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Enhancing sustainability of agricultural land use in Indonesia: Integrating water, energy, and food resources for achieving long-term development goals

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ABSTRACT

Background: By 2050, the global population is expected to reach 9.7 billion, doubling the demand for food and water. Rapid urbanization has increased the demand for ecosystem services and led to significant land use changes, including deforestation and agricultural expansion. In Indonesia, the growth rate of 1.31% annually is not aligned with improvements in food security, highlighted by declines in rice harvests and productivity. The Sustainable Development Goals, particularly Goal 2, aim to end hunger and promote sustainable agriculture. Indonesia's policies, including laws and regulations to protect agricultural land and prevent conversion, face challenges in implementation due to inefficiencies and inadequate consideration of resource interconnections. **Method:** This study uses the DPSIR model to evaluate policies on sustainable agricultural land, revealing gaps in integrating water, energy, and food resources. **Findings:** The study identifies inefficiencies in policy implementation and inadequate consideration of resource interconnections, which hinder agricultural sustainability and food security. **Conclusion:** Recommendations include developing closed-loop systems to enhance agricultural sustainability and address environmental, social, and economic issues effectively. **Novelty/Originality of this article:** This study highlights policy gaps using the DPSIR model and proposes closed-loop systems as an integrated approach to sustainable agriculture.

KEYWORDS: sustainable agriculture; DPSIR model; resource integration.

1. Introduction

Globally, the human population is predicted to reach 9.7 billion by 2050, which will drive an increase in food and water consumption by more than double (UN, 2019; Baillie & Zhang, 2018). Rapid urban growth in recent years has also created high demand for materials and ecosystem services, such as housing, safe water supply, waste collection, waste disposal, and other basic services (Marten, 2001). This has led to global land-use changes between 1992 and 2015, causing deforestation and the expansion of agricultural land (Nowosad et al., 2018). The growing human population approaching the Earth's carrying capacity has resulted in the depletion of resources, such as land, food, and water, becoming increasingly limited (Marten, 2001). As part of a positive feedback loop, land-use changes directly impact climate change and environmental conditions (Bonan, 2008; Mahmood et al., 2014; Alkama & Cescatti, 2016).

The increasingly critical global situation has led world leaders to agree on eight specific and measurable global development goals through the current Sustainable Development Goals (SDGs). One of the SDG programs related to food security is SDG No. 2, which aims to

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eliminate hunger, achieve food security and improved nutrition, and promote sustainable agriculture. The population increase in Indonesia, with a growth rate of 1.31% from the previous year, is not in line with the food security conditions, as evidenced by a decline in rice harvest area by 700,047 hectares, productivity by 0.89 quintals per hectare, and production by 4,596,501 tons (BPS, 2020). Over the past 20 years (1978–1998), there has been significant land conversion of rice fields in Java, with an average land conversion rate exceeding 50%, and conversion rates for districts reaching 53,540 hectares and for provinces 24,040 hectares (Irawan, 2005). Population growth, the expansion of the industrial sector, and the demand for housing have increased the need for built-up land (Hidayat, 2008). To control urban development, several countries have set measurable targets in their policies. Bovet et al. (2018) conducted a comparative study to understand how land-use conversion challenges are addressed by certain countries, including Switzerland, which set a target of limiting land consumption for housing to 400 m2 per capita. On the other hand, Pasandaran (2006) proposed three policy alternatives to control land conversion that need to be considered, including 1) control policies through central authority, 2) policies aimed at providing incentives to irrigated rice field owners, both individual and collective, for performing production, conservation, and cultural heritage functions, and 3) strengthening the collective ability of farming communities to manage land and water resources.

