resilient, socially inclusive, and economically viable.

The government plays a critical role in promoting sustainable agriculture by creating an enabling environment through policies and resource allocation(Stads, 2019). As a policymaker, the government establishes frameworks that incentivize environmentally friendly farming practices (Guo et al., 2021) and encourage agroecological practices (Tittonell et al., 2020). They enforce compliance with these regulations to mitigate environmental degradation and promote sustainable resource use. Additionally, governments facilitate infrastructure development, which is essential for efficient and sustainable agricultural production and distribution(Xu et al., 2023). Moreover, governments foster multi-stakeholder collaborations to address global challenges like climate change and food security. Through education and outreach programs, governments empower farmers with knowledge and tools to implement sustainable practices, ensuring inclusivity and equity, particularly for smallholder and marginalized communities. By aligning economic, social, and environmental objectives, the government ensures that sustainable agriculture becomes a cornerstone of national and global development strategies.

Technology, including infrastructure and the digital realm, plays a transformative role in advancing sustainable agriculture by enabling efficient practices and promoting awareness of sustainability (Rodriguez et al., 2009). Digital data platforms are capable of providing farmers with real-time data on crop conditions and market trends (Borrero & Mariscal, 2022). This information allows for informed decision-making, optimizing resource use while minimizing waste and reducing environmental impact. Media platforms are powerful tools for raising awareness about the importance of sustainable agriculture (Ofori & El-Gayar, 2021). They amplify the reach of educational campaigns that inspire farmers and policymakers to adopt environmentally friendly methods (Mustafa et al., 2021). Virtual platforms also enable global knowledge exchange, connecting farmers across different regions to share solutions tailored to specific challenges.

Additionally, e-commerce and digital marketplaces connect farmers directly with consumers, increasing market access and promoting sustainability in supply chains. By fostering integrated collaboration, digital technology and media play integral roles in accelerating the adoption of sustainable agricultural practices. It is ensuring that these approaches reach a global audience and address the pressing challenges of food security and environmental conservation.

Moreover, social networks also contribute to the dissemination of sustainable agricultural knowledge. Local knowledge-sharing platforms empower individuals and groups to adopt innovative and sustainable techniques (Izadi et al., 2024). By reinforcing cultural values that prioritize a cooperative approach to resource management, society ensures the long-term viability and success of sustainable agriculture initiatives.

2.3 Sustainable agriculture at the regency level

Sustainable agriculture is commonly practiced in countries like Indonesia. Many studies report agricultural dynamics that specifically use regency as the scope area(Salam et al., 2024). Several studies discuss agriculture at the regency level in various regions of Indonesia, focusing on different types of agricultural food commodities (Maulidiyah et al., 2024; Mulya & Hudalah, 2024; Sahara et al., 2024). Food commodities are among the most studied subjects in the agricultural sector by researchers in Indonesia (Kusnandar et al., 2024). One reason is that food commodities have been a national priority for several decades. Until now, research related to food agriculture has continued to develop to address various increasingly dynamic challenges (Swastika et al., 2024). In this study, we focus on assessment points related to sustainable agriculture at the regional level to investigate several crucial aspects that have consistently challenged agriculture in Indonesia. Agricultural challenges in Indonesia are highly complex, as evidenced by the continual updates to various government policies. The latest regulations of the Ministry of Agriculture of the Republic of Indonesia are beginning to consider empowering farming communities to achieve sustainability (Murhaini & Achmadi, 2021). Empowering farming is a positive development, as various societal groups possess diverse resources. This step is considered very effective in minimizing various systemic problems. By engaging multiple stakeholders and utilizing their resources, more systemic issues can be effectively addressed.

In Indonesia, several provinces are national food agricultural areas (Mulya & Hudalah, 2024; Rosdiana et al., 2014). However, it cannot be denied that several food crop farming areas still have relatively low performance. The existence of this inequality necessitates an effective solution to improve regional agricultural performance. This inequality in performance is also quite interesting for agricultural researchers, both from a science and technology-based perspective and a social and policy-based perspective. A simple step to overcome this gap is to conduct investigations in national rice granary areas, which often achieve food self-sufficiency. Researchers can make closer observations to find out the factors that determine harvest success and post-harvest management. Through these factors, the government and stakeholders can consider implementing it in various regions deemed not to have achieved self-sufficiency. This step is certainly not simple; therefore, it requires collective efforts from various parties and resources to optimize the process of overcoming this gap.

