Policy pathway to resilience: Shifting to high-yielding rice seeds to reduce emissions and strengthen rice production in Indonesia

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Abstract. Addressing climate change in rice farming to strengthen national food security while mitigating greenhouse gas (GHG) emissions presents complex challenges warranting policy support. Rice cultivation needs actionable emission reduction strategies, given its 57% share of Indonesia's total agricultural emissions. Concurrently, climate change has led to reduced yields, even crop failure. While prior studies have proposed some mitigation measures, their applicability to smallholder farmers remains economically and socially constrained. The absence of effective mitigation strategies might jeopardise national food security. This study assesses optimal emissions-cutting approaches tailored for rural cultivation using a narrative literature review and qualitative field survey, encompassing interviews with 523 farmers in five provinces: North Sumatra (86), Lampung (116), West Java (94), Central Java (156), and East Java (71). A Comparison Group analysis reveals that users of high-yielding variety seeds (HYV) produced fewer GHG (1.3 tons CO_2e/tons rice produced) than non-users (1.5 tons CO_2e/tons rice produced), attributed to increased productivity with the same fertiliser input. Encouraging HYV adoption surfaces as a pragmatic strategy, surpassing the viability of alternative interventions. Thus, implementing national policies that promote HYV production and utilisation has emerged as an effective mitigation strategy for reducing emissions in rice cultivation while concurrently strengthening national food security.

1 Introduction

The agriculture sector is confronting a barrage of alarming challenges due to the escalating impacts of climate change. This sector is especially vulnerable to various climate phenomena, encompassing intensified rainfall patterns, increased temperatures, and the relentless emergence of invasive pests. Recent statistics provided by the Ministry of Agriculture reveal that in the initial half of 2023, there are 14,000 hectares of rice fields impacted by flood, coupled with an additional 27,000 hectares affected by drought [1].

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Given rice's pivotal role as Indonesia's staple food, a wealth of research has been conducted to study rice's susceptibility towards climate change. Saputra's study (2022) indicates that farmers exposed to floods and droughts face a 2.23 times higher risk of significant yield decline than those unaffected by climate-related events. Meanwhile, farmers confronting pest attacks are 12.33 times more susceptible to yield reductions compared to their previous year [2]. Yuliawan's study (2016) additionally shows that a mere 1°C temperature rise leads to an 11.1% decline in yields for irrigated paddy fields and an even more pronounced 14.4% reduction for rainfed paddy fields across the nation [3].

This means, should the World Meteorological Organization's forecast hold true that in the next five years the Earth's temperature would increase up to 1.8°C [4], Indonesia's national rice production could drop by 20%. This translates to a national production decline from 54,75 million tons of milled rice in 2022 [5] to 43,8 million tons of milled rice in 2027. This situation poses a challenge to Indonesia's food security, considering the country's annual population growth rate of 1.13% [6], which results in increased rice demand.

As climate change events lead to reduced rice yields, it is noteworthy that rice cultivation also contributes a significant amount of GHG that causes climate change, encompassing methane (CH_4) and nitrous oxide (N_2O). Paddy fields specifically account for approximately 5–19% of anthropogenic global methane emissions. Continuous flooding, a common water management practice implemented by farmers, releases a significant amount of CH_4 due to anaerobic conditions favourable to methanogenic bacteria. Additionally, agricultural soils treated with fertilisers contribute around 13–24% of the world's annual N_2O emissions [7]. The application of chemical fertilisers stimulates CH_4 and N_2O production in soil due to losses of N through nitrification and denitrification [7]. GHG emissions from rice fields are multifactorial, influenced by plant physiology, soil characteristics (physical, biological, and chemical), redox potential, and pH. These factors, in turn, are shaped by agricultural practices, including water management, fertiliser application, tillage methods, and rice varieties used [8].

While there are available strategies to mitigate GHG from rice fields, most of these approaches may not be economically and socially viable for sustainable adoption by farmers. Salampessy's study (2018) highlights that most climate change adaptation strategies are impractical at the farmer's level due to their incompatibility with geographical locations and the socioeconomic conditions of farmers [9]. Farmers' adoption of GHG mitigation options highly depends on the simplicity of implementation and the benefits for the farmers [7].