Achieving the SDGs targets is not an easy task. Nevertheless, the Indonesian government has made food security a national development priority by enacting legislation to control urban development, which triggers the conversion of agricultural land. To achieve the global targets by 2030, including ensuring sustainable food production systems and implementing resilient agricultural practices that increase production and productivity, the national targets in the Medium-Term Development Plan (RPJMN) for 2015–2019 include the designation of Sustainable Food Agriculture Areas (KP2B). Therefore, several legal products related to KP2B designation have been established, including the Indonesian Law No. 41 of 2009 on the Protection of Sustainable Food Agriculture Land, Government Regulation No. 1 of 2011 on the Designation and Conversion of Sustainable Food Agriculture Land, Ministry of Agriculture Regulation No. 07/Permentan/OT.140/2/2012 on Technical Guidelines for Criteria and Requirements for Sustainable Food Agriculture Areas, Land, and Reserve Land, and the latest regulation, Presidential Regulation No. 59 of 2019 on the Control of Paddy Field Conversion

Thus, the government and local governments are required to ensure the welfare of the people through the protection of sustainable food agriculture land (LP2B), including formulating incentives and disincentives through the establishment of legal instruments. However, the implementation of LP2B protection policies through Regional Spatial Planning Regulations, which are then derived into Regional Regulations on the Protection of Sustainable Food Agriculture Land, has not been smooth (Nurrokhman, 2019). The policy-making framework addressing natural resource management has historically been characterized by a sectoral approach and isolated policy responses, resulting in segmented planning and placing pressure on water, energy, and food resources, which in turn exacerbates livelihoods and undermines sustainable development (Pittock et al., 2013; Bizikova et al., 2013; Alboelnga et al., 2018). The interrelationship between water, energy, and food resources is illustrated in Figure 1, which relates to ecosystem resilience. Therefore, this study aims to comprehensively examine food security efforts in Indonesia through the history of agricultural policy from the New Order to the implementation of Law No. 41 of 2009 on the Protection of Sustainable Food Agriculture Land, as well as evaluate LP2B policies in Indonesia using the DPSIR (Driver-Pressure-State-Impact-Response) analysis.

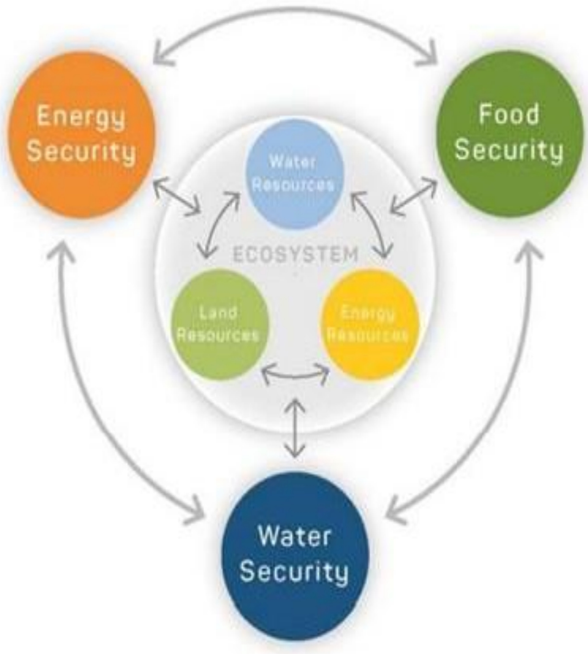

Fig. 1. The relationship between water, energy, and food from an ecosystem perspective (GIZ, 2016; Alboelga et al., 2018)

2. Methods

This research employs a mixed-methods approach to provide a comprehensive assessment of the impact of climate variability and land-use policies on agricultural sustainability in Indonesia. The study integrates both quantitative and qualitative analyses to evaluate the effectiveness of Sustainable Food Agricultural Land (LP2B) policies and their implications for resource management.

Quantitative data on climate variables, such as temperature and rainfall, as well as agricultural yield, are collected from meteorological stations and agricultural reports. The study focuses on historical climate data spanning 30 years (1990-2020), with particular emphasis on recent datasets from 2009 to 2019 due to data availability constraints.

In addition, a thorough review of policy documents is conducted. This includes analyzing legislative texts, government reports, and policy evaluations related to the SDGs, RPJMN, and LP2B regulations to understand the framework and implementation challenges associated with LP2B.

Qualitative data are gathered through field observations and interviews with various stakeholders, including farmers, local government officials, and policy experts. These interactions help capture practical challenges and perceptions regarding the implementation of LP2B and its impact on agricultural practices.