3. METHODOLOGY

3.1 Scope and data source

This research was conducted in the context of 11 districts in West Sumatra from 2013 to 2023, using official data from the Indonesian Central Bureau of Statistics. Since the concept of social entrepreneurship gained popularity through several stages of practice, particularly around 2000, entrepreneurial activities have accelerated the renewal of attitudes among new market players and introduced new driving forces in economic development. In this case, we pay attention to productivity, farmer exchange value (FEV), environment quality index (EQI), regional gross domestic product in agriculture (RGDPA), salary, poverty index (PI), and human development index (HDI). The variability in innovation and entrepreneurship levels in the sample locations needs to be demonstrated before empirical analysis is carried out.

3.2 Data Processing and Analysis: statistical method

This study utilizes seven data variables analyzed through statistical methods and correlation analysis. Data processing is conducted to understand the relationships between variables and to identify significant patterns or trends. Statistical methods are employed to describe data characteristics, such as distribution, mean, and standard deviation. At the same time, correlation analysis aims to measure the degree of relationships between variables, whether positive or negative. The results of this analysis are expected to provide deeper insights into the interactions among these variables.

3.3 Analysis of Social Entrepreneurship and Penta-helix

In West Sumatra Province, we reviewed 11 districts to assess the indices of social entrepreneurship (SE) and the penta-helix (PH). Given the complexity of quantifying these variables, we simplified the analysis by focusing on their downstream aspects. SE was represented by a combination of FEV, income/salary, and the human development index (HDI), while PH was represented by the regional gross domestic product in agriculture (RGDPA). SE is inherently associated with comprehensive social well-being, whereas PH reflects the strong interconnection among various elements. As is widely recognized, GDP is an aggregate measure encompassing multiple factors, including the collaborative climate among involved actors. When this collaborative climate strengthens, GDP tends to increase, and conversely, it declines when the collaboration weakens.

3.4 Analyze the SE and PH impacts on SA

In this study, we conducted a qualitative analysis to understand how social entrepreneurship (SE) and the penta-helix (PH) impact sustainable agriculture (SA). Here, SA is represented by a combination of productivity and the environmental quality index (EQI). Through this straightforward analysis, we can gain insights into the interrelationships among seven essential variables and a broader understanding of SE, PH, and SA within a specific region.

4. RESULT AND DISCUSSION

The penta-helix collaboration model consists of five key elements, with social entrepreneurship playing a crucial role. In agriculture, this model fosters sustainable farming by encouraging cooperation among government, academia, business, communities, and the media. Social entrepreneurship drives innovation and inclusivity by addressing challenges in resource efficiency and rural development. By integrating these five elements, the framework promotes synergy among stakeholders to adopt sustainable agricultural practices. This approach balances economic growth with social welfare and environmental preservation, ensuring agriculture meets current and future needs.

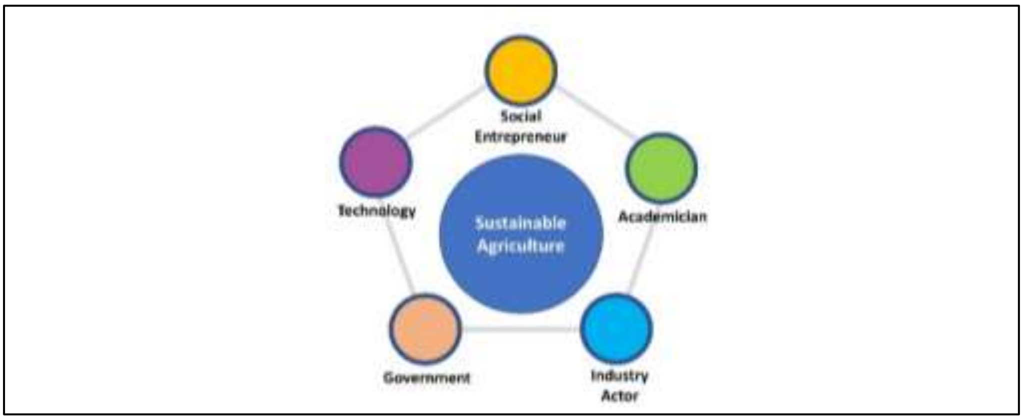


Fig. 1 Schematic description of sustainable agriculture supported by five elements: social entrepreneur, academician, industrial actor, government, and technology