Consequently, there is a pressing need for a climate adaptation strategy for both accessible to farmers and offers economic benefits while being adaptable to diverse geographical settings. An easily adapted mitigation strategy is needed to familiarise smallholder farmers with climate change mitigation for rice fields. This study is undertaken with the objective of furnishing comprehensive insights into demographic characteristics, economic viability, and agricultural practices among farmers to identify the most viable approach for reducing GHG emissions from rice cultivation at the farmer's level and simultaneously strengthening national rice production.

2 Methodology

2.1 Research design

The study employed the Comparison Group (CG) method to analyse variations in productivity, income, and greenhouse gas emissions between the user and non-user groups by comparing predefined *before* and *after* periods. The user group comprised farmers who had adopted certified high-yielding varieties (HYV) of rice seeds released by the Centre for

Rice Research (BBPadi) in the last decade. Three newly released high-yielding rice varieties (Inpari 32, Inpari 42, Inpari 48) were selected due to their similar planting periods and their widespread adoption by farmers in the sampled regions. Conversely, the non-user group consisted of farmers who had not transitioned to HYV during the data collection and decided to utilise old-released varieties (e.g., IR 64, Ciherang, Mekongga) [10], despite their awareness of the existence of HYV.

For the user group, the *after* period conformed to the most recent planting season in which they used HYV and the *before* period referred to the last planting season in which they used older varieties. To minimise the influence of environmental variables when comparing these two planting seasons, the surveys *before* and *after* periods are ensured equivalent. For instance, if a user farmer last used HYV in the 2023 dry season *(after* period*)* and last used older varieties in the 2022 rainy season, the *before* period was adjusted to the 2021 dry season. This study also found that HYV entered the survey areas' market around 2017/2018. Hence, for early adopter user farmers, the *before* period could extend back to 2016/2017.

The same determination of *before* and *after* periods also applied to the non-user group. However, in both planting seasons compared, the non-user group consistently used local varieties, non-certified, or older varieties. It is also noteworthy that during the data collection process if a farmer experienced crop failure (with a decrease in yield of up to 50%) during the selected planting season, the yield data is retrospectively collected from a season where no crop failure occurred.

2.2 Data collection

This study combines primary and secondary data as its research foundation. The sample frame was formed based on information gathered from distributors and kiosks responsible for distributing HYV rice seeds produced by partnered organisations. Primary data collection was undertaken through interviews with smallholder rice farmers using structured questionnaires conducted from April to May 2023. The study comprised a total sample size of 523 respondents across five provinces: North Sumatra (Deli Serdang and Medan) with 86 participants, Lampung (Metro and Lampung Tengah) with 116 participants, West Java (Karawang) with 94 participants, Central Java (Boyolali, Brebes, Semarang, Sukoharjo, Tegal, and Wonogiri) with 156 participants, and East Java (Bojonegoro) with 71 participants. Within these samples, 299 rice farmers were identified as users, while 224 were categorised as non-users.

A narrative literature review was employed based on their relevance to explore potential strategies for reducing greenhouse gas emissions in rice cultivation and strengthening rice production. Secondary data sources include research publications, policy briefs, and reports. The analysis involves disaggregating sources by focus, such as impact on yields, emission reduction strategies, and challenges faced by smallholder farmers. The themes emerging from the literature are synthesised to provide a coherent narrative that highlights the complexities of the problems and potential pathways to address them.

2.3 Income increases calculation

In calculating the increased income observed within the user and non-user groups, the authors undertook a comparative analysis of their yields during the *before* and *after* periods. A standardisation procedure was applied to unify their varied yield measurements into a uniform metric, dried unhusked grain (*gabah kering giling*/GKG). This standardised approach was also employed in the calculation of farmers' productivity. Notably, the authors implemented adjustments to account for inflation rates when computing revenue and income figures in this study, encompassing both the *before* and *after* periods.