For data analysis, statistical methods are employed to analyze trends and correlations between climate variables and agricultural yield. Regression and correlation analyses are conducted to determine the relationships between temperature, rainfall, and rice yield, particularly at the Nkhate rice scheme.

A DPSIR (Driver-Pressure-State-Impact-Response) framework is used to evaluate the effectiveness of LP2B policies. This framework helps in identifying key drivers and pressures influencing agricultural sustainability, assessing the current state of land use and resource management, and analyzing the impacts and responses related to LP2B implementation.

Thematic analysis is applied to the qualitative data obtained from interviews and observations. This approach allows for the identification of common themes and issues related to the implementation of LP2B policies and their effects on farmers and local communities.

The integration of quantitative and qualitative findings offers a comprehensive understanding of the challenges and opportunities in achieving sustainable agricultural land use. The synthesis of data from various sources provides informed recommendations for enhancing LP2B policies and improving the efficiency of water, energy, and food resource management.

The study acknowledges limitations such as the availability and precision of historical meteorological data due to the sparse distribution of weather stations. Additionally, the reliance on qualitative data from interviews may introduce subjective biases.

3. Results and Discussion

3.1 Agricultural policy history from the new order to the reform era

In the 1970s, Indonesia's food sector policy was implemented on a large scale, involving small-scale farmers, particularly in Java and transmigration areas, as well as ministries, state-owned enterprises, and local rice traders. This agricultural system still applied conventional methods grounded in an industrial approach, characterized by capital intensity, large-scale operations, agricultural mechanization in monoculture cultivation, and a heavy reliance on chemical agro-inputs, largely imported (fertilizers, pesticides, herbicides, etc.). This intensive production system led to a dependency on external agricultural inputs alone (Knorr & Watkins, 1984), which had a positive impact on significantly increasing agricultural production. However, it also neglected the negative effects on environmental degradation and health issues, as only a small portion of the fertilizer applied to rice plants was utilized by the plants, while the majority became a source of water and air pollution (Adnyana, 2001)

On the other hand, during the New Order era, Indonesia's food security, which appeared sufficient and abundant, masked the dire condition of human resources, particularly farmers who were the primary subjects in the agricultural sector. The 1993 agricultural census concluded that around 88% of Indonesian farmers had a maximum education level of elementary school completion, with about 15% having no schooling at all (Damanhuri, 1999). Agricultural income also showed significant inequality due to disparities in land ownership and control (Santosa, 2005). This situation was exacerbated by unfair partnership patterns that disadvantaged farmers (Ermawati, 1996). Many farmers bore the brunt and suffered losses due to the underdeveloped role of cooperatives in strengthening the agricultural sector.

In the 1990s, sustainable agriculture began to emerge globally, with concepts like organic farming, biological agriculture, ecological agriculture, low external input sustainable agriculture (LEISA), biodynamic farming, regenerative agriculture, permaculture, and agroecology, incorporating social values such as equity for future generations, indigenous knowledge, self-sufficiency, support for the underprivileged, recognition of local cultural values, and land tenure rights (Adnyana, 2001). However, measuring the sustainability of such farming systems is not easy. In 1997, Indonesian agriculture stagnated or remained dependent on imports due to widespread crop failures caused by El Niño. The unstable political situation in 1998 worsened the situation, leading to inflation of goods. This shifted agriculture from being a primary priority in economic development to just one of several priorities.

3.2 Implementation of LP2B policies

The enactment of Law No. 41 of 2009 marked the beginning of sustainable development in Indonesia in terms of food security, followed by derivative regulations at both the central and regional government levels. The established regulations covered issues of designation, incentives, information systems, and funding for the protection of sustainable agricultural land (LP2B). However, over the 12 years since the enactment of

Law No. 41 of 2009, land conversion issues have not been significantly addressed, particularly in agricultural lands

The implementation of LP2B policy, according to Grindle's (1980) definition of implementation, is an administrative process whose success is influenced by two interrelated fundamental variables: the content of the policy and the context of implementation. In other words, policy content that fails to consider its interrelation with other sectors and issues within its context can lead to implementation failures