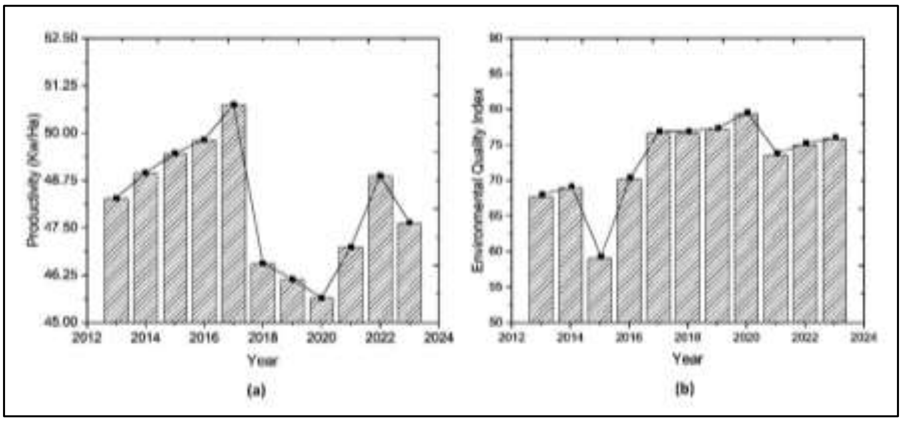


Fig. 2 (a) Productivity of rice land, and (b) environmental quality index

The productivity of the agricultural sector has exhibited notable fluctuations over the past decade, influenced by a variety of factors. From 2013 to 2017, there was a consistent upward trend in productivity, reflecting advancements in agricultural practices, improved resource management, and favorable policy support. However, this growth trajectory experienced a reversal in subsequent years. A significant decline was observed, particularly during 2019, when productivity levels were adversely affected by factors and market disruptions. This period of decline underscored the sector's vulnerability to both environmental and economic challenges.

Nevertheless, recovery began to materialize in 2022, with productivity indices showing a positive rebound. This improvement can be attributed to renewed investments in sustainable agricultural technologies, increased access to financial resources, and effective collaboration among key stakeholders. The fluctuations over the years emphasize the importance of adaptive strategies that address systemic vulnerabilities while promoting long-term resilience in the agricultural sector. Understanding these dynamics is crucial for formulating policies and practices aimed at stabilizing productivity and ensuring food security. As the sector continues to navigate complex challenges, fostering innovation and sustainable resource management will remain critical in maintaining productivity gains and mitigating future risks.

The Environmental Quality Index (EQI) in West Sumatra has exhibited a relatively stable trend over the period from 2013 to 2023, fluctuating within the range of 60 to 80 units. A notable decline was observed in 2015; however, subsequent years demonstrated a significant improvement in the index values, reflecting positive progress in environmental management. This stability and gradual enhancement indicate that agricultural practices in West Sumatra have been effectively managed to maintain environmental sustainability. The observed trends suggest a strong commitment to sustainable agricultural development, emphasizing practices that minimize environmental degradation and ensure the longevity of natural resources. Moreover, the ability to sustain a favorable EQI is crucial for long-term agricultural productivity, as it supports biodiversity, soil health, and water resource preservation. The data underscores that farmers and stakeholders in West Sumatra have likely adopted practices that collectively contribute to maintaining environmental integrity. Moreover, the gradual improvement in the EQI post-2015 highlights the region's adaptability and resilience in addressing environmental challenges. These findings reinforce the importance of integrating sustainable agricultural practices with environmental conservation strategies to achieve balanced economic and ecological outcomes, ensuring the continued viability of agriculture in West Sumatra.