2.4 Greenhouse gas emissions calculation

The GHG emission was only accounted for using nitrogen-based fertiliser (N fertiliser), including the production, transportation, and application of the fertiliser. Below is the amount of N-based fertiliser used in Indonesia and its composition.

Table 1. Amount of N-based fertiliser used by Indonesians in 2018 and its composition.

Total N consumed (tons)	Ammonium sulphate	Calcium ammonia	Urea	Ammonium phosphate	N K compound	N P K compound	Other NP
3,237,087	11.12%	0.05%	72.51%	1.73%	0.04%	14.20%	0.36%

Source: [11]

The total emission is presented in CO_2e, with the kg CO_2e emitted per kg N fertiliser used is 13.01. This number represents the various N fertilisers used in Indonesia as presented in Table 1, however, this study only measured the urea and NPK which rice farmers widely used. Detailed emission generated from the fertiliser manufacture until its application is presented in Table 2.

Table 2. Emissions of carbon dioxide equivalent from the production and use of N-based fertiliser in Indonesia.

Emission source	CO_2e emissions (kg/kg N)
Production	3.55
Transport	0.25
Application	1.17
Direct N_2O soil emissions	4.88
Indirect N_2O soul emissions (volatilisation)	1.02
Indirect N_2O soil emissions (leaching)	2.13
Total	13.01

Source: [11]

3 Results and discussion

This study found that the average age of farmers in both user and non-user groups was 54 years old, representing the average age of Indonesian rice farmers [12]. A substantial majority, approximately 90% of the respondents engaged in rice cultivation on irrigated land, while the remaining 10% cultivated on rainfed land. Land ownership of the respondents varied from 0.4 ha per household to 1.6 ha per household, the average land area was 0.72 ha per household.

3.1 Existing climate change mitigation for rice cultivation

Presented in Table 3 is a comparative analysis of prevailing greenhouse gas emissions mitigation approaches for irrigated rice fields in regions overlapping with the study's research areas. This study assessed the economic and social viability of these existing mitigation strategies by consolidating the authors' explanations from their academic papers with our field findings. This study found that most of the existing GHG mitigation options are not economically and socially viable for smallholder farmers due to not economically benefitting farmers and require major changes in agricultural practices.

Table 3. Comparative analysis of existing GHG emission mitigation approaches.

Mitigation options	*Locations*	*Insights from prior studies*	*Analysis based on studies and field findings*
Water management	Pati, Central Java	Alternate Wetting & Drying (AWD) reduced CH_4 by 33-39% compared to continuous flooding (CF), with no difference in yields [13].	Achieving successful implementation at the farm level will depend on many factors including land location and farming practices, which currently lack social and economic viability.
	Sukamandi, West Java	Intermittent irrigation and saturated soil resulted in lower CH_4 emissions, around 53–67% less than CF [7].	Rice irrigation is typically controlled by the Water Users Association (HIPPA) or collaborative farmer groups (*gapoktan*) [14], primarily focusing on the irrigated area without regard for water allocation. It is potentially socially viable, depending on engagement with irrigation organisations.
Rice seed varieties	Pati, Central Java	Inpari 18 had the lowest CH4 emissions compared to Inpari 14, Inpari 15, Inpari 17, Inpari 20, Ciherang, Situ Bagendit, and IR 64 [15].	The rice varieties tested are old-released and local varieties that yield less than newer HYV, making them not economically viable.
	Pati, Central Java	The combination of Inpari 1 with cattle manure emitted the lowest GHG compared to Inpari 6 and Ciherang with cattle manure [16].	The rice varieties tested are old-released and local varieties that currently yield less than newer HYV, suggesting that this option is not economically viable.
Cultivation methods	Pati, Central Java	The use of steel slag showed no significant impact on reducing GHG emissions and only slightly increased yields by 5% compared to its absence [17].	It is suggested to increase the rate of steel slag application, but this may make it less economically viable and may result in resistance among farmers.
Nutrient management	Pati, Central Java	Zero tillage can reduce CH_4 emissions by 25% in paddy fields, with a slightly higher yield of approximately 5% compared to deep tillage [18].	Zero tillage could decrease labour and equipment expenses, yet its viability requires further study, especially since the Ciherang variety used in the experiment yields less than HYV. Its economic feasibility may depend on soil conditions and overall management practices.
	Pati, Central Java	Adding 5 tons of rice straw per ha of rice field can significantly reduce GHG, but without increasing yield [19].	Farmers usually use/sell their rice straw for cattle feed [14]. Using rice straw to enrich fields rather than selling it for cattle feed leads to income loss and extra costs for buying cattle feed, making it economically unviable.