A deeper examination of the substance of these policies reveals that they have not addressed the fundamental issues related to land, specifically agricultural land undergoing conversion due to market mechanisms (Nurrokhman, 2019). LP2B designation is often perceived as hindering regional investment growth and reducing potential local revenue (Bappenas, 2016). Although there are regulations regarding administrative and criminal sanctions for those who convert agricultural land, it is essential to consider that many victims of these rules are plant breeders who have been imprisoned, even though they should be among the small-scale farmers who need protection (BPHN, 2016)

From a social perspective, issues are also found in Government Regulation No. 12 of 2012 concerning Incentives for the Protection of Sustainable Agricultural Land. Article 12, paragraphs 1 and 2, relate to the provision of agricultural production facilities and infrastructure, but paragraph 3 imposes a limitation on provision, stating that it should be based on need, without clearly defining what constitutes a need, despite recommendations from an assessment team. This ambiguity could lead to subjective judgments and potential misuse by certain individuals if clearer regulations are not in place.

Article 23, related to Article 20, indicates that farmers with a minimum planting area of 25 hectares in a contiguous plot can be considered for incentives, potentially favoring large-scale farmers (corporations) rather than small farmers. The issue with this article also relates to Article 25, where incentives are prioritized for LP2B that have not experienced fragmentation in a single plot. Incentives should still be provided to fragmented lands. Overall, the provision of incentives to farmers whose land is designated as LP2B has not yet fully addressed all farmer segments and scopes, particularly concerning fulfilling the needs to improve farmers' welfare, including education guarantees for farmers' children

Considering that water consumption for agriculture accounts for 70% of available freshwater (FAO, 2018), it is necessary to highlight the applicable rules within the LP2B policy concerning the nexus between water, energy, and food. This interrelationship illustrates the interconnectedness and interdependence between the water, energy, and food sectors, which are inseparable. In essence, sustainable food agriculture is supported by irrigation infrastructure, a form of incentive, and energy in technology to facilitate farmers' work.

Fig. 2. Subak irrigation system at Bali
(Kemdikbud, 2019)

In Government Regulation No. 12 of 2012 on Incentives for Sustainable Agricultural Land Protection, Article 24 states that incentives are provided for irrigation areas covering a maximum of 3,000 hectares across provinces and 1,000 hectares across districts/cities within a province. Meanwhile, soil and water conservation is addressed in Law No. 41 of 2009 on Sustainable Agricultural Land Protection, Article 33, which states that LP2B utilization must ensure soil and water conservation, including the protection, preservation, quality management of land and water resources, and pollution control. The explanatory section related to this article mentions the concept of the subak irrigation system in Bali. According to Mangunwijaya (1985), subak principles include (i) activities based on self-reliance, (ii) decentralized operations, (iii) cooperation-based activities rather than competition, and (iv) technology that is conscious of social and ecological responsibilities. This indicates that human roles in the subak system are crucial in harmonizing irrigation management systems with social and environmental considerations. However, irrigation systems still need to be adapted to local conditions. This is not yet reflected in the existing KP2B regulations concerning sustainable irrigation mechanisms, so synchronization with Law No. 17 of 2019 on Water Resources is necessary.

3.3 Evaluation of LP2B policies in Indonesia

Efforts to ensure food security in Indonesia require the government's commitment to implementing LP2B in synergy with various sectors to achieve the national targets outlined in the RPJMN in terms of both quantity and quality. The evaluation of LP2B policies is conducted through the DPSIR (Driver, Pressure, State, Impact, and Response) framework, which can identify potential solutions to complex environmental issues arising from the interactions involved (Troian et al., 2021), encompassing water, food, and energy issues. Figure 3 illustrates the framework of LP2B policy evaluation, covering social, economic, and environmental conditions. Figure 4 outlines the subsequent DPSIR sequence, explaining the responses needed to address emerging problems by involving stakeholders, encompassing aspects of policy, targets, and technology.