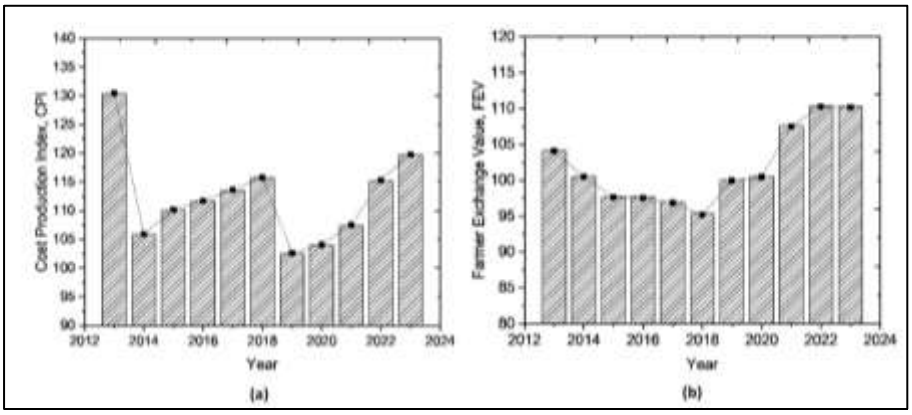


Fig. 4. (a). The cost production index, and (b) farmer exchange values

An analysis of the Cost Production Index (CPI) in agriculture from 2013 to 2023 indicates a relatively stable trend from 2014 onwards, despite a notable peak observed in 2013. During 2013, the CPI reached a value of 130, which is significantly higher than in subsequent years. This elevated figure is likely attributable to substantial initial investments in the agricultural sector during that period. Following this peak, the index experienced a decline and stabilized around an average value of 110 for the remainder of the observed time frame. The consistency in CPI from 2014 to 2023 suggests effective cost management practices and a relatively predictable expenditure pattern within the agricultural industry. The stability of production costs could be indicative of a mature agricultural sector that has optimized resource utilization and minimized financial volatility.

Furthermore, the initial high CPI in 2013 highlights the potential impact of significant capital inflows, which may have been directed toward enhancing infrastructure, technology, or other productivity-enhancing measures. These investments likely laid the foundation for the subsequent stabilization of production costs, ensuring the sustainability of agricultural operations. Overall, the CPI data reflects a sector that has transitioned from a period of substantial financial input to one of sustained operational efficiency.

The Farmer Exchange Value (FEV) exhibited a declining trend between 2013 and 2018, followed by a steady increase until 2023. This downward trend during the earlier period can be attributed to fluctuations in agricultural productivity, which adversely affected the overall economic resilience of farmers. However, the subsequent rise in FEV reflects a significant shift, indicating that farmers and stakeholders within the agricultural sector, including government institutions, have taken conscious and collective efforts to address the challenges and reinvigorate the sector. This revival demonstrates heightened awareness and proactive measures aimed at improving productivity. The commitment to revitalizing agriculture is evident in the consistent improvements observed from 2020 to 2023, with the sector regaining its stability and contributing to better economic outcomes for farmers. The data also highlights the broader impact of this agricultural resurgence, showcasing increased collaboration among industry actors and effective policy implementation to address prior inefficiencies. This recovery aligns with sustainable development goals, ensuring that agricultural growth translates into enhanced livelihoods for farmers and supports regional economic stability. The observed FEV trends underline the critical role of integrated efforts in fostering agricultural resilience and advancing economic sustainability within the agricultural sector.