3.2 Lowering rice cultivation emissions with HYV

3.2.1 HYV adoption and emissions intensity

Based on field observations, it was noted that there was little disparity in the usage of nitrogen (N) fertiliser between farmer users and non-user groups, both in the *before* and *after* periods. On average, N fertiliser application amounted to 565 kg N/ha. Therefore, multiplying the N-based fertiliser used with 13.01 kg CO_2 per kg N fertiliser used, the average CO_2e emissions resulting from N fertiliser application in research areas were approximately 7,350 kg CO_2e per ha. Although on both *before* and *after* periods the non-user group used fewer N fertiliser, this research found that in the study area, the average yield for the user group after adopting high-yielding varieties (HYV), reached 5.7 tons/ha. In comparison, the non-user group achieved a more modest yield of approximately 4.59 tons/ha (further elaborated in section 3.2.2). This suggests that, despite using comparable amounts of N fertiliser, the emissions intensity generated by the user group was lower (1.33 tons CO_2e/ton of rice) than that of the non-user group (1.58 tons CO_2e/ton of rice) due to their higher yield resulting from HYV adoption. Figure 2 provides a visual comparison of emission intensity per ton of rice produced between the user and non-user groups.

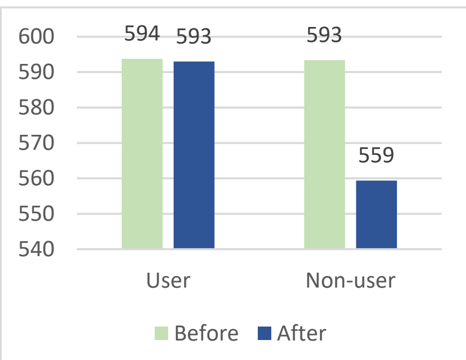

Fig. 1. N fertiliser applied between user and non-user groups.

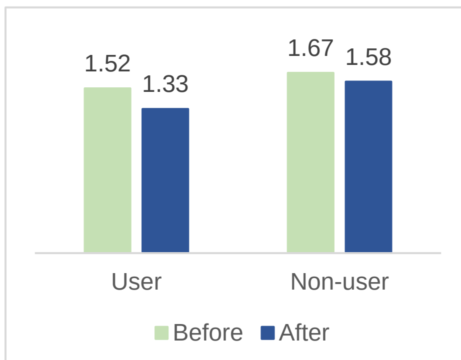

Fig. 2. Emission intensity between user and non-user group.

3.2.2 HYV as economically and socially viable climate mitigation for smallholder farmers

Developing climate mitigation strategies that are feasible for smallholder farmers necessitates ensuring their social and economic viability. A climate adaptation strategy's social viability depends on its capacity to generate profitability within farming operations [20]. This implies that a mitigation approach exhibiting economic benefits is more likely to gain acceptance among farmers.

Figure 3 presents a comparative analysis of average and maximum potential yields between HYV and older rice varieties. Evidently, HYV exhibits superior yield performance when compared to older varieties. Among the commonly adopted HYV seeds, Inpari 42 stands out with the highest average productivity, approximately 6.1 tons/ha, while Inpari 32 boasts the highest potential yield, reaching up to 12.1 tons/ha.