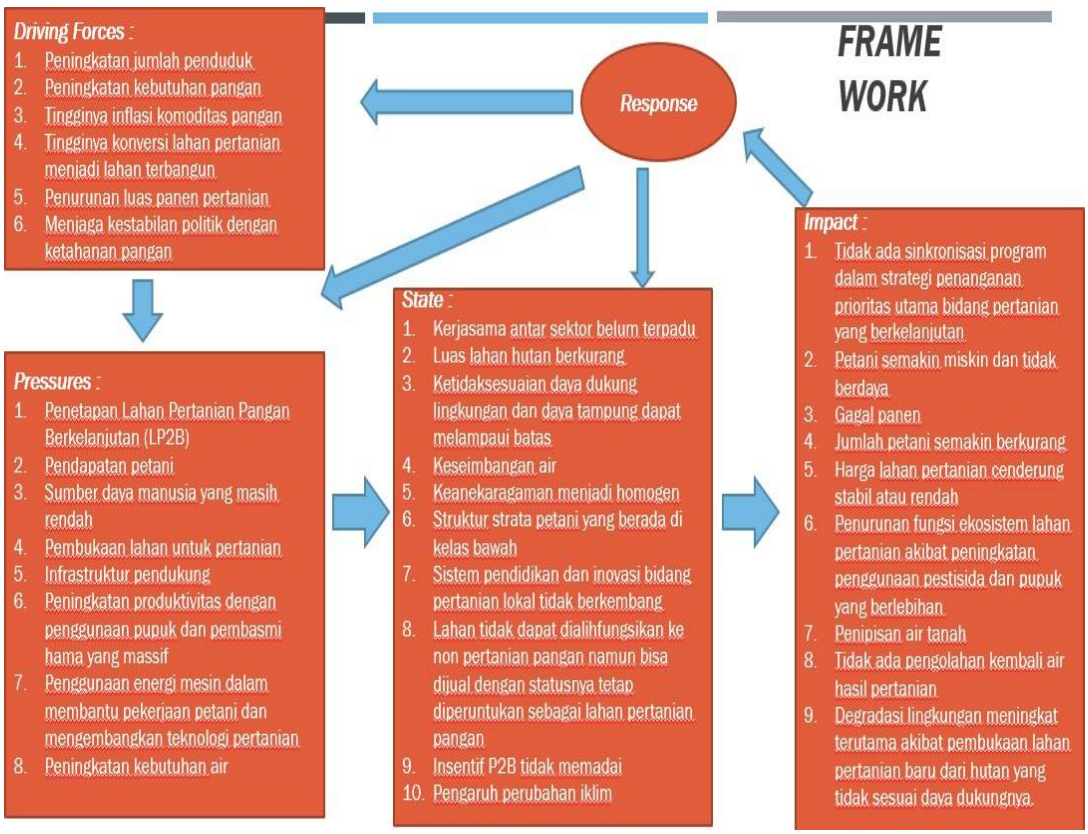

Fig. 3. The DPSIR framework in evaluating LP2B agricultural policy in Indonesia

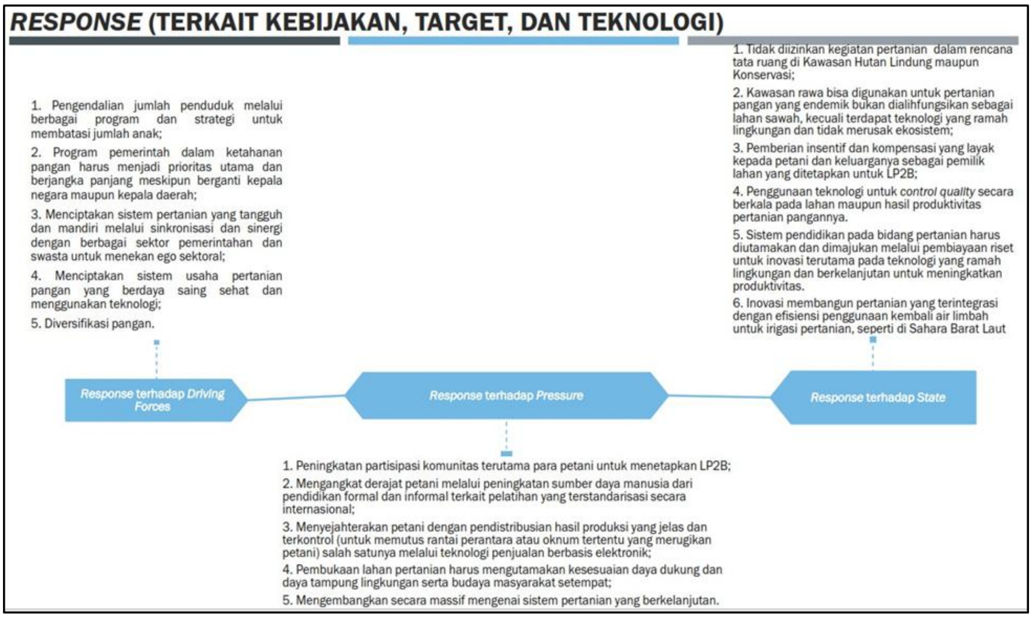

Fig. 4. The extended framework of DPSIR in the evaluation of LP2B agricultural policy in Indonesia.

In Indonesia, LP2B policies have yet to address the efficiency of the interconnected relationships between water, energy, and food. While water is discussed in the legislation, it primarily focuses on protection rather than integrated utilization. Research by Ramirez et al. (2021), which uses the North Western Sahara Aquifer System (NWSAS) scheme as illustrated in Figure 5, demonstrates that treated wastewater reuse for agricultural irrigation in the North Western Sahara can reduce groundwater pressure by up to 49%. This research highlights the efficiency of water use due to higher water costs, but the ideal scenario involves government subsidies to help farmers use irrigation water, as minimal water use would hinder system effectiveness since less treated wastewater would be available for utilization.

The success of the NWSAS implementation requires comprehensive technology and policy support from all stakeholders to better integrate water, energy, and food. However, another factor to consider is the suitability of the implementation with local characteristics, as NWSAS was applied in arid land areas, necessitating further research if such a concept were to be implemented in Indonesia.