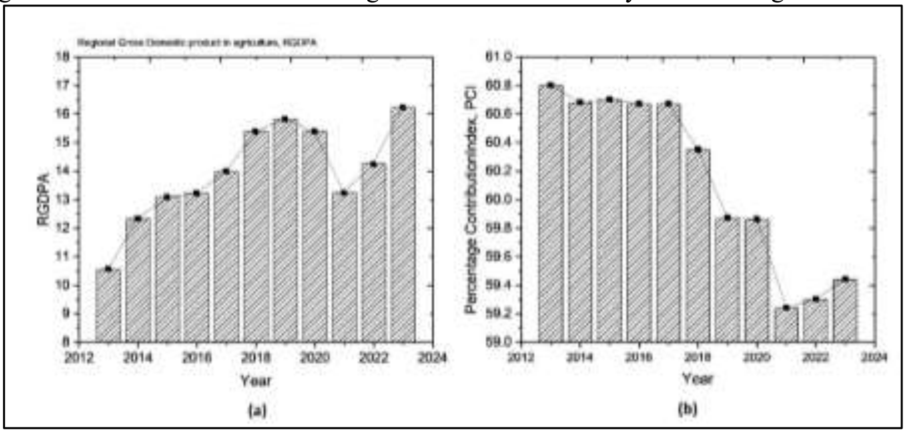
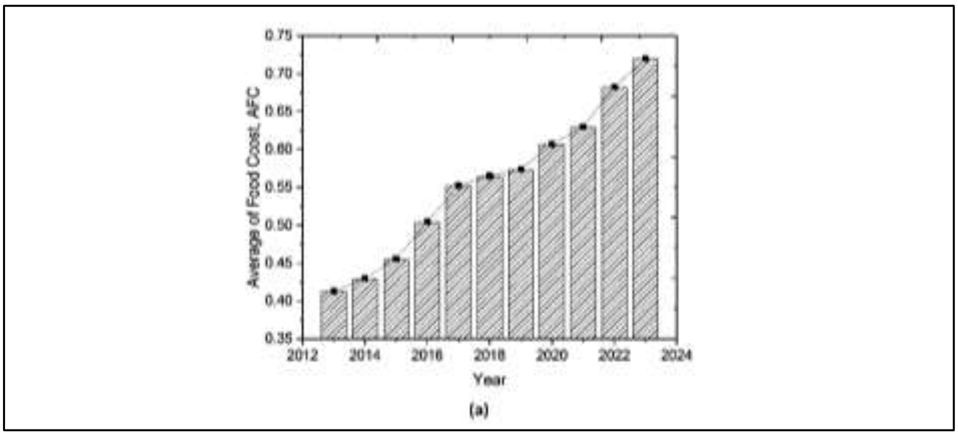


Fig. 4. (a) The Regional Gross Domestic Product in Agriculture (GDP), and (b) percentage contribution index

The Regional Gross Domestic Product in Agriculture (RGDPA) in West Sumatra demonstrated a generally positive trend from 2013 to 2019, reflecting consistent economic growth within the agricultural sector during this period. Despite a slight decline observed in 2021, the RGDPA rebounded the following year, highlighting the sector's resilience and ability to recover from minor economic setbacks. This recovery signifies the stability of the agricultural economy in the region, as no significant downturns or extreme fluctuations were recorded over the decade. The observed trends suggest that the agricultural sector in West Sumatra remains robust, supported by sustainable practices and effective economic strategies. Factors contributing to this stability likely include efficient resource management, policy interventions, and the proactive engagement of stakeholders in maintaining productivity and market access. The ability of the sector to regain momentum after the 2021 decline reflects adaptive mechanisms in place to counter challenges and ensure steady performance. Furthermore, the consistent growth trajectory in most years underscores the importance of agriculture as a cornerstone of the regional economy. It also emphasizes the need for continued investment and innovation to sustain this positive momentum, fostering economic resilience and supporting the livelihoods of those dependent on agriculture.

The percentage contribution index of the agricultural sector showed a declining trend from 2013 to 2018, despite a simultaneous increase in agricultural productivity. This paradox suggests that heightened productivity did not translate proportionately into revenue contributions to the region. From 2018 to 2021, the downward trend persisted, reflecting structural challenges in converting agricultural outputs into significant economic value. A slight improvement was observed in the percentage contribution index between 2021 and 2023, but it remained insufficient to offset the earlier declines. These patterns highlight critical inefficiencies within the agricultural value chain. The findings suggest that higher productivity alone cannot guarantee proportional economic benefits unless accompanied by strategies that enhance market integration, product diversification, and regional competitiveness. Strengthening the linkages between agricultural production and regional economic systems, particularly through improved supply chains and infrastructure, is essential to ensure that productivity gains are fully realized as significant contributions to regional income. Addressing these gaps will require coordinated efforts among policymakers, industry stakeholders, and local communities. Such efforts must focus on fostering innovation, supporting smallholder farmers, and implementing policies that prioritize equitable resource distribution and sustainable economic development.