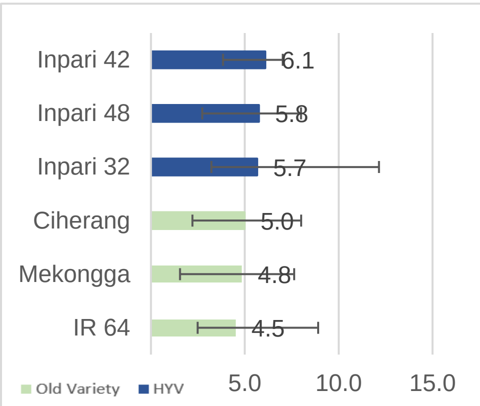

Fig. 3. Productivity average and maximum productivity potential of high-yielding variety and old variety.

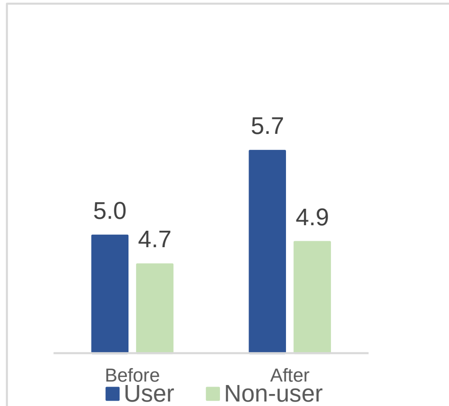

Fig. 4. Productivity increase comparison between user and non-user groups (ton GKG/ha).

Additionally, as shown in Figure 4, the farmer user group, primarily utilising older rice varieties in the *before* period (5.0 tons/ha), experienced a notable increase in productivity after transitioning to HYV (5.7 tons/ha). Most of these farmers initially planted certified older variety seeds. Conversely, the non-user group displayed insignificant productivity growth both in the *before* (4.7 tons/ha) and *after* (4.9 tons/ha) periods. This group predominantly relied on non-certified seeds from older varieties before using certified older rice varieties in the *after* period.

The user group experienced a substantial income increase of 70.8% compared to the period when they were using old varieties, while the non-user group only had a 38.1% income increase. This increase in income was attributed to both increased productivity (0.7 tons/ha for users and 0.2 tons/ha for non-users) and a 10% rise in the selling price of their harvest. In the long run, farmers who have higher incomes are more likely to adopt other climate mitigation strategies, as they have enough income to deal with the risks of adaptation [21].

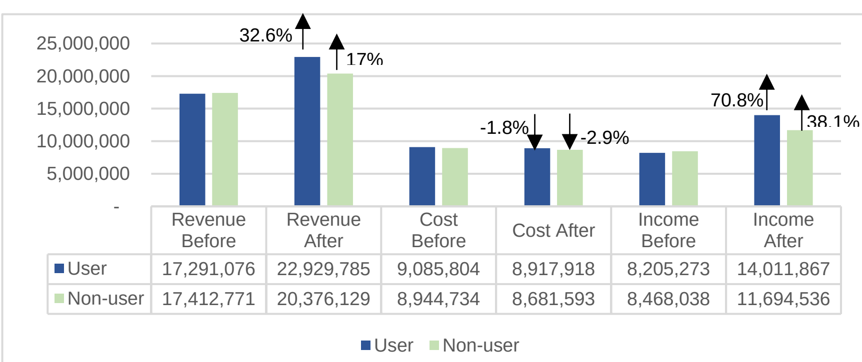

Fig. 5. Revenue, cost, and income comparison between user and non-user groups.

Furthermore, the shift from old varieties to HYV is an economically viable climate mitigation strategy for farmers, as the cost of rice seed accounts for only 3% of the total farming production cost, and there is minimal price difference between certified old varieties of rice seeds and certified HYV rice seeds in the market.

This study also identified that a significant portion of Indonesian rice farmers exhibit risk aversion, primarily due to limited farming capital and the inherent agricultural risks they face. Particularly, experienced farmers are less inclined to adopt new methods, often adhering to traditional practices honed over decades [21]. Given this challenge, inbred HYV (surveyed in this research are Inpari 32, Inpari 42, and Inpari 48) present an ideal climate mitigation strategy for risk-averse farmers, as they entail minimal alterations to existing agricultural practices and are akin to other inbred rice seeds.