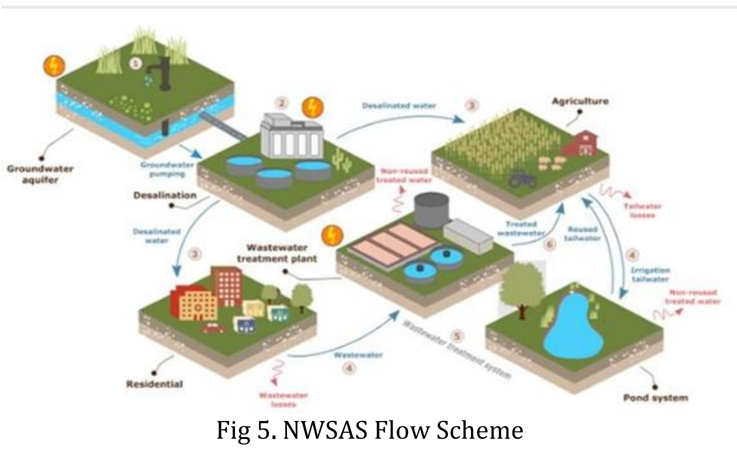

Fig 5. NWSAS Flow Scheme
(Ramirez et al., 2021)

4. Conclusions

Sustainability in land designated as Sustainable Food Agricultural Land (LP2B) extends beyond merely preventing land conversion; it requires significant and comprehensive efforts to transform Indonesia's agricultural system into one that supports sustainable development. Government policies incorporating SDGs objectives into the RPJMN and related LP2B regulations are insufficient for implementing sustainable agricultural land designations. Effective policies must enhance targets for resource efficiency and integration among water, food, and energy to ensure continuous functionality. Such policies should address environmental, social, and economic issues within the scope of LP2B. Strategic efforts needed include further research and development of innovations, such as creating a closed-loop system linking water, energy, and food to maintain both the quantity and quality of agriculture in Indonesia.

Author Contribution

All author contributed fully to the writing of this article.

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Conflicts of Interest

The author declare no conflict of interest.

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