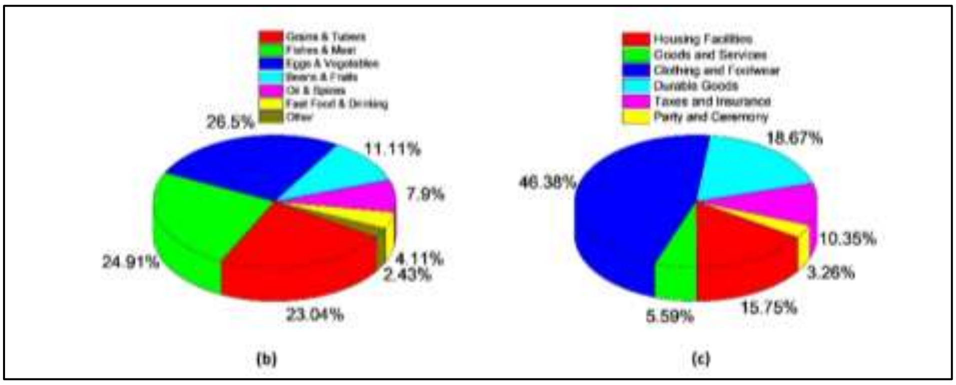


Fig. 5 Consumption patterns of the people of West Sumatra in 10 years. (a) Average usual food consumption. (b) Distribution of consumed food commodities. (c) Non-food commodities.

Fig. 5(a) shows that AFC experienced an upward trend from 2013 to 2023. The high value of AFC is caused naturally by population growth, which continues to increase every year. Fig. 5(b) presents the analysis of consumption expenditure patterns from 2013 to 2023, revealing a consistent upward trend in total household consumption costs, especially between 2013 and 2019. This increase is also evident in food consumption, which exhibits a similar rising trend. A closer examination of consumption data, as depicted in a pie chart, highlights three dominant categories of consumed commodities: eggs and vegetables account for 26.5%, fish and meat for 24.91%, and various types of tubers for 23.04%. Collectively, these categories represent the largest share of household consumption expenditures. This consumption pattern suggests that the general population retains a conservative approach to food preferences, characterized by reliance on traditional and staple food items. This notion is further supported by the relatively minimal consumption of fast food, which accounts for only 4.11% of total food expenditures. Such a distribution implies that, despite increasing total expenditures, dietary habits remain focused on essential and culturally rooted food groups rather than modern or convenience-based options. These findings show the importance of traditional food commodities in shaping consumption behavior. Traditional food commodities contribute to agricultural production and market supply chains, in meeting the nutritional needs and economy of households. Fig. 5(c) An analysis of non-food consumption patterns from 2013 to 2023 reveals that clothing and footwear constitute the largest proportion of total consumption, accounting for 46.3% of all non-food commodities. This significant share highlights the critical role of apparel-related goods in shaping consumer spending habits. Following clothing and footwear, goods and services rank as the second-highest category, contributing 18.67% to the overall consumption pattern. This category encompasses a broad range of essential and discretionary items, reflecting the diverse needs and preferences of consumers.

Additionally, housing facilities, which include expenditures on utilities, maintenance, and related services, make up 15.75% of non-food consumption. This figure underscores the importance of housing-related expenditures as a fundamental component of household budgets, particularly in addressing basic living standards. The dominance of clothing and footwear within non-food consumption suggests a strong emphasis on personal and social presentation, which cultural, seasonal, or economic factors may influence. The significant shares of goods and services, along with housing facilities, indicate a balanced allocation of resources between essential and lifestyle-related expenditures. This distribution of non-food consumption reflects broader socio-economic trends and provides insights into the priorities and preferences of the population over the analyzed period.

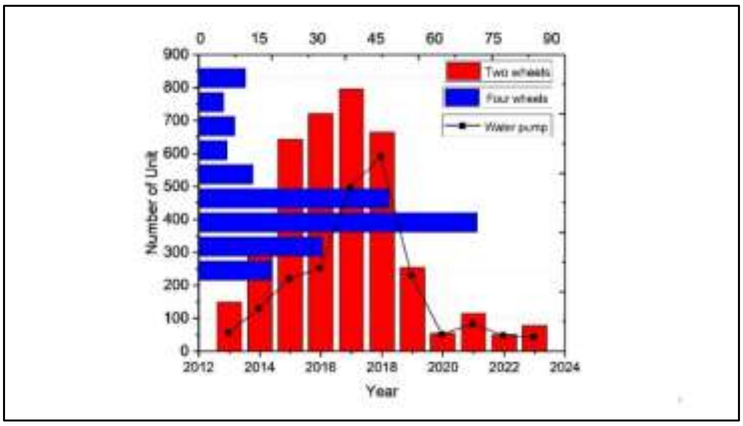


Fig. 6. Comparison of two or four wheels tractor and a water pump for agricultural procurement over the past 10 years