It is crucial to emphasise that the emissions intensity calculation in this study solely focuses on nitrogen-based fertiliser application and does not encompass other activities contributing to emissions. However, considering its economic benefits and ease of implementation, the shift from traditional rice varieties to High-Yielding Varieties (HYV) deserves consideration as an initial climate mitigation strategy for smallholder farmers. It is noteworthy that the effectiveness of this measure is likely to be enhanced when complemented by other climate mitigation approaches that are equally adaptable, thus creating a synergistic impact.

3.3 Enhancing national rice production through HYV adoption

Research conducted by LPEM FEB UI further substantiates that farmers adopting HYV experience a remarkable 24% increase in productivity compared to those employing older rice varieties [22]. This heightened productivity, in conjunction with the compatibility of HYV with existing agricultural methods, renders HYV adoption an attractive and feasible choice for farmers.

As more farmers willingly cultivate HYV, the collective outcome is an increase in national rice production. Consequently, advocating for the widespread adoption of HYV emerges as a strategy to fortify and enhance national rice production. This aligns with the Government of Indonesia’s vision to increase national rice production by promoting shifting from older rice varieties to HYV [23].

4 Conclusions and policy recommendations

4.1 Conclusions

Advocating and promoting the adoption of High-Yielding Varieties (HYV) emerges as an effective strategy for mitigating greenhouse gas (GHG) emissions from rice cultivation, while at the same time strengthening national rice production. Transitioning to HYV serves as an initial climate mitigation step, particularly suitable for smallholder farmers, due to its economic advantages and ease of implementation, even among older farmers.

It is noteworthy that the user group, utilising HYV, demonstrates lower emissions intensity (1.3 tons CO2e/ton of rice produced) compared to the non-user group (1.5 tons CO2e/ton of rice produced). However, it is crucial to acknowledge that this emissions calculation solely addresses nitrogen (N) based fertiliser application and does not encompass other emission-contributing factors in the rice cultivation process. To attain maximal emissions reduction in rice fields, combining HYV adoption with additional climate mitigation measures that are similarly adaptable to ensure optimum emission reduction is necessary.

4.2 Policy recommendations

Considering the pivotal role of rice as a staple food in Indonesia, it is imperative that government support is extended to initiatives aimed at rice cultivation’s vulnerability to climate change. The ensuing recommendations present various intervention strategies aimed to optimise GHG reduction from rice fields while strengthening national rice production.

Firstly, encourage more HYV usage and production. Despite the prevalent utilisation of Inpari 32 by farmers, our field research reveals a lingering reluctance among many farmers to embrace HYV cultivation. The government can play a pivotal role in stimulating HYV adoption through educational campaigns highlighting the advantages of HYV and facilitating their adoption via subsidised or free seed programs. Furthermore, heightened governmental demand for high-quality HYV can incentivise seed producers to expand their HYV production.

Secondly, develop HYV seeds that produce low methane. As we endorse the utilisation of HYV to increase farmers' productivity and reduce GHG emissions per ton of rice yield, it is important for both researchers and governmental bodies to allocate resources towards the creation of HYV engineered with plant physiology aimed at minimising methane production. Existing rice varieties with low methane production as indicated by research findings (e.g., Inpari 1 and Inpari 18) suffer from low productivity, thereby making them unprofitable for farmers and detrimental to national rice production.

Thirdly, HYV should serve as a model for other climate mitigation strategies. The transition to HYV as a climate mitigation approach represents a straightforward innovation that is not only readily adoptable but also offers tangible benefits to farmers, rendering it an effective mitigation measure. The ease with which farmers are drawn to adopt this innovation should be extended to other climate mitigation strategies, thereby facilitating the broader adoption of multiple climate mitigation approaches by farmers.

Fourthly, incorporate HYV into the government's Climate Smart Agriculture (CSA) strategy. The Ministry of Agriculture is in the process of formulating a CSA program designed to proactively address climate change impacts on Indonesia's agricultural sector and enhance national food security [24]. Considering the economic and social viability of HYV as a climate mitigation measure, it is a judicious step to integrate HYV utilisation into the CSA strategy, thereby reinforcing the Ministry of Agriculture's overarching objectives.

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