Fig. 6 shows the time-series analysis of agricultural infrastructure provision from 2013 to 2023, highlighting three primary support facilities: two-wheel tractors, four-wheel tractors, and water pumps. These facilities play a critical role in enhancing agricultural productivity and efficiency. Between 2013 and 2018, all three types of infrastructure exhibited a consistent upward trend, indicating increased accessibility and utilization. However, this trend reversed from 2018 to 2023, with a gradual decline observed in the availability and functionality of these essential tools. This pattern suggests that agricultural machinery and equipment require systematic replacement every five years or, at a minimum, significant rejuvenation efforts. Failure to implement timely replacement or maintenance measures could adversely impact operational performance and agricultural productivity. The decline in infrastructure quality and availability underscores the importance of regular investment in technological updates and resource management to sustain agricultural output. Policymakers and stakeholders should prioritize long-term planning to address the challenges posed by aging infrastructure. Additionally, periodic assessments of machinery efficiency and usability can aid in determining the optimal timing for upgrades or replacements. These strategies are essential to ensuring the continued reliability of agricultural systems, thereby contributing to the resilience and growth of the sector in the face of evolving demands and environmental changes.

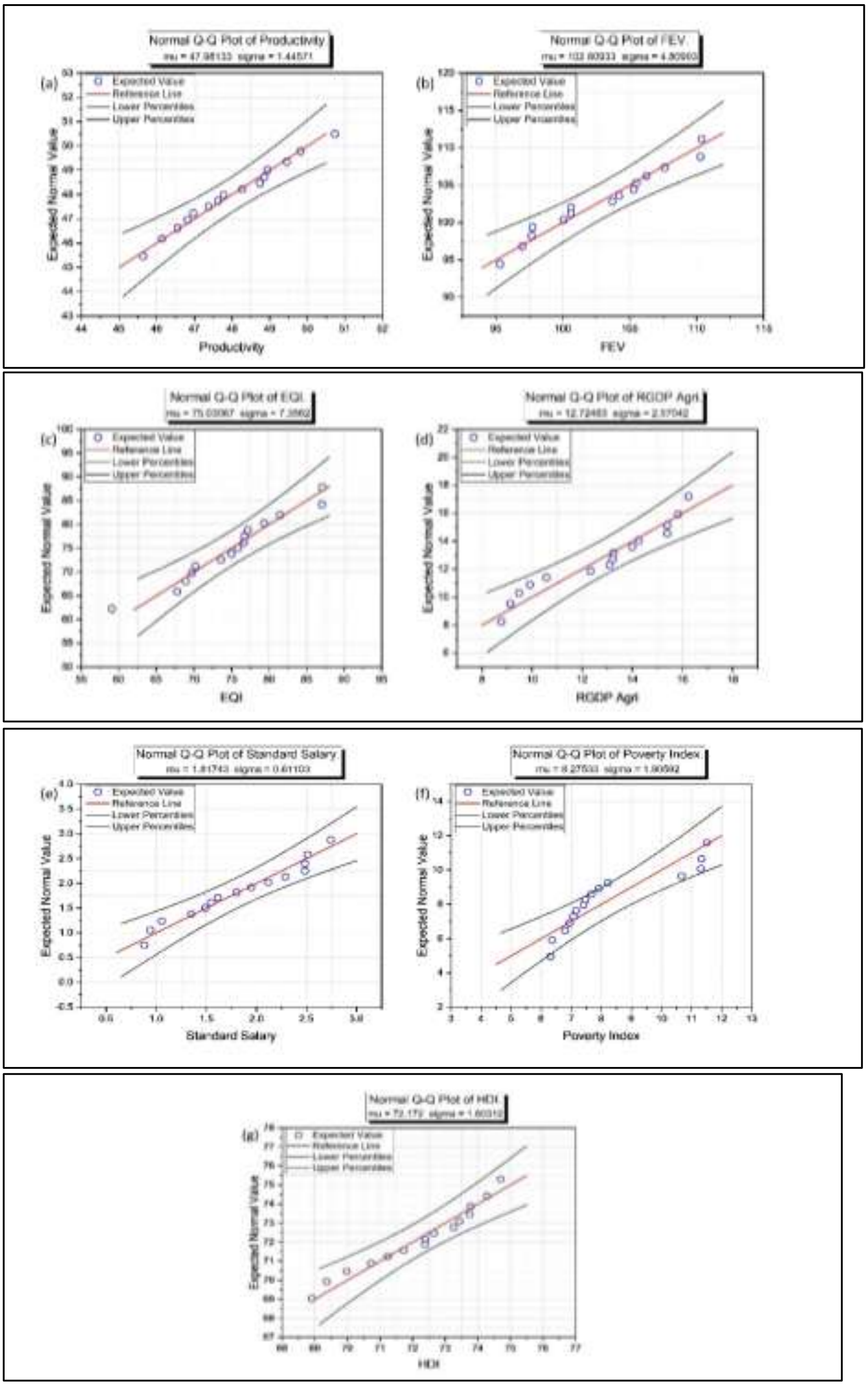


Fig. 7. Normal Q-Q plot of some agricultural essential parameters related to sustainable agriculture

Figure 7 presents an analysis of the normal Q-Q plot for various parameters related to sustainable agriculture from 2013 to 2023, indicating that the data strongly adheres to normality. The majority of data points lie within the lower and upper percentiles, with no significant deviations observed. However, a few parameters, particularly the poverty index, demonstrate relatively lower levels of normality. To provide a comprehensive understanding, the results of the Shapiro-Wilk normality test and descriptive statistics are presented in Table 1, offering a detailed view of the data distribution.

Table 1. Normality test using Shapiro-Wilk and descriptive statistics

Parameter	Shapiro-Wilk Statistic	p-value	Mean	Std Dev	SE of Mean	variance	Coefficient of variance
Productivity	0.98297	0.98578	47.98133	1.44571	0.37328	2.09007	0.03013
PV	0.9503	0.52914	102.8093	4.80903	1.24169	23.12681	0.04678
Standard Salary	0.94399	0.43524	1.81743	0.61103	0.15777	0.37336	0.33621
RGDP Agriculture	0.91714	0.17422	12.72483	2.57042	0.66368	6.60707	0.202
EQI	0.96259	0.73738	75.03133	7.35737	1.89966	54.13083	0.09806
HDI	0.94773	0.4894	72.172	1.80312	0.46556	3.25123	0.02498
Poverty	0.80084	0.28116	8.27533	1.90592	0.49211	3.63251	0.23031

A correlation analysis between agricultural productivity and six other parameters using the Pearson correlation test is provided in Table 2. Based on statistical calculations, almost all variables show a weak correlation, with only a few exceptions. These results indicate that there may be certain policy implementations that have not been well integrated. Another possibility is that existing strategies and policies are not sufficiently appropriate for the region in question. Effective implementation of policies and strategies should produce a harmonious set of intercorrelated results. Using the analogy of a spider web, the symmetry of the web would be disrupted if some sections were damaged. In this case, inadequate strategies and policies have the potential to produce outputs that disrupt the overall system.

Table 2. The correlation between productivity and several parameters according to the Pearson test

Coefficient of Correlation	FEB	EQI	RGDP Agri	Salary	Poverty Index	HDI
Productivity r-Pearson	-0.16354	-0.50592	-0.13434	-0.208	-0.03883	-0.3659
p-value	0.56031	0.05434	0.63313	0.45695	0.89073	0.17984

5. CONCLUSION

The analysis of the impact of Social Entrepreneurship (SE) and Penta-Helix (PH) implementation in supporting sustainable food crop agriculture was conducted across 11 regencies in West Sumatra from 2013 to 2023. In this context, SE was represented by several variables, including FEV, income/salary, and the Human Development Index (HDI). In contrast, PH was represented by the Regional Gross Domestic Product in Agriculture (RGDPA). Based on the data, the condition of food crop agriculture in the province remains relatively stable. Descriptive statistical results and the Normal Q-Q plot indicate that data linearity is still within acceptable limits. However, correlation analysis on the seven variables used as indicators to measure SE and PH levels revealed relatively weak relationships. This time-series data pattern provides valuable insights for re-evaluating and restructuring agricultural strategies to ensure more effective and efficient implementation in the future.

Credit author statement
Author: Conceptualization, Formal analysis, Funding acquisition, Writing – original draft.
Author: Data curation, Formal analysis, Methodology, Writing – original draft.
Author: Project administration, Resources, Software, Writing – review & editing.
Author: Conceptualization, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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

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